Reviews in Fisheries Science & Aquaculture
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/brfs21

World Squid Fisheries

Alexander I. Arkhipkin[a], Paul G. K. Rodhouse[b], Graham J. Pierce[cd], Warwick Sauer[e], Mitsuo Sakai[f], Louise Allcock[g], Juan Arguelles[h], John R. Bower[i], Gladis Castillo[h], Luca Ceriola[j], Chih-Shin Chen[k], Xinjun Chen[l], Mariana Diaz-Santana[m], Nicola Downey[e], Angel F. González[n], Jasmin Granados Amores[o], Corey P. Green[p], Angel Guerra[n], Lisa C. Hendrickson[q], Christian Ibáñez[r], Kingo Ito[s], Patrizia Jereb[t], Yoshiki Kato[f], Oleg N. Katugin[u], Mitsuhisa Kawano[v], Hideaki Kidokoro[w], Vladimir V. Kulik[u], Vladimir V. Laptikhovsky[x], Marek R. Lipinski[d], Bilin Liu[l], Luis Mariátegui[h], Wilbert Marin[h], Ana Medina[h], Katsuhiro Miki[y], Kazutaka Miyahara[z], Natalie Moltschaniwskyj[aa], Hassan Moustahfid[ab], Jaruwat Nabhitabhata[ac], Nobuaki Nanjo[ad], Chingis M. Nigmatullin[ae], Tetsuya Ohtani[af], Gretta Pecl[ag], J. Angel A. Perez[ah], Uwe Piatkowski[ai], Pirochana Saikliang[aj], Cesar A. Salinas-Zavala[o], Michael Steer[ak], Yongjun Tian[w], Yukio Ueta[al], Dharmamony Vijai[am], Toshie Wakabayashi[an], Tadanori Yamaguchi[ao], Carmen Yamashiro[h], Norio Yamashita[ap] & Louis D. Zeidberg[aq]

[a] Fisheries Department, Stanley, Falkland Islands
[b] British Antarctic Survey, Natural Environmental Research Council, Cambridge, UK
[c] Oceanlab, University of Aberdeen, Newburgh, UK
[d] CESAM & Departamento de Biologia, Universidade de Aveiro, Aveiro, Portugal
[e] Department of Ichthyology and Fisheries Science, Rhodes University, Grahamstown, South Africa
[f] Tohoku National Fisheries Research Institute, Fisheries Research Agency, Hachinohe-shi, Aomori, Japan
[g] School of Biological Sciences, Queen's University, Belfast, Belfast, UK
[h] Instituto del Mar del Perú (IMARPE), Callao, Perú
[i] Faculty of Fisheries Sciences, Hokkaido University, Hakodate, Hokkaido, Japan
[j] FAO MedSudMed, Rome, Italy
[k] Institute of Marine Affairs and Resource Management, National Taiwan Ocean University, Keelung, Taiwan
[l] College of Marine Sciences, Shanghai Ocean University, Shanghai, China
[m] Centro Interdisciplinario de Ciencias Marinas-IPN, La Paz, BCS, México
[n] Instituto de Investigaciones Marinas (CSIC), Vigo, Spain
[o] Centro de Investigaciones Biológicas del Noroeste SC, La Paz, BCS, México
[p] Department of Environment and Primary Industries, Fisheries Victoria, Queenscliff, Victoria, Australia
[q] Northeast Fisheries Science Center, U.S. National Marine Fisheries Service, Woods Hole, Massachusetts, USA
[r] Departamento de Ciencias Ecológicas, Facultad de Ciencias, Universidad de Chile, Santiago, Chile
[s] Fisheries Research Institute, Aomori Prefectural Industrial Technology Research Center, Aomori, Japan
[t] ISPRA, Rome, Italy
[u] Pacific Research Fisheries Centre (TINRO-Centre), Vladivostok, Russia
[v] Yamaguchi Prefectural Fisheries Research Center, Nagato, Yamaguchi, Japan

[w] Japan Sea National Fisheries Research Institute, Fisheries Research Agency, Niigata, Japan
[x] Fisheries Division, CEFAS, Lowestoft, Suffolk, UK
[y] National Research Institute of Fisheries Science, Kanazawa, Yokohama, Kanagawa, Japan
[z] Hyogo Fisheries Technology Institute, Futami, Akashi, Hyogo, Japan
[aa] School of Environmental and Life Sciences, University of Newcastle, Ourimbah, New South Wales, Australia
[ab] National Oceanic and Atmospheric Administration (NOAA), United States Integrated Ocean Observing System (US IOOS), Operations Division, Silver Spring, Maryland, USA
[ac] Excellence Centre for Biodiversity of Peninsular Thailand (CBIPT), Faculty of Science, Prince of Songkla University, Hatyai, Songkhla, Thailand
[ad] Fisheries Research Institute, Toyama Prefectural Agricultural, Forestry and Fisheries Research Center, Namerikawa, Toyama, Japan
[ae] Atlantic Research Institute of Marine Fisheries and Oceanography (AtlantNIRO), Kaliningrad, Russia
[af] Tajima Fisheries Technology Institute, Hyogo Prefectural Technology Center for Agriculture, Forestry and Fisheries, Kasumi, Kami, Mikata, Hyogo, Japan
[ag] Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Tasmania, Australia
[ah] Centro de Ciências Tecnológicas da Terra e do Mar (CTTMar), Universidade do Vale do Itajaí (UNIVALI), Itajaí, SC, Brazil
[ai] Leibniz-Institute of Marine Sciences IFM-GEOMAR, Kiel, Germany
[aj] Bureau of Fisheries Expert, Department of Fisheries, Kaset Klang, Chatuchak, Bangkok, Thailand
[ak] South Australian Research and Development Institute (Aquatic Sciences), Henley Beach, South Australia, Australia
[al] Tokushima Agriculture, Forestry and Fishery Technology and Support Center, Fisheries Research Institute, Tokushima, Japan
[am] Graduate School of Fisheries Sciences, Hokkaido University, Hakodate, Hokkaido, Japan
[an] National Fisheries University, Shimonoseki, Japan
[ao] Saga Prefectural Genkai Fisheries Research and Development Center, Karatsu, Saga, Japan
[ap] Hokkaido National Fisheries Research Institute, Fisheries Research Agency, Katsurakoi, Kushiro, Hokkaido, Japan
[aq] California Department of Fish and Wildlife, Marine Region, Monterey, California, USA

To cite this article: Alexander I. Arkhipkin, Paul G. K. Rodhouse, Graham J. Pierce, Warwick Sauer, Mitsuo Sakai, Louise Allcock, Juan Arguelles, John R. Bower, Gladis Castillo, Luca Ceriola, Chih-Shin Chen, Xinjun Chen, Mariana Diaz-Santana, Nicola Downey, Angel F. González, Jasmin Granados Amores, Corey P. Green, Angel Guerra, Lisa C. Hendrickson, Christian Ibáñez, Kingo Ito, Patrizia Jereb, Yoshiki Kato, Oleg N. Katugin, Mitsuhisa Kawano, Hideaki Kidokoro, Vladimir V. Kulik, Vladimir V. Laptikhovsky, Marek R. Lipinski, Bilin Liu, Luis Mariátegui, Wilbert Marin, Ana Medina, Katsuhiro Miki, Kazutaka Miyahara, Natalie Moltschaniwskyj, Hassan Moustahfid, Jaruwat Nabhitabhata, Nobuaki Nanjo, Chingis M. Nigmatullin, Tetsuya Ohtani, Gretta Pecl, J. Angel A. Perez, Uwe Piatkowski, Pirochana Saikliang, Cesar A. Salinas-Zavala, Michael Steer, Yongjun Tian, Yukio Ueta, Dharmamony Vijai, Toshie Wakabayashi, Tadanori Yamaguchi, Carmen Yamashiro, Norio Yamashita & Louis D. Zeidberg (2015) World Squid Fisheries, Reviews in Fisheries Science & Aquaculture, 23:2, 92-252, DOI: 10.1080/23308249.2015.1026226

To link to this article: http://dx.doi.org/10.1080/23308249.2015.1026226

Reviews in Fisheries Science & Aquaculture, 23:92–252, 2015
Published with license by Taylor & Francis Group, LLC
ISSN: 2330-8249 print / 2330-8257 online
DOI: 10.1080/23308249.2015.1026226

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ALEXANDER I. ARKHIPKIN*,[1] PAUL G. K. RODHOUSE,[2] GRAHAM J. PIERCE,[3,4] WARWICK SAUER,[5] MITSUO SAKAI,[6] LOUISE ALLCOCK,[7] JUAN ARGUELLES,[8] JOHN R. BOWER,[9] GLADIS CASTILLO,[8] LUCA CERIOLA,[10] CHIH-SHIN CHEN,[11] XINJUN CHEN,[12] MARIANA DIAZ-SANTANA,[13] NICOLA DOWNEY,[5] ANGEL F. GONZÁLEZ,[14] JASMIN GRANADOS AMORES,[15] COREY P. GREEN,[16] ANGEL GUERRA,[14] LISA C. HENDRICKSON,[17] CHRISTIAN IBÁÑEZ,[18] KINGO ITO,[19] PATRIZIA JEREB,[20] YOSHIKI KATO,[6] OLEG N. KATUGIN,[21] MITSUHISA KAWANO,[22] HIDEAKI KIDOKORO,[23] VLADIMIR V. KULIK,[21] VLADIMIR V. LAPTIKHOVSKY,[24] MAREK R. LIPINSKI,[4] BILIN LIU,[12] LUIS MARIÁTEGUI,[8] WILBERT MARIN,[8] ANA MEDINA,[8] KATSUHIRO MIKI,[25] KAZUTAKA MIYAHARA,[26] NATALIE MOLTSCHANIWSKYJ,[27] HASSAN MOUSTAHFID,[28] JARUWAT NABHITABHATA,[29] NOBUAKI NANJO,[30] CHINGIS M. NIGMATULLIN,[31] TETSUYA OHTANI,[32] GRETTA PECL,[33] J. ANGEL A. PEREZ,[34] UWE PIATKOWSKI,[35] PIROCHANA SAIKLIANG,[36] CESAR A. SALINAS-ZAVALA,[15] MICHAEL STEER,[37] YONGJUN TIAN,[23] YUKIO UETA,[38] DHARMAMONY VIJAI,[39] TOSHIE WAKABAYASHI,[40] TADANORI YAMAGUCHI,[41] CARMEN YAMASHIRO,[8] NORIO YAMASHITA,[42] and LOUIS D. ZEIDBERG[43]

[1]Fisheries Department, Stanley, Falkland Islands
[2]British Antarctic Survey, Natural Environmental Research Council, Cambridge, UK
[3]Oceanlab, University of Aberdeen, Newburgh, UK
[4]CESAM & Departamento de Biologia, Universidade de Aveiro, Aveiro, Portugal
[5]Department of Ichthyology and Fisheries Science, Rhodes University, Grahamstown, South Africa
[6]Tohoku National Fisheries Research Institute, Fisheries Research Agency, Hachinohe-shi, Aomori, Japan
[7]School of Biological Sciences, Queen's University, Belfast, Belfast, UK
[8]Instituto del Mar del Perú (IMARPE), Callao, Perú
[9]Faculty of Fisheries Sciences, Hokkaido University, Hakodate, Hokkaido, Japan
[10]FAO MedSudMed, Rome, Italy
[11]Institute of Marine Affairs and Resource Management, National Taiwan Ocean University, Keelung, Taiwan
[12]College of Marine Sciences, Shanghai Ocean University, Shanghai, China
[13]Centro Interdisciplinario de Ciencias Marinas-IPN, La Paz, BCS, México
[14]Instituto de Investigaciones Marinas (CSIC), Vigo, Spain
[15]Centro de Investigaciones Biológicas del Noroeste SC, La Paz, BCS, México
[16]Department of Environment and Primary Industries, Fisheries Victoria, Queenscliff, Victoria, Australia
[17]Northeast Fisheries Science Center, U.S. National Marine Fisheries Service, Woods Hole, Massachusetts, USA
[18]Departamento de Ciencias Ecológicas, Facultad de Ciencias, Universidad de Chile, Santiago, Chile
[19]Fisheries Research Institute, Aomori Prefectural Industrial Technology Research Center, Aomori, Japan
[20]ISPRA, Rome, Italy

*Address correspondence to Alexander I. Arkhipkin, Fisheries Department, Bypass Road, Stanley, FIQQ 1ZZ, Falkland Islands. E-mail: AArkhipkin@fisheries.gov.fk

[21]Pacific Research Fisheries Centre (TINRO-Centre), Vladivostok, Russia
[22]Yamaguchi Prefectural Fisheries Research Center, Nagato, Yamaguchi, Japan
[23]Japan Sea National Fisheries Research Institute, Fisheries Research Agency, Niigata, Japan
[24]Fisheries Division, CEFAS, Lowestoft, Suffolk, UK
[25]National Research Institute of Fisheries Science, Kanazawa, Yokohama, Kanagawa, Japan
[26]Hyogo Fisheries Technology Institute, Futami, Akashi, Hyogo, Japan
[27]School of Environmental and Life Sciences, University of Newcastle, Ourimbah, New South Wales, Australia
[28]National Oceanic and Atmospheric Administration (NOAA), United States Integrated Ocean Observing System (US IOOS), Operations Division, Silver Spring, Maryland, USA
[29]Excellence Centre for Biodiversity of Peninsular Thailand (CBIPT), Faculty of Science, Prince of Songkla University, Hatyai, Songkhla, Thailand
[30]Fisheries Research Institute, Toyama Prefectural Agricultural, Forestry and Fisheries Research Center, Namerikawa, Toyama, Japan
[31]Atlantic Research Institute of Marine Fisheries and Oceanography (AtlantNIRO), Kaliningrad, Russia
[32]Tajima Fisheries Technology Institute, Hyogo Prefectural Technology Center for Agriculture, Forestry and Fisheries, Kasumi, Kami, Mikata, Hyogo, Japan
[33]Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Tasmania, Australia
[34]Centro de Ciências Tecnológicas da Terra e do Mar (CTTMar), Universidade do Vale do Itajaí (UNIVALI), Itajaí, SC, Brazil
[35]Leibniz-Institute of Marine Sciences IFM-GEOMAR, Kiel, Germany
[36]Bureau of Fisheries Expert, Department of Fisheries, Kaset Klang, Chatuchak, Bangkok, Thailand
[37]South Australian Research and Development Institute (Aquatic Sciences), Henley Beach, South Australia, Australia
[38]Tokushima Agriculture, Forestry and Fishery Technology and Support Center, Fisheries Research Institute, Tokushima, Japan
[39]Graduate School of Fisheries Sciences, Hokkaido University, Hakodate, Hokkaido, Japan
[40]National Fisheries University, Shimonoseki, Japan
[41]Saga Prefectural Genkai Fisheries Research and Development Center, Karatsu, Saga, Japan
[42]Hokkaido National Fisheries Research Institute, Fisheries Research Agency, Katsurakoi, Kushiro, Hokkaido, Japan
[43]California Department of Fish and Wildlife, Marine Region, Monterey, California, USA

Some 290 species of squids comprise the order Teuthida that belongs to the molluscan Class Cephalopoda. Of these, about 30–40 squid species have substantial commercial importance around the world. Squid fisheries make a rather small contribution to world landings from capture fisheries relative to that of fish, but the proportion has increased steadily over the last decade, with some signs of recent leveling off. The present overview describes all substantial squid fisheries around the globe. The main ecological and biological features of exploited stocks, and key aspects of fisheries management are presented for each commercial species of squid worldwide. The history and fishing methods used in squid fisheries are also described. Special attention has been paid to interactions between squid fisheries and marine ecosystems including the effects of fishing gear, the role of squid in ecosystem change induced by overfishing on groundfish, and ecosystem-based fishery management.

Keywords catch, Cephalopoda, fisheries, lifecycle, squid

1. *INTRODUCTION*

Interactions between human societies and fish stocks have played an important part in our history. Regrettably, it is now recognized that the humankind has failed in many instances to conserve marine species and obtain the optimal social and economic benefits from the marine environment. However, scientists and managers involved in cephalopod fisheries arguably find themselves in a better position than those responsible for finfish. Although the total world catch from marine and freshwater fish stocks appears to have peaked and may be declining (Hilborn et al., 2003), the catch of cephalopods has continued to increase as fishers concentrate efforts away from more traditional finfish resources. This is not a modern phenomenon, May et al. (1979) highlighted a shift toward harvesting "unconventional" stocks of marine organisms, which typically occupy lower trophic levels. Over the last four decades, cephalopod catches have increased from approximately 1 million t in 1970 to over 4.3 million t in 2007 (Jereb and Roper, 2010). However, we cannot assume that cephalopod catches will continue to rise and there is some evidence of landings leveling off recently. After the peak of 4.3 million t in 2007, world cephalopod landings fell sharply to under 3.5 million t in 2009, although they had recovered to just over 4 million t again in 2012. The fall in landings since 2007 was almost entirely attributable to a temporary collapse of the Argentine shortfin squid *Illex argentinus* landings (notably by Argentina, Taiwan, China, and Korea); the recovery since 2009 was mainly driven by increased landings of Humboldt squid *Dosidicus gigas* by Peru, Chile, and (especially) China (FAO, 2012) and recovery of the Argentine shortfin squid since 2011 (Falkland Islands Government, 2012). These figures remind us that a significant component of world cephalopod landings relies on a very small number of oceanic squid species.

There are about 800 living cephalopod species belonging to three main groups represented by different orders. Squids belong to the Order Teuthoidea. They are characterized by the presence of a remnant of the molluscan shell which has been retained in the form of the gladius, a stiff chitinous structure that lies inside the dorsal surface of the mantle muscle. The molluscan foot has evolved into the eight arms and two tentacles (the latter absent in some groups of squids), and these are armed with suckers and in some cases hooks which are modified suckers. Squid swim using the fins and by jet propulsion, using the mantle to expel water explosively from the mantle cavity through the funnel. There are some 290 species of squids and about 30–40 species have substantial commercial importance (Table 1). The other main cephalopod groups exploited for food are the cuttlefish and octopus, plus to a much lesser extent the sepiolids.

Table 1. Squid species and unidentified groupings of squid published by FAO ftp://ftp.fao.org/fi/CDrom/CD_yearbook_2010/root/capture/b57.pdf.

Family	Species	Distribution	Habitat	Fishing method
Ommastrephidae	*Todarodes pacificus*	Northwest Pacific 20°–60°N	Shelf and upper slope	Largely jigging with lights; some bottom trawling and purse seine
	Todarodes sagittatus	Eastern Atlantic 70°N–10°S	Neritic/Oceanic	Bycatch in trawls
	Nototodarus sloanii	New Zealand south of the Subtropical Convergence	Neritic/Oceanic	Jigging with lights and trawling
	Illex argentinus	Southwest Atlantic 22°–54°S	Shelf and upper slope	Largely jigging with lights; some bottom trawling
	Illex illecebrosus	Northwest Atlantic 25°–65°S	Shelf and upper slope	Jigging and bottom trawling
	Illex coindetii	Western Atlantic 5°–40°N and eastern Atlantic 20°S–60°N	Shelf and upper clope	Bycatch in trawls
	Ommastrephes bartramii	Circumglobal, bisubtropical 30°–60°N and 20°–50°S	Oceanic	Jigging with lights
	Dosidicus gigas	Eastern Pacific 50°N–50°S	Largely oceanic but extends over the narrow shelf of the western seaboard of the Americas	Jigging with lights
	Martialia hyadesi	Circumpolar, Antarctic Polar Frontal Zone north to Patagonian Shelf and New Zealand	Oceanic and over continental slope	Jigging with lights
Loliginidae	*Doryteuthis (Loligo) gahi*	South America, Gulf of Guayaquil to northern Patagonian Shelf	Shelf	Bottom trawls
	Doryteuthis (Loligo) opalescens	Western North and Central America, southern Alaska to Baja California	Shelf	drum seine; purse seine; brail net
	Doryteuthis (Loligo) pealeii	Eastern Americas, Newfoundl and to Gulf of Venezuela	Shelf	Bottom trawls and trap nets
	Loligo reynaudii	Southern Africa	Shelf	Jigs
	Loligo forbesii	Eastern Atlantic, 20°–60°N and Mediterranean	Shelf	Trawls and around Madeira and Azores caught on jigs
	Sepioteuthis lessoniana	Indo-West Pacific, Japan to Northern Australia and New Zealand and to northern Red Sea and Mozambique/ Madagascar, Hawaii	Shelf	Trawls, traps, seines, jigs, hooks, spears, etc.
Onychoteuthidae	*Onykia (Moroteuthis) ingens*	Circumpolar sub-Antarctic north to Patagonian Shelf, central Chile, southern Australia, and North Island New Zealand	Benthic/pelagic	
Gonatidae	*Berryteuthis magister*	North Pacific from Sea of Japan to Southern California via Aleutians	Demersal on continental slope and mesopelagic	Trawl

There are a number of characteristics of squid that, although not unique, set them apart from many other commercially exploited marine species (although not necessarily from other cephalopods). They are short-lived, semelparous and fast growing, with high feeding rates and conversion efficiencies. They also have high reproductive rates, although loliginid squids usually produce fewer eggs than do ommastrephids. These features have adapted them to be ecological opportunists that can rapidly exploit favorable environmental conditions, but equally their abundance responds rapidly to poor conditions, so recruitment and abundance may be highly variable on annual time scales (Rodhouse et al., 2014). There is evidence that squid populations have benefited from ecological change driven by overexploitation of groundfish in some regions (Caddy and Rodhouse, 1998). A recent extensive expansion of the geographical range of the jumbo flying squid *D. gigas* has occurred on the west coast of the Americas following the 1997/98 El Niño Southern Oscillation and there has been debate whether this was caused by physical drivers or ecosystem change associated with fishing (Watters et al., 2008; Zeidberg and Robison, 2008). This highlights the challenge of discriminating between the effects of climate variability and change, and the effects of fishing, on squid populations.

Squid fisheries make a relatively small contribution to world landings from capture fisheries, but the proportion has increased steadily over recent decades, although as noted above landings have apparently leveled off recently. Although squid fishery production is small relative to that of fish, a large proportion of the world squid catch is composed of a small number of species. The fisheries for those species remove substantial biomass from local marine ecosystems.

Squids are important prey for large numbers of vertebrate predators including many fish species, toothed whales, pinnipeds, and seabirds (Clarke, 2006; Jereb and Roper, 2010). Estimates of global squid consumption by predators suggest that they consume a greater mass of squid than the total world catch of all marine species combined (Voss, 1973; Clarke, 1983). Squid are also predators themselves that make long migrations over their lifecycle, are responsible for spatial transfer of substantial biomass (Arkhipkin, 2013) and may be keystone species (Gasalla et al., 2010). There are therefore important relationships between squid fisheries and marine ecosystems and this is especially relevant in the context of ecosystem-based fishery management (EBFM). Squid fisheries themselves need to be managed with regard to their impact on the ecosystem but it is also important that squid stocks should be considered as a key element in many ecosystems in the context of the management of other fisheries.

The natural ability of squid stocks to recover from low biomass levels following a period of unfavorable environmental conditions might make them less susceptible to long-term reduction in numbers due to overfishing. Conversely heavy fishing pressure coinciding with poor environmental conditions might generate a critical tipping point for populations. The biological characteristics of squid raise interesting questions about the response of populations to future climate change. It can be argued that in some situations opportunism in a changing environment might enable populations to expand (Rodhouse, 2013).

In order for squid species to be suitable for commercial exploitation they must be of suitable size (medium/large) and have an acceptable flavor and texture. Only the muscular, negatively buoyant, species meet all these criteria. The more neutrally buoyant squids store light ammonium ions in vacuoles in the muscle tissues, or in the case of the cranchiids, in the coelomic fluid (Clarke et al., 1979). As a result of these adaptations the flesh has an ammoniacal flavor and flaccid texture which humans find unacceptable. Nevertheless, predators are not deterred from consuming ammoniacal squids which may predominate in the diet of some species (Lipinski and Jackson, 1989). It has been proposed that chemical processing of the flesh of ammoniacal squids could result is a palatable product for human consumption (Pierce and Portela, 2014).

Fisheries need to target aggregations of squid near the surface to be commercially viable so those species that do not aggregate for at least part of their lifecycle are generally of little interest other than as bycatch in other fisheries. Detailed accounts of the lifecycle and biology of the most important exploited species of squids are given in Rosa et al. (2013a and b).

The bulk of the global squid catch comprises species from two families, the Ommastrephidae and Loliginidae. The species for which capture production data are published by FAO are listed in Table 2 together with details of the distribution, habitat, and fishing method. The FAO data provide the only information on global fisheries but they are unavoidably incomplete because of both non-reporting and lack of identification (or misidentification) of species. Views differ as to how much can be inferred from the data (Pauly et al., 2013) and they should be used with some caution. Nevertheless, it is clear that members of the family Ommastrephidae dominate in terms of biomass with five main commercial species. Four of these—*Todarodes pacificus*, *Nototodarus sloanii*, *I. argentinus*, and *I. illecebrosus*—inhabit high velocity western boundary current systems of the Pacific and Atlantic Oceans. The fifth species, *D. gigas*, inhabits the low-velocity eastern boundary current systems of the eastern Pacific which are characterized by coastal upwelling. Another neritic/oceanic species, *Nototodarus gouldi*, is not reported by FAO but is caught off the southern part of Australia and around North Island, New Zealand.

Larger numbers of loliginid species are also caught and at least some of these will have been included in the "Loliginidae" and "various squids" categories in Table 1. The main species targeted include *Doryteuthis gahi, D. pealeii, L. bleekeri*, and *L. reynaudii*. Twenty species of loliginid other than those identified in Table 1 were reported by Jereb et al. (2010) to be of fisheries interest.

Apart from the ommastrephids and loliginids there are also targeted fisheries for members of the families Enoploteuthidae,

Table 2. Capture production (tonnes) in the major squid fisheries reported by FAO 2001–2010 ftp://ftp.fao.org/fi/CDrom/CD_yearbook_2010/root/capture/b57.pdf.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Todarodes pacificus	528,523	504,438	487,576	447,820	411,644	388,087	429,162	403,722	408,188	357,590
Todarodes sagittatus	1,915	3,163	954	594	574	526	1,112	774	980	973
Nototodarus sloanii	44,862	63,096	57,383	108,437	96,398	89,403	73,921	56,986	47,018	33,413
Illex argentinus	750,452	540,414	503,625	178,974	287,590	703,804	955,044	837,935	261,227	189,967
Illex illecebrosus	5,699	5,527	10,583	28,103	13,837	21,619	10,479	20,090	22,912	20,660
Illex coindetii	2,596	2,559	2,006	2,264	5,533	4,650	4,132	4,573	4,349	3,889
Ommastrephes bartramii	23,870	14,947	18,964	11,478	14,430	9,401	22,156	24,400	36,000	16,800
Dosidicus gigas	244,955	412,431	402,045	834,754	779,680	871,359	688,423	895,365	642,855	815,978
Martialia hyadesi	117	2	37	59	3	0	4	0	4	0
Doryteuthis (Loligo) gahi	76,865	36,411	76,746	42,180	70,721	52,532	59,405	58,545	48,027	71,838
Doryteuthis (Loligo) opalescens	85,829	72,879	39,330	39,596	55,732	49,205	49,447	36,599	92,376	129,936
Doryteuthis (Loligo) pealeii	14,211	16,684	11,929	13,537	16,967	15,899	12,327	11,400	9,293	6,689
Loligo reynaudii	3,373	7,406	7,616	7,306	10,362	6,777	9,948	8,329	10,107	10,068
Loligo forbesii	70	140	536	261	272	472	721	664	455	554
Loligo vulgaris	2	2	2	1	3	5	7	7	6	22
Sepioteuthis lessoniana	5,574	5,826	6,333	5,500	3,811	3,584	3,646	4,528	4,523	4,526
*Loliginid*s	198,893	218,551	261,907	209,894	209,110	202,616	206,861	208,218	216,658	236,499
Onykia (Moroteuthis) ingens					109	22	68	34	87	36
Moroteuthis robusta					5	13	6			
Berryteuthis magister				1,132	1,068	1,084	48,981	54,868	60,639	59,306
Various squid (Loliginidae, Ommastrephidae, other families)	230,214	281,935	317,097	303,241	327,225	316,989	337,574	356,864	372,825	430,416
Total	2,218,020	2,186,411	2,204,699	2,235,131	2,435,074	2,746,047	2,913,424	2,938,860	2,238,529	2,389,160

Gonatidae, Onychoteuthidae, and Thysanoteuthidae (Jereb and Roper, 2010).

There are a number of ommastrephid species that are probably underexploited including *Sthenoteuthis pteropus, Ommastrephes bartramii, Martialia hyadesi, Todarodes sagittatus, Sthenoteuthis oualaniensis, Nototodarus philippinensis,* and *Todarodes filippovae* (Jereb and Roper, 2010). *Dosidicus gigas* was earlier included in this list but since 2004, global landings have risen to almost 1 million t annually (FAO, Fishstat J). Other species that apparently have fisheries potential are *Gonatus fabricii* (Gonatidae) and *Thysanoteuthis rhombus* (Thysanoteuthidae). These are all large and medium size squids found in offshore habitats.

Annual capture production for the decade 2001–2010 for each species published by FAO is given in Table 2. The total world capture production of cephalopods (squid, octopus, and cuttlefish) in 2010 was 3.65 million t. This was 15% less than the maximum for the 10 years up to 2010, which reached 4.31 million t in 2007. In 2010, 2.98 million t of the total cephalopods was squids, of which 48% was ommastrephids, 30% was loliginids and 2% was gonatids. The remaining 20% of squids were not identified.

The data for the major fisheries show large interannual variations over the decade, by up to a factor of 5 in the case of *I. argentinus*, with no clear trends within or between species. While the inter-annual variations can be expected to reflect underlying changes in stock size the capture production data may be influenced by variable reporting and by changes in fishing effort which in turn may be driven by management restrictions, market conditions, fuel prices, etc.

Hunsicker et al. (2010) have assessed the contribution of cephalopods to global marine fisheries both as a commodity and in terms of a supportive ecosystem services provider (as food for other commercially exploited species). A variety of ecosystems, including continental shelves, major currents and upwelling zones, gulfs, seas, and open oceans were evaluated. In each ecosystem, data for the top 25 taxonomic groups contributing to fishery landings were analyzed. The contribution of cephalopods, in terms of their supportive service, is substantial in many marine systems. For example, on the Patagonian Shelf, the contribution (commodity and supportive) of cephalopods to total fishery landings and landed values (US$) reached 55% and 70%, respectively. Across all the ecosystems studied, average estimates of commodity and supportive contributions by cephalopods to total fishery landings and revenue were 15% and 20%, respectively. The study also compared the importance of cephalopods as a commodity versus a supportive service. In 8 of 28 ecosystems evaluated, cephalopod contribution as direct landings was greater than their contribution to predator landings. However, the reverse was true for another eight ecosystems evaluated. Generally, the contribution of cephalopods as a commodity was greatest in the coastal ecosystems, whereas their contribution as a supportive service was greatest in open ocean systems. In terms of landed values, the average price per tonne of cephalopods was greater than or near the average price per tonne of the predator species in many of the ecosystems. Hunsicker et al. (2010) point out that the expansion of fisheries to lower trophic level species, such as squids, is not necessarily the equivalent of an expansion to lesser value species as further discussed by Pauly et al. (1998).

When considering the expansion of cephalopod fisheries Hunsicker et al. (2010) suggest that within ecosystems where cephalopods are both valuable as a commodity as well as in a supportive capacity, further scrutiny of the trade-offs is required. In future, recognition by managers of the interconnectedness of commercial cephalopods and commercial predatory fishes could contribute to sustainable management of fisheries in ecosystems under current and increased levels of exploitation. This issue has not been addressed yet in scientific publications.

2. BRIEF HISTORY OF SQUID FISHERIES FROM ANCIENT TIMES TO THE 19TH CENTURY

Very little is known about ancient fisheries, and even for the 18th and 19th centuries information is scarce. According to Erlandson and Rick (2010), the earliest marine fisheries may date back as far as 160,000 years on the South African coast. Ancient communities here seem to have had a substantial impact on the marine ecosystem, frequently reducing the size of exploited populations. However, in contrast to what is often seen in terrestrial habitats (especially on islands) this probably did not result in extinctions. Cephalopods were not specifically mentioned in their study, but it is likely that this prehistoric coastal community and others like it exploited littoral octopods, and probably used squid which stranded on beaches as bait, fertilizer, and fodder for domestic animals, as well as for human consumption. As with primitive communities today, squid have probably been spearfished and caught using jigs (similar to modern jigs made from wood such as *amaiki* and *kusaiki* in Japan). There is no technical information about fishing nets used in ancient times. Nevertheless, the octopus culture of the middle to late Minoan period on Crete in the eastern Mediterranean, in which images of octopuses appear on items from earthenware pots to coffins, is clear evidence that these ancient people were, at least, thoroughly familiar with cephalopods.

We find information about cephalopod biology and fisheries in ancient Greek literature, reviewed by Diogenes Laertios (1925) (Lives of Eminent Philosophers, compiled in the 3rd century AD). Two philosophers, Aristotle and his disciple Theophrastus, wrote about cephalopod biology but unfortunately only the botanical volumes of Theophrastus survived; 12 volumes about animals (among them animals which change color) have been lost. Aristotle (1970, 1991), in his History of Animals (books 4–10 which survive to this day), describes *T. sagittatus* (= teuthos) and *Loligo vulgaris* (= teuthis). He described the morphology, anatomy, behavior and parts of the life history of these squids. He did not explicitly mention fisheries but his observations point to the fact that squid were fairly easily accessible live and in good condition. There is evidence in what he wrote that he had close contact with fishermen.

The only systematic source of information about cephalopods in ancient Roman literature is in Pliny the Elder; other authors like Claudius Aelianus, Galen and Athenaeus, mentioned cephalopods only in passing. However, Pliny did not mention fisheries for cephalopods specifically; instead he focused on anecdotes about octopus stealing fish from fish farms.

It is Oppian of Anazarbus (or Corycus) who wrote the first major treatise on sea fishing, the *Halieutica* or *Halieutika*, composed between 177 and 180 AD. The treatise, written to honor the Roman emperor Marcus Aurelius and his son Commodus, includes descriptions of mating and predation of various marine animals and descriptions of fishermen, fishing tools, and fishing techniques. These include the use of nets cast from boats, scoop nets held open by hoops, spears and tridents, and various traps, and the treatise specifically mentions cephalopods many times. For instance, the following description about squid (*L. vulgaris*) fishing is given: "Against the calamaries a man should devise a rod fashioned after the manner of a spindle. About it let him fasten close to one another many hooks with recurving barbs, and on these let him impale the striped body of a rainbow-wrasse to hide the bent teeth of bronze, and in the green depths of the sea let him trail such snare upon a cord. The Calamary when it sees it, darts up and grasps it in the embrace of its moist tentacles and becomes impaled upon the tips of bronze, and no more can it leave them for all its endeavor but is hauled against its will, having of itself entangled its body."

Perhaps not surprisingly, there are also records of cephalopod fisheries in ancient Japan. Judging from the present-day artisanal fisheries in the Mediterranean (similar to the descriptions of Oppianus) and present-day artisanal fisheries in the Far East, methods and experiences were similar. The developmental history of squid fishing in Japan was described by Ogura (2002): squid were presented to the Imperial Court, according to an ancient legal code called "*Engishiki*" during the Heian period (794–1185); however, no clear description exists on fishing methods. In 1458, a prototype of modern squid jigging gear was invented for a small scale fishery for the Japanese flying squid *T. pacificus* in Sado Island, Sea of Japan. This was a hand-held, jointed, squid-jig with several hooks along its axis and a weighted sinker. The squid jig was developed independently in Japan, no later than in the Mediterranean Basin. Traditional methods of jigging are described by Yoshikawa (1978).

Squids and other cephalopods appear again much later in the western Mediterranean literature, in the work of Conrad Gesner (Historiae animalium, 1551–1558), Guillaume Rondelet (Libri de piscibus marinis, 1556), and Ulysse Aldrovandi (*De reliquis animalibus exanguibus* libri quarto, 1606).

What might be called modern literature on squid biology starts with Lamarck (1815–1822) and Cuvier (1817), and was continued by Verrill (1879–1882) and Tryon (1879). However, all accounts up to the beginning of the 20th century lack information about fishery landings. Tryon (1879) reported large scale fishing for *Illex illecebrosus* in the Newfoundland area, mainly for bait, but statistics relating to catches are not given. The same author reported on fishing for *T. pacificus* in Japan, near Hakodate. Squid were caught by small boats at night using lights, and dried for human consumption (*surume-ika*). For this fishery, he provides some quantitative information: “During the quarter ending June 1872 imports from Japan to the three Chinese ports of Kinkiang, Shanghai and Ningpo, totalled 4198 picals (= 265 t).” Elsewhere during the 19th century statistics for squid fisheries, if collected at all, were mostly descriptive and anecdotal.

Modern squid fisheries started to develop in the early part of the 20th century with the appearance of motorized fishing vessels and the development of specific trawling and jigging gear. It was only after World War II, with the development of ocean going fishing vessels, that catches of cephalopods in general and squids in particular started to reach hundreds of thousands of t and later millions of t annually. At this point, they started making a substantial contribution to the total of marine products caught for human consumption. The fishing history of each abundant and commercially important species of squid is presented in the species accounts below.

3. *SQUID STOCK EXPLOITATION AND MANAGEMENT*

3.1. *Fishing Methods*

Cephalopods in general and squids in particular possess ecological and behavioral features that are quite similar to those of fishes. In fact, Packard (1972) has pointed out that functionally cephalopods are fish and Pauly (1988) develops this theme further. Many nektonic squids migrate in dense schools similar to those of pelagic fishes and fishing methods are common to both groups. Squid fishing methods are described in detail by Boyle and Rodhouse (2005). Here, we briefly introduce the main fishing methods leaving specifics to the species accounts.

3.1.1. Nets

Various types of fishing gear based on nets have been used for catching squids since the early days of exploitation. These include the various trap nets, set nets, and purse seines that have mainly been used in artisanal fisheries. Currently, seine nets are used in conjunction with lights in the Californian *Doryteuthis opalescens* fishery and pumps are sometimes used to remove the squid from the net. Set nets are used in fisheries for *I. illecebrosus*, *Doryteuthis pealeii*, and *Watasenia scintillans* with the variety of traps used for a large number of different squid species especially in east Asian countries.

The advent of motorized vessels in the early 20th century created opportunities for targeting large schools of pelagic and near bottom squids as well as fish. Trawlers use various types of the trawling gear (pelagic, semi-pelagic, and bottom) which are deployed during daytime to exploit the natural behavior of squids over the continental shelf as they aggregate near the seabed during daylight. The trawling gear used is essentially the same as that used for finfish. Pelagic trawls are used to catch *I. argentinus* near the bottom in the Southwest Atlantic and semipelagic nets are employed to catch *T. sagittatus* and *Todarodes angolensis* in the north and south east Atlantic. Bottom trawls are used mainly to catch near-bottom aggregations of loliginid squids such as *D. gahi* around the Falkland Islands (Figure 1A).

The commercial otter trawl has two hydrovanes, known as otter boards or doors, one on each side of the net to spread the trawl horizontally. Special cables called bridles and sweeps

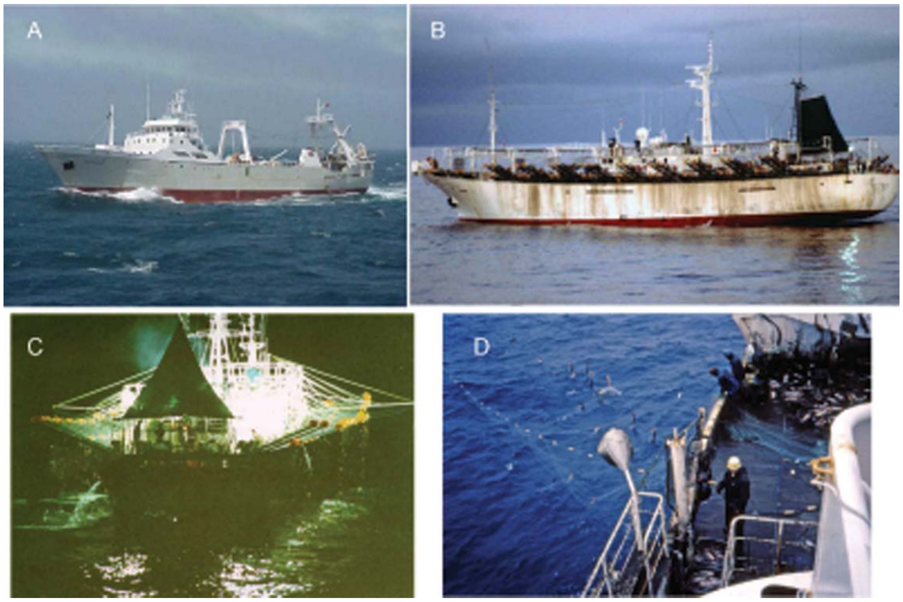

Figure 1. Vessels for squid fishing: (A) factory trawler; (B) large oceanic jigger; (C) jigger light fishing at night; and (D) drift netter.

connect the doors to the trawl wings. The movement of the cables through the water creates disturbance that is sensed by the fish lateral line, herding the fish close to the midline of the net. Unlike fish, squid use mainly vision for their orientation in the water column, and disturbance of water by the door cables has a lesser effect on their behavior in front of the trawl. In order to concentrate squid schools from a wide area into the wings of the trawl, polyvalent oval shaped doors are used. These scrape the seabed, creating clouds of silt that the squids attempt to avoid and so concentrate close to the midline of the net. This method has a negative impact on the sea floor as the trawl doors effectively plough the seabed and damage benthic communities (e.g., Jones, 1992, and many others). Increasingly bottom trawling is prohibited on environmental grounds.

Trawlers use acoustic target-finding technology to locate aggregations of squids. However, squids provide weak acoustic targets because they lack a swim bladder so the technology has limited use where squid targets are mixed with fish possessing swim bladders. Squid targets can be also confused with aggregations of similar sized fish that do not have a swim bladder, such as the rock cod *Patagonotothen ramsayi*. In the Falkland Islands fishery, the target shape and strength of this species are so similar to those of the squid *D. gahi* that the catch cannot be identified until it is hauled onboard (Falkland Islands Government, 2012).

As trawls catch most individuals that are larger than the mesh size of the net, the total catch is very often mixed with the target species. The texture of squid skin is more delicate than that of fish, which is usually covered with scales, so in a mixed catch it becomes damaged and is sometimes completely removed from the body as a result of contact with knots in the mesh of the net and with other elements of the catch. Squid with damaged skin have less value than those with intact skin, so the total value of a trawled catch can be considerably reduced depending on the type of bycatch. Another common problem occurs when squid in the net are mixed with small fish as these tend to penetrate the squid's mantle when the catch accumulates in the codend of the trawl. It takes time to remove the fish from the mantle by hand, and the quality of the catch is again reduced. Silt or sand can get into the mantle of squid if the trawl ground rope is too heavy and stirs up the bottom. In general then, squid from trawlers is of inferior quality compared with the catch using methods such as jigging or trapping. However, where trawlers target squid, a "clean" catch can be obtained. In the Moray Firth (UK), targeted squid-fishing operations yield fairly clean hauls, with few fish by-caught in large numbers. Only whiting are caught occasionally in large amounts (up to 25% of the catch; Hastie et al., 2009).

3.1.2. Jigging

Jigging for squid is less damaging to the marine environment and produces a more valuable product. This technology exploits the natural behavior of the squid which moves up in the water column toward the surface at night where they can then be attracted using lights toward the fishing vessel and the jigs. Many large scale fisheries for both ommastrephid and loliginid squids employ jigging with lights. This method results in a higher value product where the squid can be sold whole because the process causes little or no damage to the skin. Although squid jigging vessels remain stationary in the water there is little or no saving on energy costs because the fuel used to generate the electricity to power the fishing lights is broadly equivalent to that consumed by trawling.

Commercial squid jigging was developed on Sado Island during the Meiji era in the 19th century and jigs were first demonstrated in a fisheries exhibition held in 1883 (Igarashi, 1978). At that time hand jigging gear deployed two rods with the line connected to both and the method was used to catch squid from the surface to 100 m depth. The increasing engine power of fishing vessels later enabled the development of squid jigging gear using one line per jig in the northern part of Hokkaido (Igarashi, 1978). The design of jigging gear currently used, in which multiple jigs are attached to one line in series, was developed in 1951. Simultaneously, barbless hooks for use on jigs were developed to facilitate release of captured squid on board. From the late 1950s hand-wound drums with a line of 10–40 jigs were used in artisanal fisheries. In the mid-1960s electrically powered, automatic jigging machines were introduced and these drastically increased squid catches. Hand drums could only be used close to the surface whereas electric machines had enough power to catch squid in much deeper water (50–200 m) (Inada and Ogura, 1988).

Modern squid jigging vessels have three elements: (1) a large parachute drogue deployed as a sea anchor to hold the vessel still in the water; (2) an array of incandescent lights to attract the squid at night when the squid naturally migrate upward to feed; and (3) jigging machines which lower and raise the weighted lines to which are attached a series of colored or luminescent jigs—each of which is armed with an array of barbless hooks. Some vessels operate one or two submarine lights of 2–5 kW each. They are lowered on cables and then slowly hauled to the surface to concentrate the squid and lure them upward toward the vessel (Figure 1B).

Fishing operations are automatic or semiautomatic and under centralized control which reduces the labor required and aids optimal use of the gear (Inada, 1999). Intermediate size vessels over 30 GRT and large vessels over 100 GRT are equipped with 10–50 automatic jigging machines, respectively (Mikami, 2003). The jigs are deployed on 100 or more lines, each carrying some 25 jigs. A large squid jigger will operate 150 or more metal halide lamps which are usually 2 kW each (but can be 1–3 kW). The lamps are mostly white but a smaller number of green lamps are sometimes included (Inada and Ogura, 1988) (Figure 1C). Small artisanal jigging boats less than 10 GRT are the most labor efficient as only two fishermen can do all the work, operating the jigging machines and packing the catch, etc. (Mikami, 2003). In spite of a high level of automatization of fishing operations on large jigging vessels,

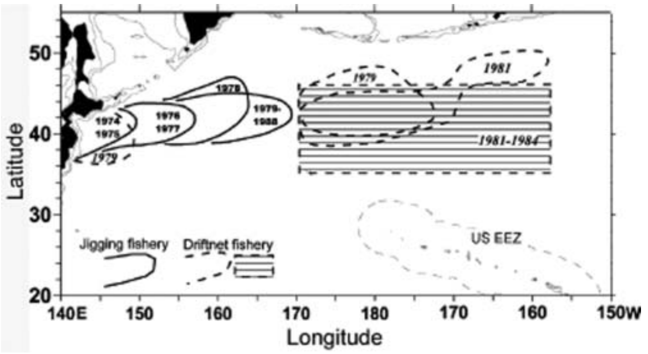

Figure 2. Changes in locations of Japanese jigging and driftnet fisheries. Modified from Araya (1987) and Murata (1990).

sorting the catch and packing the squid is still done by the crew. Operating a sea-anchor on a large vessel, controlling the fishing lines and preventing them from tangling are also relatively labor intensive.

3.1.3. Driftnets

The Japanese squid driftnet fishery for neon flying squid, *O. bartramii*, was developed in the northwestern Pacific to compensate for reduced catches of *T. pacificus* when the stock decreased sharply in the 1970s (Figure 1D). From 1974 to 1978, the driftnet fishery operated off the Pacific coast of Japan west of 150°E (Figure 2) but it conflicted with the jig fishery (Yatsu et al., 1993). In response, the Japanese government adopted a limited entry licensing system in 1981 and regulated the season and area where the driftnet fishery could operate (Figure 2).

The Japanese squid drift netters were converted from, or were also engaged in, other fisheries such as salmon driftnet fisheries, tuna fisheries, the Pacific saury fishery, squid jigging fisheries, distant water trawl fisheries, the North pacific longline, and gillnet fishery (Nakata, 1987).

Some 400–500 driftnet vessels, ranging from 59.5 to 499.9 GRT were used between 1981 and 1990. Japanese squid driftnets were made of nylon monofilament with a diameter of about 0.5 mm. The corkline length of a panel ("*tan*") ranged from 45 to 50 m. Panel depth when deployed was usually 7–10 m. A stretched mesh size of 110–120 mm was specified by the regulations. A single driftnet section could have 70–200 tans connected together, and would be deployed before sunset and retrieved 2–3 hr before sunrise. Several sections were usually set and would be separated by distances of 2–3 nautical miles. The soak time for an operation varied from 5 hr to more than 15 hr. From 1982 to 1986, the average number of tans used per day increased from 663 to 1000 (Yatsu et al., 1993).

In the early 1980s, the Republic of Korea driftnet fishery also developed (Araya, 1987). There were 99 Korean driftnet vessels in 1984 and 150 by 1989. They operated from coastal waters off northwest Japan to 150°W (Gong et al., 1993a, b). In the autumn and early winter, the Korean fishery concentrated from 142°E to 160°E where the Japanese jigging fleet was operating (Figure 3). Vessels ranged from 100 to 500 GRT, but were mostly from 200 to 300 GRT. A progressive increase of catch of *O. bartramii* by driftnets occurred, rising from 37,000 t in 1983 to 124,000 t in 1990.

Taiwanese driftnetting for *O. bartramii* in the North Pacific emerged in the late 1970s. From the early 1980s, escalation of oil prices accelerated the replacement of squid jiggers (which had been introduced in the early 1970s) by driftnetters (Yeh and Tung, 1993). The driftnet fishery for *O. bartramii* coexisted with the jig fishery until 1983, but thereafter driftnets replaced jigging. From 1985 to 1988, the Taiwanese driftnet catch was concentrated between 155°E and 165°E. From 1983 to 1990, 94–179 vessels were operating for 6,000–18,000 days per year. Annual catch ranged from 10,000 to 30,000 t.

The principle fish bycatch was Pacific pomfret (*Brama japonica*) but blue shark, albacore, pelagic armorhead, and skipjack catches were also high. Large numbers of seabirds, especially dark shearwaters, marine mammals, and turtles were also taken as bycatch (Nakata, 1987; Yatsu et al., 1993). Because of the excessive bycatch and because lost or discarded nets can continue "ghost fishing" at unquantifiable levels for an indefinite period they were banned worldwide by a UN moratorium in 1991. The *O. bartramii* fishery has now switched to jigging with lights.

3.2. Processing

In many fisheries, the squid are frozen whole on board the fishing vessel, often after grading according to size. Otherwise, the only processing normally carried out on board is that the viscera are removed and the "tubes" and "tentacles" (mantles and brachial crowns) are frozen. This is mainly done in the larger ommastrephids. In the Falkland Islands fishery over 92% of *I. argentinus* and over 98% of *D. gahi* is frozen whole (Laptikhovsky et al., 2006).

In processing factories ashore, the squid are eviscerated and separated into the edible "wings" (fins)," tubes" (mantles), and "tentacles" (brachial crown) either by hand or using machines. The tubes are often sectioned to produce "squid rings" and usually frozen. Squid meat from the tubes and tentacles is also processed in a variety of other ways including canning, drying, and smoking. In most cases, the viscera and trimmings are discarded but a specialized product is made in Japan by fermenting the digestive gland (Yoshikawa, 1978).

Recently, the nutraceutical industry has begun to utilize squid for essential omega-3 fatty acids that are increasingly being used as supplements in human diet. Crude oil is extracted from the viscera and trimmings, mainly from the large oil-filled digestive gland of ommastrephids, and is then purified by distillation and refining for bottling or encapsulation. The oil is rich in eicosapentaenoic acid and especially docosahexaenoic acid.

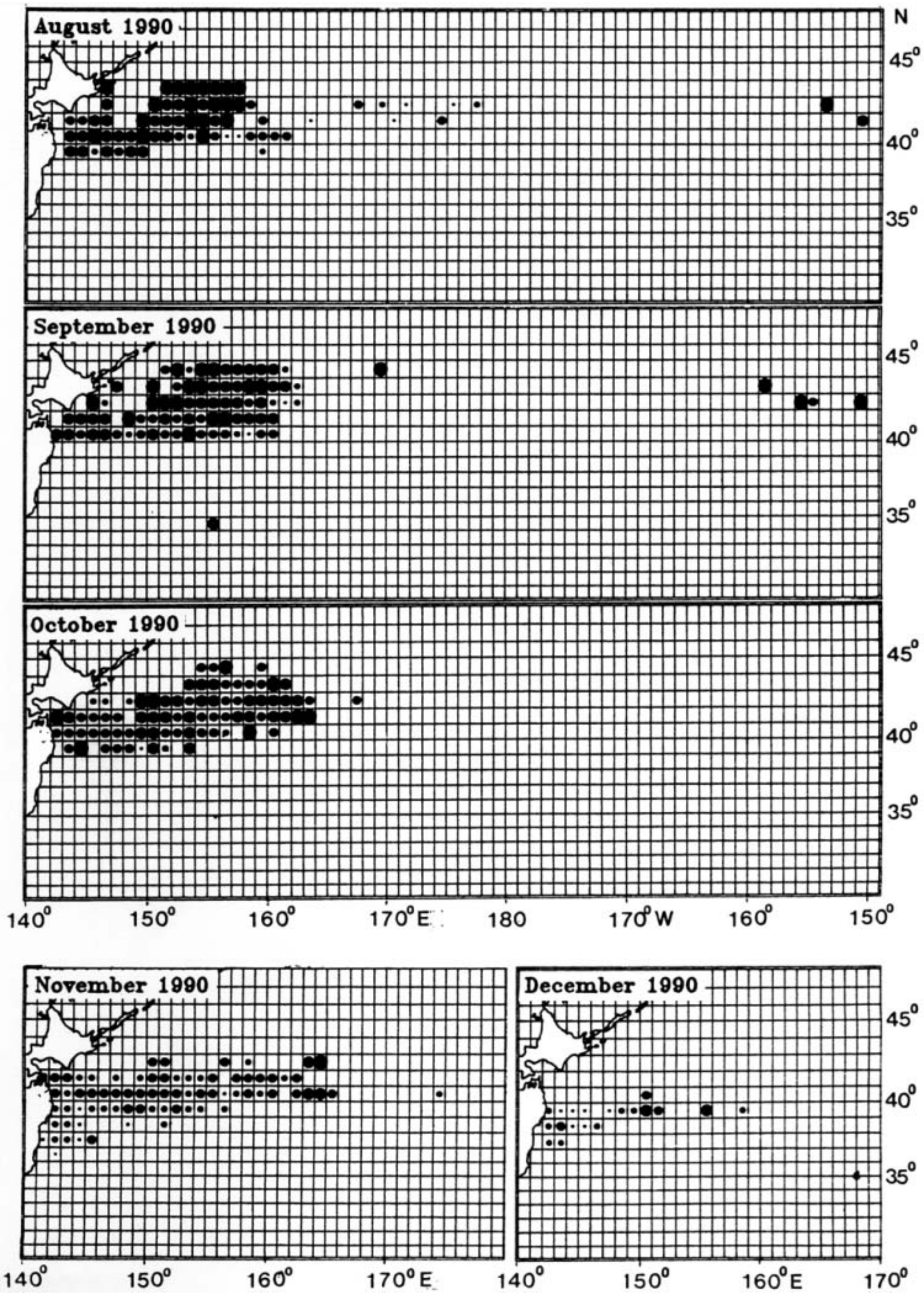

Figure 3. Monthly distribution of Korean driftnet fishery for neon flying squid in 1989. Dots indicate relative CPUE (kg/net) by 1° square.

3.3. Assessment of Squid Stocks

Assessments of squid stocks have been carried out before, during and after the fishing season (Pierce and Guerra, 1994). Methods that have been successfully applied include: (1) depletion methods (Rosenberg et al., 1990), which have cost and other advantages because they use data from the commercial fishery (as they are normally operated in real-time, they require significant man-power, on-board and on land, to collect and process catch, effort, and biological data); (2) swept area methods (using nets) (Cadrin and Hatfield, 1999); and (3) acoustics (Starr and Thorne, 1998; Goss et al., 1998, 2001). An "ecological approach" has also been used to set a precautionary catch for a potential new fishery for *Martialia hyadesi* in the CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources) area (Rodhouse, 1997). This used estimated total consumption by predators (seabirds, seals, and toothed whales) to set a TAC (total allowable catch) that was sufficiently low to have a negligible effect on dependent predator populations and was consistent with the ecosystem-based approach to fishery management adopted by CCAMLR.

A number of other assessment methods have been attempted or proposed for squid stocks (Rodhouse et al., 2014). Surveys of paralarval numbers prior to recruitment have been carried out (e.g., Okutani and Watanabe, 1983) but were found to have little practical application. Stock-recruitment relationships have been tested (Okutani and Watanabe, 1983) but with inconsistent results, as the relationship between stock and recruitment is weak in squid stocks. The surplus production method has also been tried, sometimes unsuccessfully (perhaps for the same reason) but with some success in Saharan Bank fisheries (possibly because cephalopod stocks rapidly adjust to effects of exploitation, so that equilibrium can be achieved) (Pierce and Guerra, 1994). Cohort analysis has been attempted several times but is often impractical because of the difficulties associated with sectioning and reading large numbers of statoliths (to collect age data) in the short fishing season operating in most squid fisheries. However, a successful application to *Loligo* in the English Channel was reported by Royer et al. (2002).

The mark-recapture method, which has been used widely in population ecology, has potential utility for assessment of squid stocks. The method involves sampling the population, tagging a subsample, and releasing them back into the population. The population is then resampled and population size estimated based on the proportion of tagged individuals recaptured (Krebs, 1999). Although large scale tagging of squid has been successfully carried out (Nagasawa et al., 1993; Sauer et al., 2000), these have been for research on distribution and migration but no stock assessment has yet been done by mark-recapture. Squid are fragile so the potential for tagging related mortality biasing the results would be a consideration.

3.4. Management of Squid Fisheries

The short life span of squids (approximately 1 year in the case of most commercially exploited species) requires a different management approach to that taken for most finfish fisheries. There are usually only one or two cohorts per year depending on the number of seasonal spawning groups present in the population. The members of these cohorts spawn, sometimes in more than one batch and die soon afterward. This means that there is usually a period in the year when adults are largely absent and the population is represented by eggs, paralarvae, and prerecruits. Following recruitment, there is generally a relatively short fishing season during which growth and individual biomass increases rapidly.

The annual lifecycle means that managers have very little information on the potential size of the exploitable stock until shortly before recruitment. Prerecruit surveys may provide some information (Roa-Ureta and Arkhipkin, 2007) but it is only when the squid are large enough to be susceptible to the fishing gear that reliable estimates of stock size can be made. Given the challenges of managing squid fisheries Caddy (1983) proposed that management should be based on effort limitation, with the possibility of short-term adjustment of effort, and with the objective of allowing a maximum proportion (40%) of the catchable biomass to be removed each year.

The approach was adopted and refined in the Falkland Islands fishery for *I. argentinus* and *D. gahi* (Beddington et al., 1990; Rosenberg et al., 1990; Beddington et al., 1990; Rodhouse et al., 2013). Stock assessment is carried out in-season using a modified Lesley–Delury depletion method. Target escapement in *I. argentinus* was initially based on allowing a proportion of the preseason numbers of squid to escape but this was later changed to a precautionary minimum spawning biomass, estimated on the basis of experience, needed to generate adequate recruitment (Basson et al. 1996). The approach has been considered elsewhere for management of fisheries for *D. pealeii* (Brodziak and Rosenberg, 1999) and *Loligo reynaudii* (Augustyn et al., 1992) but it has not been widely adopted.

Management of the Japanese *T. pacificus* fishery has been described by Okutani (1977), Caddy (1983), Okutani (1983), Murata (1989, 1990), and Suzuki (1990). Management has been concerned with balancing market demand and price as well as ensuring the stock is fished sustainably (Boyle and Rodhouse, 2005). Maintaining price by limiting the catch, and hence market availability, will tend to have the effect of limiting overfishing unless the stock drops to a low level when price increases, resulting in pressure on stocks in the absence of restrictions.

Fisheries for *D. gigas* take place off the west coast of the Americas from Chile to California, though the species range now extends northward to Alaska. Fisheries are pursued off Peru, Chile and in Baja California (BC), Mexico, and their management has been recently reviewed by Rosa et al. (2013c). The Peruvian fishery is managed by setting quotas based on data from acoustic surveys and data from the fishery. In Mexico, the fishery is managed on the basis of allowing at least 40% escapement of the stock to spawn. In practice, a higher proportion of the stock survives to spawn and the fishery is considered by managers to be underexploited. In Chile, the fishery is managed by restricting access and limiting use of product for human consumption. TAC is flexible and based on a combination of historical catch and in-season catch rates.

Other management approaches adopted elsewhere have been outlined by Boyle and Rodhouse (2005). These include spatial and seasonal restrictions, mesh size restrictions and the introduction of individual transferable quotas, which eliminates "competitive" fishing. In the future, marine protected areas (MPAs) will undoubtedly play their part in the management of squid fisheries.

It is worth noting that small-scale squid fisheries exist in many parts of the world, for example, in coastal waters of southern Europe. These are often essentially unregulated (except for minimum landing sizes (MLSs) in some areas).

If further management is introduced, approaches used in large-scale fisheries are unlikely to be suitable. Regionally and locally based measures, involving comanagement have been proposed for small-scale octopus fisheries and such an approach may be suitable for small-scale squid fisheries.

4. NORTHWEST ATLANTIC

The Northwest Atlantic region includes the coastal, shelf and oceanic waters off the eastern coasts of Canada and the United States of America (USA). The continental shelf broadens in a northward direction and lies primarily within the jurisdiction of these two countries, but the Flemish Cap and the Nose and Tail of the Grand Bank are located in international waters. Regional oceanographic conditions are mainly driven by the cold, relatively fresh Labrador Current which flows southwestward and a warmer, saltier western boundary current, the Gulf Stream, which flows northeastward (Loder et al., 1998). Two species of squids are subject to commercial exploitation in the region: *I. illecebrosus* (Northern shortfin squid) is an oceanic squid species that is fished in USA, Canadian and international waters and *D. pealeii* (longfin inshore squid) is a neritic squid species that is fished on the USA shelf. Both species have been exploited since the late 1800s, originally mostly as bait, but fishing pressure increased rapidly in the region and was highest during the 1970s when large factory trawlers from Japan, the former USSR, and Western Europe targeted both species for food.

4.1. *Illex illecebrosus* (Northern Shortfin Squid)

4.1.1. *Geographic Range and Distribution*

Northern shortfin squid, *I. illecebrosus*, are distributed across a broad latitudinal range in the Northwest Atlantic Ocean, in continental shelf, slope, and oceanic waters located off the east coast of Florida (26°–29°N) to 66°N, including southern Greenland, Baffin Island, and Iceland (Roper et al., 2010).

Distribution is highly influenced by water temperatures and water masses, and on the eastern USA shelf, temperature preferences during the fall are size-specific (Brodziak and Hendrickson, 1999). The species is associated with bottom water temperatures greater than 6°C on the Scotian Shelf (Rowell et al., 1985a) and greater than 5°C on the Newfoundland shelf (Mercer, 1973a). On the USA shelf, shortfin squid are most abundant at bottom temperatures of 8–13°C during fall and 10–14°C during spring (Hendrickson and Holmes, 2004). Although common in nearshore waters north of the Gulf of Maine during summer and fall, the species is uncommon in shallow waters (<18 m) on the USA shelf (Hendrickson and Holmes, 2004).

The timing of migrations into the fishing areas varies interannually (Fedulov and Amaratunga, 1981) and begins earliest in the southern portion of the species' range. During March and April, on-shelf migration occurs simultaneously along the USA shelf/slope edge, from South Carolina to Browns Bank on the southern Scotian Shelf, and squid densities are highest in the southernmost and deepest survey strata as well as on Browns Bank (Hendrickson, 2004). Migration onto the Scotian Shelf also begins by April (Fedulov and Amaratunga, 1981; Black et al., 1987), but migration onto the Grand Banks generally occurs later, during May and June (Squires, 1957), and densities are highest along the Bank edge in Northwest Atlantic Fisheries Organization (NAFO) Divisions 3O and 3N (Figure 4; Black et al., 1987; Hendrickson, 2006). During late May, both juveniles with a modal mantle length (ML) of 40 mm and adults were caught near the USA shelf edge (Hendrickson, 2004). By July, the species is broadly distributed across the USA shelf, Scotian Shelf and Gulf of St. Lawrence (Hendrickson, 2004, Black et al., 1987) and has migrated to the inshore fishing grounds off Newfoundland (Dawe, 1981). Fall offshore migrations also begin earliest in the southern portion of the species' range. During September and October, squid remain distributed throughout the USA shelf but density and squid body size increase with depth for individuals greater than 100 mm ML (Brodziak and Hendrickson, 1999), indicating an off-shelf migration along the entire length of the USA shelf (Hendrickson, 2004). However, migration from the Newfoundland inshore fishing grounds occurs later, generally during November (Dawe, 1981).

I. illecebrosus concurrently inhabits the continental shelf, slope and oceanic waters during portions of the year. However, sampling beyond the depth limit of USA and CA spring and fall bottom trawl surveys (about 366 m) is limited. Small quantities of shortfin squid have been caught in Northeast Fisheries Science Center (NEFSC) bottom trawl surveys (Azarovitz, 1981) on the upper slope between the Gulf of Maine and Cape Hatteras in April (381–460 m depths). Concurrent with the USA fishery on the continental shelf, shortfin squid were also caught offshore in July near the Bear Seamount, with the maximum catch at 2510 m depth (NEFSC, 2003), and during late fall, catch rates declined with depth and bottom temperature at depths ranging from 384 to 1,038 m, between Georges Bank and Cape Canaveral, Florida (Rathjen, 1981). Concurrent with the July inshore jig fishery off Newfoundland, shortfin squid were consistently caught offshore in Division 3M (Figure 4) bottom trawl surveys of the Flemish Cap (i.e., 20–5,143 t during 2003–2012), at depths up to 1460 m (Hendrickson and Showell, 2013).

4.1.2. *Stock Identification*

The *I. illecebrosus* population is considered to constitute a single stock throughout its range in the Northwest Atlantic Ocean (Dawe and Hendrickson, 1998). Based on an allozyme polymorphism analysis, there is no significant genetic heterogeneity of *I. illecebrosus* populations located off Newfoundland and Cape Cod (Martínez et al., 2005a,b). The stock was managed as single unit during 1974–1976

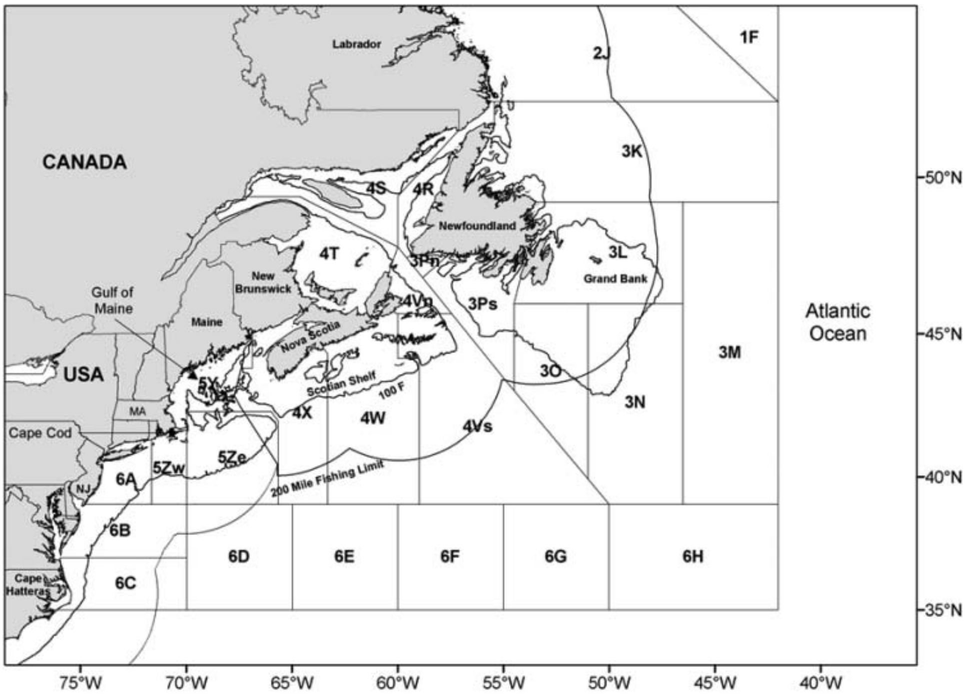

Figure 4. Northwest Atlantic Fisheries Organization (NAFO) reporting areas, Subareas 3–6 and associated Divisions, for fisheries that occur in the Northwest Atlantic Ocean.

(Amaratunga, 1981a) by NAFO; formerly the International Commission for Northwest Atlantic Fisheries (ICNAF). However, since the 1977 implementation of the 200-mile fishing limits for the USA and Canada, this transboundary species has been managed as two separate stock components. The northern stock component consists of squid from Canadian and international waters and is managed by NAFO. The northern stock component (NAFO Subareas 3+4) includes squid from Subarea 3, which includes the Grand Banks, Flemish Cap, and inshore Newfoundland waters, and Subarea 4, which includes the Scotian Shelf, Bay of Fundy, and southern Gulf of St. Lawrence (Figure 4). The southern stock component (NAFO Subareas 5+6) consists of squid from USA waters, between the Gulf of Maine and the east coast of Florida, and is managed in the USA by the Mid-Atlantic Fishery Management Council.

4.1.3. Life History

Shortfin squid utilize continental shelf, slope, and oceanic habitats during their lifecycle and adults undergo long-distance migrations among boreal, temperate, and subtropical waters. Similar to several other ommastrephids, the lifecycle of Northern shortfin squid is associated with a western-boundary current system (Coelho, 1985; Hatanaka et al., 1985a), the Gulf Stream, which has been hypothesized as the primary transport mechanism for egg "balloons," paralarvae, and small juveniles northeastward toward the Grand Banks (Trites, 1983). The neutrally buoyant egg "balloons" have not been found in nature (O'Dor and Dawe, 1998), but laboratory studies indicate that normal embryonic development occurs at a minimum temperature of 12.5°C with hatching in sixteen days (O'Dor et al., 1982), and at a maximum temperature of about 26°C, hatching occurs in 6 days (Balch et al., 1985). The ML of *I. illecebrosus* hatchlings is approximately 1.1 mm (Durward et al., 1980). *Illex* sp. paralarvae have been captured during most of the year in the warm, nutrient-rich waters of the Gulf Stream/Slope Water Convergence Zone, between central Florida and south of Newfoundland (Dawe and Beck, 1985), but were most abundant during February and March, above the thermocline, at temperatures greater than 13°C (Dawe and Beck, 1985; Hatanaka et al., 1985b). During spring, epipelagic juveniles migrate from the Convergence Zone to cooler, more productive, neritic waters where individual growth rates are more rapid (Perez and O'Dor, 1998). During late May, juveniles (34–68 mm ML) have been collected near the USA shelf edge along the southeast flank of Georges Bank, at depths of 140–260 m, where surface and bottom temperatures were 10.6 and 9.9°C, respectively (Hendrickson, 2004).

Bakun and Csirke (1998) suggested that the southwestward-flowing Slope Water Countercurrent may aid the species during its fall migration to an inferred winter spawning area located south of Cape Hatteras (Trites, 1983; Rowell and Trites, 1985). The fall, off-shelf migration from all fishing areas and southwest migration patterns of several individuals tagged on the northern fishing grounds (Amaratunga, 1981b; Dawe et al., 1981) lend support to the lifecycle hypothesis of Rowell and Trites (1985). However, unlike males, females are not yet mature when they emigrate from inshore

Newfoundland waters during late fall (Squires, 1967; Mercer, 1973b). In addition, the *Illex* sp. hatchlings which have been collected south of Cape Hatteras during winter were not identified to the species level, despite the fact that *I. illecebrosus* is sympatric with *I. oxygonius* and *I. coindetii* south of New Jersey and Virginia, respectively (Roper and Lu, 1979; Roper et al., 2010). Thus, the winter spawning area remains unknown, as do the migration patterns between the northern and southern stock components (refer to Section 4.1.4), and the autumn spawning migration route (Hendrickson and Holmes, 2004).

The only confirmed spawning area is located along the USA shelf edge, in the Mid-Atlantic Bight (between 39°10′ N and 35°50′ N), where the winter cohort was found spawning during late May at depths of 113–377 m and surface and bottom temperatures ranging from 13.4–20.1°C and 11.4–20.3°C, respectively (Hendrickson, 2004). Mature and spawning individuals have also been caught in the USA directed bottom trawl fishery during June-September (Hendrickson and Hart, 2006). Thus, the Mid-Atlantic Bight is the primary spawning area during at least May–September, but some spawning may also occur in the Gulf Stream/Slope Water frontal zone where paralarvae and juveniles have been collected during most winter months (Hatanaka et al., 1985b). The presence of spawners during May–September, combined with the documentation of November–June hatch dates (Dawe and Beck, 1997; Hendrickson, 2004), indicate that spawning occurs year-round.

The maximum ML and weight recorded for the species are 350 mm and 700 g and females achieve larger sizes than males (O'Dor and Dawe, 1998). The lifespan of mated females from the winter cohort inhabiting the USA shelf was 115–215 days (Hendrickson, 2004) whereas a maximum age of 250 days was documented for females caught in the Newfoundland jig fishery and which were not mature (Dawe and Beck, 1997). The species exhibits latitudinal clines in growth rate and size-at-maturity such that individuals inhabiting warmer waters of the Mid-Atlantic Bight exhibit faster growth and maturation rates, and possibly have a shorter lifespan, than squid from the colder waters off Newfoundland (Hendrickson, 2004).

4.1.4. Recruitment

Recruitment is highly variable, particularly at the northern limit of the species' range, primarily due to the effects of variability in water temperatures and broad-scale oceanographic conditions. Dawe et al. (2007) found that variation in atmospheric forcing, as well as the latitudinal position of the Shelf-Slope Front (SSF), were closely related to oceanographic processes that exert opposing effects on the distribution and abundance of *I. illecebrosus* and *D. pealeii*, which are sympatric on the USA shelf during summer and fall. For *I. illecebrosus*, southward displacement of the SSF and north wall of the Gulf Stream were related to a warm oceanographic regime off Newfoundland and improved efficiency of northeasterly transport by the Gulf Stream along with enhanced survival of paralarvae and juveniles from the winter spawning period (Dawe et al., 2007). Coelho and O'Dor (1993) and O'Dor and Coelho (1993) hypothesized that squid abundance in the northernmost fishing area, off Newfoundland, is highest when the winter cohort is predominant.

The winter cohort (i.e., squid hatched primarily during December and January), which is predominant on the USA shelf during May, provides recruitment to the USA fishery during the early part of the fishing season (Hendrickson, 2004). However, squid from the winter cohort were not predominant in the Newfoundland jig fishery catches during July–November. Instead, squid caught in the jig fishery during July–September were predominately hatched during March (Dawe and Beck, 1997), which corresponds to the March-hatched juveniles present on the northern USA shelf during May (Hendrickson, 2004). During October–November, the Newfoundland jig fishery catches were dominated by squid hatched during April–May, which corresponds to the hatching period of the progeny of the spawning squid that were present on the USA shelf during May.

4.1.5. Fisheries

The onset and duration of the directed fisheries generally reflect the timing of squid migrations through each fishing area and can vary interannually. Since 1996, the duration of the USA bottom trawl fishery in Subareas 5+6 (Figure 5A) has also been affected by fishery closures which occur when a

Figure 5. Gear types used in the *Illex illecebrosus* fisheries. (A) The squid catch of a USA bottom trawler (a freezer vessel) is pushed from the "pen" area, shown here, to a conveyor belt for sorting on deck prior to packing and freezing the catch in the hold. (B) A fisherman manually operates a jig reel while fishing for squid near the Newfoundland coast. (C) A view from the dock of jig reels used in the small-boat (4–14 m in length) squid fishery off Newfoundland and a day's catch. (D) Fishermen jigging for squid in a Newfoundland embayment. Photograph credits: (A) Lisa C. Hendrickson; (B) downhomelife.com.

percentage of the annual quota is landed (i.e., 80% in 1996 and 95% during 1997–2014) and which triggers a shortfin squid trip limit of 45,359 kg (the regulatory definition of a directed trip). The seasonal peak of landings for each fishing area also varies interannually depending on fishing effort, squid availability, and abundance. Since 1992, the Subarea 4 and 5+6 fisheries have occurred mainly during June-October, with a landings peak in July or August, and the Subarea 3 inshore fishery has generally occurred about one month later, during July–October or November, with a peak in September (Hendrickson et al., 2002).

In Subarea 3, a majority of the landings have been taken in a jig fishery that occurs in small, open boats in the nearshore waters (depths < 20 m) of Newfoundland (Mercer, 1973c; Hendrickson and Showell, 2013) (Figure 5B–D). During 1970–1980, international midwater and bottom trawlers and jig vessels fished offshore in Subareas 3 and 4 (Dawe, 1981; Hatanaka and Sato, 1980). During 1963–1969, small amounts (65–433 t) of *I. illecebrosus* were landed from Subarea 4 during a June–November inshore trap fishery (Amaratunga et al., 1978).

4.1.6. *Total Catches*

Since 1963, total landings (nominal catches) from Subareas 3–6 have varied considerably and have consisted of three distinct levels of magnitude. The period of highest landings (1976–1981), which occurred when international fishing fleets were active in all fishing areas, was bracketed by periods of substantially lower landings (Hendrickson and Showell, 2013; (Figure 6). Total landings were primarily from the northernmost fishing area (Subarea 3 inshore jig fishery) during 1963–1967 (average = 7,354 t) and from the southernmost area (international fishery in Subareas 5+6) during 1968–1974 (average = 13,470 t). Following a sustained period of record high landings in Subareas 3+4 during 1976–1981 (average = 100,300 t), these northern fisheries collapsed; declining from 162,092 t in 1979 to 426 t in 1983. However, landings from Subareas 5+6 remained stable during the same period and did not exceed 25,000 t, in part, due to effort restrictions. Since 1987, total landings have been mainly from the USA fishery in Subareas 5+6.

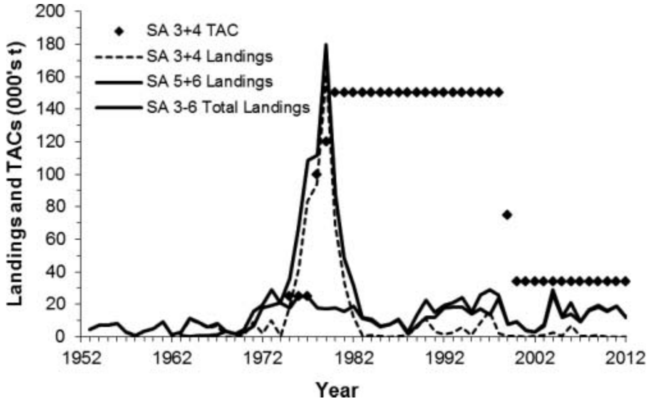

Figure 6. Landings of *Illex illecebrosus* and TACs (000's t) in Subareas 3+4, during 1953–2012, and in Subareas 5+6 during 1963–2012.

4.1.6.1. Subareas 3+4. The Subarea 3 inshore jig fishery has occurred since the late 1800s, but landings have only been quantified since 1911 and totalled less than 1,000 t during most years between 1911 and 1952 (Dawe, 1981). During 1920–1952, landings from Subarea 4 averaged 269 t with a peak of 1990 t in 1926 (Mercer, 1973c). Landings from Subareas 3+4 were predominately from the Subarea 3 inshore jig fishery during 1953–1969 (average = 4,647 t) due to increased export market demand and the use of mechanized jiggers beginning in 1965 (Dawe, 1981). The inshore jig fishery has repeatedly been defined as "passive" and entirely driven by squid availability (e.g., Mercer, 1973c). However, the lack of fishing effort data for the jig fishery prior to 1990 (Dawe and Hendrickson, 1998) and lack of inshore abundance and distribution data do not allow one to discern whether landings fluctuations were attributable to resource availability or changes in fishing effort and/or abundance. During the 1970s, landings from Subareas 3+4 increased rapidly with the development of offshore international fleets, from 1,485 t in 1970 to a peak of 162,092 t in 1979 (Hendrickson and Showell, 2013; Figure 6). During 1970–1978, landings from Subareas 3+4 were predominately from the Subarea 4 international fleets (average = 18,659 t). During this same period, Subarea 3 landings were predominately from the inshore jig fishery (average = 10,172 t). Landings by the offshore international fleets in Subarea 3 occurred primarily during 1975–1979 and were much lower, with a peak of only 5,700 t in 1978 (Dawe, 1981). Due to a strong export market demand, revenues from the jig fishery landings increased rapidly from $4,100 in 1976 to nearly $9 million in 1978 (Hurley, 1980). Landings in Subareas 3+4 were highest during 1976–1981 and averaged 80,645 t (Figure 6). Following a landings peak in 1979 (162,092 t), the fishery in Subareas 3+4 collapsed; landings declined to 426 t in 1983 and remained low thereafter with the exception of a few years (Figure 6). During 1987–1999, landings were primarily from an international fishery in Subarea 4 for *Merluccius bilinearis*, *I. illecebrosus*, and *Argentina* sp. (Hendrickson et al., 2002), but since 2000, landings have been primarily from the Subarea 3 inshore jig fishery (Hendrickson and Showell, 2013). The amounts of shortfin squid discards in the Subareas 3+4 trawl fisheries are unknown.

4.1.6.2. Subareas 5+6. Landings of squids (*I. illecebrosus* and *D. pealeii* combined) off the eastern USA coast have been recorded since 1887, and during 1928–1963, averaged 1,232 t and 700 t from New England (ME to CT) and Mid-Atlantic (NY to NC) waters, respectively (Lange and Sissenwine, 1983). Prior to 1982, USA landings of *I. illecebrosus* were mainly from a nearshore trap fishery, for bait, off the Maine coast and incidental in bottom trawl fisheries during summer and fall (Lange, 1978). Landings from Subareas 5+6 are

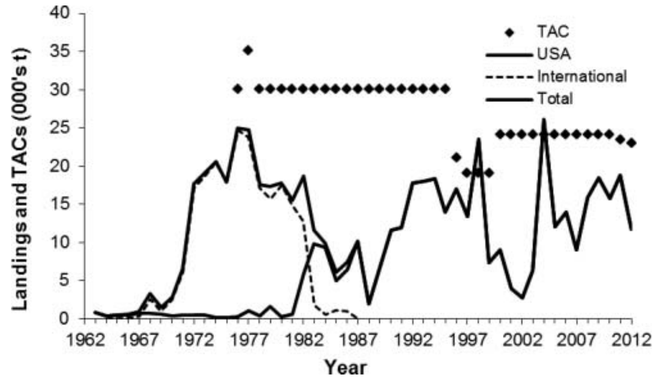

Figure 7. Landings of *Illex illecebrosus* and TACs (000's t), for Subareas 5+6, during 1963–2012.

characterized by two distinct periods (1968–1986 and 1987–2012). During 1968–1982, landings were predominately taken by international fleets and averaged 15,086 t with a peak of 24,936 t in 1976; the second highest level (Hendrickson and Showell, 2013; Figure 7). Most of the landings were taken by Spain (33%), Japan (17%), Russia (16%), Italy (12%), and Poland (13%, Figure 8). After 1976, landings gradually declined to 1958 t in 1988. The decline was due to restrictions on effort and catch allocations for international vessels, the latter which were further reduced during 1982–1986 in order to develop a domestic squid fishery which initially consisted of joint ventures between foreign "processor" vessels and American "catcher" vessels (Lange and Sissenwine, 1983). During 1987–2002, USA fishery landings averaged 11,728 t. Following an increase to 23,568 t in 1998 (which led to an August fishery closure) landings declined to 2,750 t in 2002; the lowest level since the 1987 inception of the domestic fishery. Landings reached a record high in 2004 (26,097 t), resulting in a September fishery closure, then declined again and averaged 14,453 t during 2005–2012. Discards of shortfin squid are low in the directed fishery and due to their lower value primarily occur in the *D. pealeii* fishery. Total discards in both fisheries comprised 0.5–6.0% of the directed fishery landings during 1995–2004 (NEFSC, 2006).

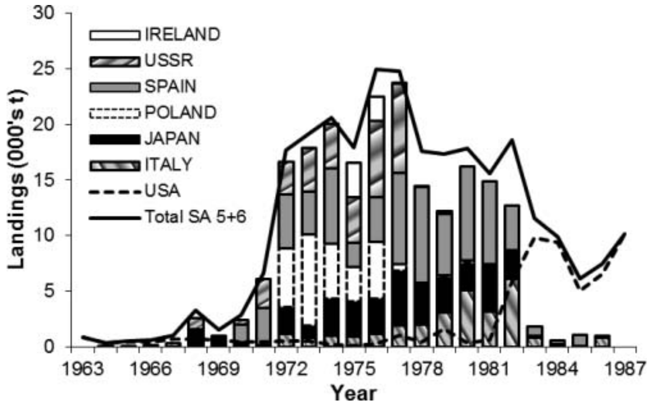

Figure 8. Landings (000's t) of *Illex illecebrosus* in Subareas 5+6, by major country, during 1963–1987. Landings by fleets from eight additional countries, not shown in the figure, ranged between 7 t and 1566 t during the same time period.

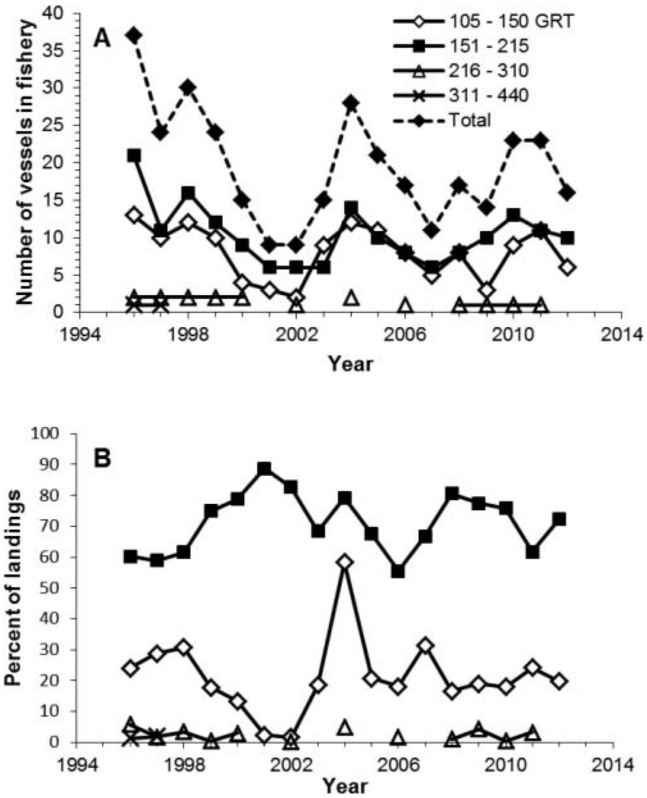

Figure 9. Fleet size (A) and percent of annual *Illex illecebrosus* landings (B), by tonnage class (gross registered tonnage, GRT), for the USA directed bottom trawl fishery during 1996–2012.

4.1.6.2.1. *Fishing fleets*. International fleets fishing in Subareas 5+6 consisted of 95 jiggers, bottom trawlers, and midwater trawlers that ranged in size from 34–87 m (298–3,697 GRT), during 1977, and which fished mainly during the day at depths of 165–200 m (Kolator and Long, 1979). The USA bottom trawl fleet consists of fewer and smaller vessels, totaling about 30 vessels, during highly productive years (e.g., 2004), but only 10–20 vessels during most years (Figure 9A). During 1996–2012, the USA fleet totalled 9–37 vessels. However, during most years, most of the landings (56–89%) were taken by 6–15 vessels in the 151–215 GRT size class (Figure 9A and B). The USA fleet fishes during the day, and during 1996–2012, vessel logbook data indicated that 95% of the landings occurred at depths of 128–238 m (mode = 183 m) with most (69%) occurring at 146–201 m.

Fishing effort by the USA fleet is affected by on-shelf availability of squid, abundance, vessel type, and ex-vessel price. Vessel types include freezer trawlers, on which catches are frozen at sea, and trawlers on which catches are stored either on ice or in refrigerated seawater (NEFSC, 2003). Freezer trawlers can fish for up to about 14 days and ice/refrigerated seawater trawlers generally fish less than 4 days. Freezer trawlers harvest a majority of the landings except during years when the landings are exceptionally high (NEFSC, 2006).

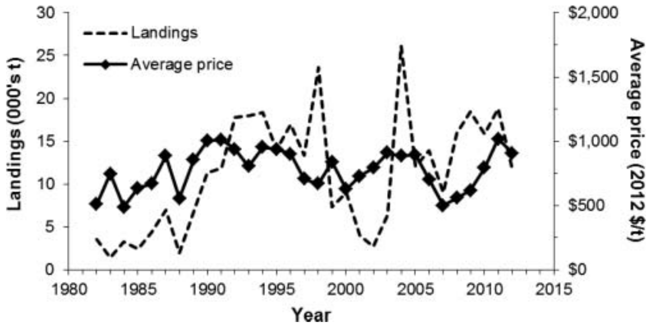

Figure 10. Landings (000's t) and average price (2012 $/t, adjusted for inflation using the Producer Price Index), of *Illex illecebrosus* in the USA directed fishery during 1982–2012.

4.1.6.2.2. *Economic importance.* A portion of the landings by the USA fleet are sold domestically as bait, but a majority is exported as food. Ex-vessel price is highly influenced by the global squid market, in particular, the amount of *I. argentinus* available from the Falklands (NEFSC, 1999). The average price of *I. illecebrosus* (in 2012 $/t, adjusted for inflation using the USA Producer Price Index (PPI)) nearly doubled during development of the domestic fishery, from $511/t in 1982 to $1,013/t in 1991, but then gradually declined to $627/t in 2000 (Figure 10). During the 1990–1999 and 2000–2009, mean prices averaged $877/t and $723/t, respectively. Average price peaked at $1,017/t in 2011 and was $908/t in 2012. During 1982–2012, trends in gross revenues (in 2012 $ adjusted using the PPI) were similar to the landings trends (Figure 10) and ranged from $1.1 million in 1983 to a peak of $23.1 million in 2004. Gross revenues were above the 1982–2011 average ($9.0 million) during 1990–1998, 2004–2006, and 2009–2012.

4.1.7. Fishery Management and Stock Assessment

4.1.7.1. Subareas 3+4. Total allowable catches (TACs) of *I. illecebrosus* for Subareas 3+4 have been established annually by ICNAF/NAFO since 1976, and during 1976 and 1977, the TACs of 25,000 t were exceeded by 167% and 343%, respectively (Figure 6) due to fishery reporting problems (Lange and Sissenwine, 1983). As landings continued to increase during 1978–1980, the respective TACs also increased to 100,000 t, 120,000 t, and 150,000 t, respectively, and were based on applying a target exploitation rate of 0.40 to the prior year's biomass estimate (Lange and Sissenwine, 1983). The 1979 TAC was exceeded by 135% (Figure 6). International fleets were also subject to effort controls which consisted of delayed fishery opening dates of June 15 and July 1 during 1978 and 1979, respectively (Roberge and Amaratunga, 1980). Beginning in 1977, small-mesh (minimum codend mesh size = 130 mm) international bottom trawlers were required to fish seaward of a "Small Mesh Gear Line" (located near the 200 m isobath in Divisions 4W and 4X) during April 15-November 15, to reduce bycatch (Waldron, 1978).

The northern stock component was assessed annually during 1974–2002 and every third year since then, with brief monitoring reports during interim years. The assessment is data-poor, and since 1998, has been based on trends in relative biomass and body size indices derived from the July bottom trawl surveys of the Scotian Shelf. Two general levels of productivity have been identified for the northern stock component. A period of high productivity occurred during 1976–1981, between two low productivity periods, 1970–1975 and 1982–2012 (Hendrickson and Showell, 2013). A TAC of 34,000 t, an estimate of the potential yield sustainable under low productivity conditions (Rivard et al., 1998), has been in effect since 2000 but landings have been well below this level since 1982 (Hendrickson and Showell, 2013).

4.1.7.2. Subareas 5+6. An initial TAC of 71,000 t (for *I. illecebrosus* and *D. pealeii* combined) was established by ICNAF in 1974–1975, for Subarea 5+6, as a preemptive measure to limit expansion of the international squid fisheries (Lange and Sissenwine, 1983). ICNAF also set *I. illecebrosus* TACs for Subareas 5+6 during 1976–1977 and the 1977 TAC was adopted by the USA as part of a preliminary Fishery Management Plan that was implemented following the USA withdrawal from NAFO (Figure 7). The TAC was 30,000 t during 1976–1995 and ranged between 19,000 t and 24,000 t during 1996–2012. Fishery closures occurred during 1998 and 2004 when the TACs of 19,000 t and 24,000 t, respectively, were attained and exceeded (Figure 7).

Beginning in March of 1977, international bottom trawl fleets targeting either squid species were subject to weekly catch reports, hiring USA fishery observers, effort restrictions and mesh size limitations. Minimum codend mesh sizes of 40 and 60 mm (inside stretched mesh measurements) were required in 1977 and 1978, respectively, and fishing was limited to specific months within five offshore "fishing windows" (depth range of 90–200 m), with a requirement of pelagic trawls (minimum codend mesh size of 45 mm) in some areas and months, in order to reduce gear conflicts with lobster pots and reduce bycatch (Kolator and Long, 1979). Since 1996, the USA *I. illecebrosus* fleet has been limited to fishing seaward of 91 m, during June-September, to avoid *D. pealeii* bycatch. Unlike the *D. pealeii* fishery minimum mesh size requirements (i.e., 48 mm codend and 114 mm strengthener during 1996-fall of 2010; 54 mm codend and 127 mm strengthener since then, inside stretched mesh), the USA *I. illecebrosus* fishery has no minimum mesh size requirements. Vessel logbook data during 2010–2012 indicated that 42% of the *I. illecebrosus* fishery landings were taken with 48–53 mm diamond mesh codends (inside stretched mesh), and the remainder were primarily taken with 28 mm (28%), 38 mm (10%), and 61–64 mm (16%) mesh. Partial and full recruitment to the USA fishery occurs at 110 and 180 mm ML, respectively (Lange and Sissenwine, 1980; NEFSC, 2003).

The stock assessments of shortfin squid are data-poor and are not conducted annually. Several models have been used to compute biomass, fishing mortality rates, and MSY-based biological reference points (BRPs), or proxies thereof (e.g., $F_{40\%}$), as required by the stock's Fishery Management Plan. The most recent assessment consisted of a weekly, age-based model for an unfished cohort that was used to estimate the maturation and natural mortality rates of non-spawners and spawners and which also incorporated aging error (Hendrickson and Hart, 2006). Output from the maturation-natural mortality model was then incorporated into a weekly, per-recruit model to estimate BRPs and biomass and fishing mortality rates were estimated from a weekly-based, DeLury-type model that utilized tow-based biological and fishery data (NEFSC, 2006).

4.2. *Doryteuthis pealeii* (Longfin Inshore Squid)

4.2.1. Geographic Range and Distribution

Longfin inshore squid inhabits the continental shelf and upper slope waters between southern Newfoundland and the Gulf of Venezuela, including the Gulf of Mexico and the Caribbean Sea (Jereb et al., 2010). In the Northwest Atlantic Ocean, *D. pealeii* is most abundant between Georges Bank and Cape Hatteras, North Carolina (Figure 4) where a commercial fishery occurs (Serchuk and Rathjen, 1974). North of Georges Bank, the species is seasonally abundant in the Gulf of Maine during summer through fall, primarily at depths <90 m (NEFSC, 2011), but is seldom found further north. However, during several years, longfin squid have been found as far north as southern Newfoundland when northern water temperatures were warmer than normal (Dawe et al., 2007). The southern limit of distribution in east coast USA waters is unknown because *D. pealeii* is sympatric with *D. plei*, mainly south of Cape Hatteras, and the two species cannot be visually distinguished between based on gross morphology (Cohen, 1976).

North of Cape Hatteras, longfin squid exhibit seasonal north-south and inshore-offshore migrations which are strongly influenced by water temperatures. Distribution patterns are known from spring and fall bottom trawl surveys conducted between the Gulf of Maine and Cape Hatteras by the NEFSC (Azarovitz, 1981). The species migrates southward and to the edge of the continental shelf, as far north as Georges Bank, during late fall then migrates inshore to embayments and sounds during spring where squid remain through fall (Summers, 1983; Black et al., 1987; NEFSC, 2011). Inshore migrations begin earlier at southern latitudes (Whitaker, 1978) as inshore waters gradually warm in spring (Black et al., 1987). Longfin squid prefer warmer water temperatures than *I. illecebrosus* (Brodziak and Hendrickson, 1999). Catch rates of longfin squid during NEFSC spring bottom trawl surveys were highest at depths of 111–185 m and bottom temperatures of 10–12°C, but catch rates were greatly reduced at bottom temperatures less than 8°C during spring and fall surveys (Serchuk and Rathjen, 1974). During NEFSC fall bottom trawl surveys, longfin squid preferred depths of 37–75 m and bottom temperatures of 11–15°C (Brodziak and Hendrickson, 1999).

4.2.2. Stock Identification

The *D. pealeii* population inhabiting the waters between the Gulf of Maine and Cape Hatteras is managed as a single stock (NEFSC, 2011) based on the results of genetics studies and the consistency of seasonal migrations to the inshore spawning grounds (Black et al. 1987). Genetics studies by Herke and Foltz (2002) and Shaw et al. (2010) found no evidence of genetically distinct subpopulations between the Gulf of Maine and the east coast of Florida. Buresch et al. (2006) found population differentiation at some of their sampling sites. However, in a follow-up genetics analysis to address comments in Shaw et al. (2012), they found that population differentiation was not temporally stable (Gerlach et al., 2012). Most studies of genetic structuring in Loliginid squid populations have suggested widespread genetic uniformity (Shaw et al., 2010).

4.2.3. Life History

The longfin inshore squid has a lifespan of less than 1 year (Macy, 1995) and spawning occurs year-round (Brodziak and Macy, 1996; Macy and Brodziak, 2001). Spawning occurs inshore during late spring through fall where egg masses have been found at depths <50 m from the Gulf of Maine to Delaware Bay (Bigelow, 1924; Haefner, 1964; Summers, 1969). Although several offshore winter spawning areas have been suggested by fishermen (Hatfield and Cadrin, 2002), the location of the main winter spawning area remains unknown. The paralarval distribution of longfin squid cannot be used to determine whether spawning occurs south of Cape Hatteras because chromatophore patterns cannot be used to distinguish between *D. pealeii* and *D. plei* paralarvae (Vecchione, 1988). Egg masses of longfin squid are attached to the substrate, macroalgae, and fixed objects at temperatures ranging from 10 to 23°C, and salinities of 30–32 ppt (McMahon and Summers, 1971). The rate of embryonic development is temperature dependent, such that hatching occurs in 27 days at 12.0–18.0°C, in 19 days at 15.5–21.3°C, and in 11 days at 21.5–23.0°C (McMahon and Summers, 1971).

Individuals are 1.8 mm ML at hatching (McMahon and Summers, 1971). Paralarvae are planktonic and both paralarvae and individuals as large as 15 mm ML have been collected near the surface in coastal waters of the Mid-Atlantic Bight, but only between May and early November, at salinities ranging between 31.5 and 34.0 ppt and water temperatures of 10–25°C (Vecchione, 1981). Individuals as small as 10 mm ML are frequently caught at shallow depths during NEFSC fall bottom trawl surveys, and to a lesser extent during spring surveys, which suggests that the onset of diel vertical migration commences at a size less than 10 mm ML.

Longfin squid undergo an ontogenetic shift in depth distribution whereby large squid occupy deeper water than smaller squid during spring and fall bottom trawl surveys (Summers, 1969; Serchuk and Rathjen, 1974; Brodziak and Hendrickson, 1999). During NEFSC fall bottom trawl surveys, catches of squid larger than 80 mm ML were highest at depths of 111–185 m and bottom temperatures of 11–16°C while catches of smaller squid were highest at depths of 27–55 m and peaked where bottom temperatures were greater than 16°C (Brodziak and Hendrickson, 1999). During NEFSC spring surveys, a majority of the individuals larger than 80 mm ML were caught at depths of 101–160 m and bottom temperatures of 8–14°C while smaller squid exhibited a bimodal depth distribution (modes at 101–140 and 21–30 m) and most were caught at bottom temperatures of 7–13°C with the highest catches at 11–13°C (Jacobson, 2005).

Longfin squid rest on the seabed (Stevenson, 1934) and forage in demersal habitats during the daytime and disperse into the upper water column at night (Summers, 1969; Sissenwine and Bowman, 1978). Diel vertical migration is more pronounced in juveniles ($\leq$ 80 mm ML) than in adults (Brodziak, 1998; Brodziak and Hendrickson, 1999). Squid $\leq$ 80 mm ML dominated daytime survey catches, averaging 75% and 78%, respectively, of the NEFSC spring and fall survey abundance indices during 1976–2008 (NEFSC, 2011). Diel vertical migrations may be influenced by the seasonal stratification of the water column because diel effects on catch rates were more pronounced during the fall when the water column is thermally stratified, than during spring and winter when the water column is well mixed (Hatfield and Cadrin, 2002; NEFSC, 2011).

Water temperatures have a major influence on longfin squid growth rates and the effect of an increase in water temperature on growth rate is most pronounced during the first three months of life (Hatfield et al., 2001). Size compositions of longfin squid are highly heterogeneous due to year-round spawning and the presence of multiple cohorts growing at different rates (Macy and Brodziak, 2001). Squid comprising the summer cohort (squid hatched during May–October) have faster growth rates than squid from the winter cohort (hatched during November–April, Brodziak and Macy, 1996; Macy and Brodziak, 2001). Males grow faster and attain larger sizes than females (Brodziak and Macy, 1996). The maximum size recorded in the NEFSC fishery and survey databases is 510 mm ML, but most individuals were $<$300 mm ML.

4.2.4. *Recruitment*

Recruitment to the fishery occurs throughout the year with seasonal peaks in overlapping "microcohorts" that have rapid and variable growth rates (Brodziak and Macy, 1996; Macy and Brodziak, 2001). Squid hatched during November–April provide recruitment to the inshore fishery (May–October) and vice versa for recruitment to the winter offshore fishery (Macy and Brodziak, 2001). Recruitment is driven primarily by environmental factors (Dawe et al., 2007). During August–September of 2000, an unusually high abundance of longfin squid which occurred off southern Newfoundland was associated with both warm local water temperatures and an unusual eastward displacement of the atmospheric features associated with the North Atlantic Oscillation (NAO; Dawe et al., 2007). Recruitment may also be negatively affected by the impacts of increasing ocean acidification on the paralarval stage (Kaplan et al., 2013).

Figure 11. Fishermen harvesting *Doryteuthis pealeii* from a weir located in shallow water off the southern coast of Cape Cod, Massachusetts. Poles are driven into the seabed in a heart-shaped configuration to which small-mesh is attached. A mesh "leader" is installed perpendicular to the shoreline to direct squid and finfish into the "bowl" shown here. After hauling in the floor of the "bowl" to concentrate the catch in a small area, the catch is "brailed" from the "bowl" using a special dip net and loaded into the boat. Photograph credits: Lisa C. Hendrickson.

4.2.5. *Fisheries*

Fisheries for longfin squid have solely occurred in NAFO Subareas 5+6 (Figure 4). USA landings of squid (*I. illecebrosus* and *D. pealeii* combined) have been recorded since 1887, and during 1928–1963, averaged 1,232 t and 700 t for the New England (Maine through Connecticut) and Mid-Atlantic (New York through North Carolina) regions, respectively (Lange and Sissenwine, 1983). Squid were landed for bait from incidental catches in summer bottom trawl fisheries and catches in nearshore weirs/traps located off Massachusetts (Figure 11). During 1887–1963, squid landings from the Mid-Atlantic and New England regions were assumed to be primarily *D. pealeii* and *I. illecebrosus*, respectively (Lange and Sissenwine, 1983). Beginning in 1964, incidental catches of squid by Russian factory trawlers were reported, and shortly thereafter, landings increased rapidly as international fleets began targeting both squid species. Landings of longfin squid were mainly from the international offshore fishery during 1967–1984 and from the USA bottom trawl fishery thereafter (Figure 12). Landings from the traditional inshore weir/trap fishery reached a record low level in 2012 (47 t), a 97% decline from 1,656 t in 1988. Since 1989, most of the weir/trap landings have occurred in Massachusetts where the decline in landings was associated with a decline in fishing effort (Figure 13).

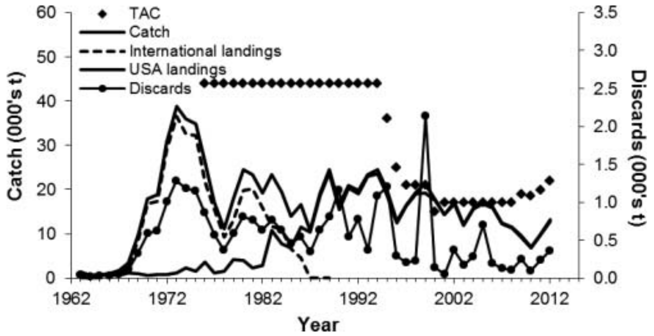

Figure 12. Landings, discards, and catches (000's t) of *Doryteuthis pealeii*, and TACs (000's t), in NAFO Subareas 5+6 during 1963–2012.

4.2.6. *Catches*

During 1964–2012, catches averaged 16,674 t with a peak of 38,892 t in 1973 when international fleets were fishing off the eastern US coast (Figure 12). During 1987–2012, catches were solely from a domestic fishery and averaged 16,327 t with a peak of 24,566 t in 1994. The discarded portion of the longfin squid catches is low, due to the species' high value, and primarily occurs in other small-mesh (<63 mm codend mesh size) bottom trawl fisheries (NEFSC, 2011).

4.2.7. *Landings*

During 1967–2012, trends in total landings of longfin squid consisted of four distinct periods. With the development of an international fishery for squid, total landings increased rapidly from 1677 t in 1967 to a time series peak of 37,613 t in 1973 and were predominately (>90% during 1969–1975) from the international fleets (Figure 14). Japan, Spain, Romania, and Bulgaria began reporting squid landings by species in 1973, which accounted for most of the total longfin squid landings (Lange and Sissenwine, 1980). After 1973, total landings declined rapidly to 10,831 t in 1978, concurrent with a decline in catch per day fished for the two major offshore fleets, Japan and Spain, during 1972–1976 (Lange and Sissenwine, 1980). In addition to Japan and Spain, Russian, and Italian trawler fleets also targeted longfin squid at various times during 1967–1986 (Figure 14). The Russian squid fishery occurred year-round beginning in 1974, but a ban on bottom trawl fishing off Virginia and country-specific quotas which began in 1976 led to gradual declines in fishing effort thereafter (Chuksin, 2006). During 1967–1978, total landings averaged 19,914 t. Prior to 1977, Japanese and Italian trawlers fished longfin squid along the edge of the continental shelf during October–March (Lange and Sissenwine, 1980). The Japanese fishery targeted Atlantic butterfish, *Peprilus triacanthus*, and longfin squid during the night and day, respectively (Lange and Waring, 1992). Spain's squid fishery resulted in substantial amounts of butterfish and Atlantic mackerel (*Scomber scombrus*) bycatch (up to 65% during March and April); most of which was discarded (Lange and Sissenwine, 1980).

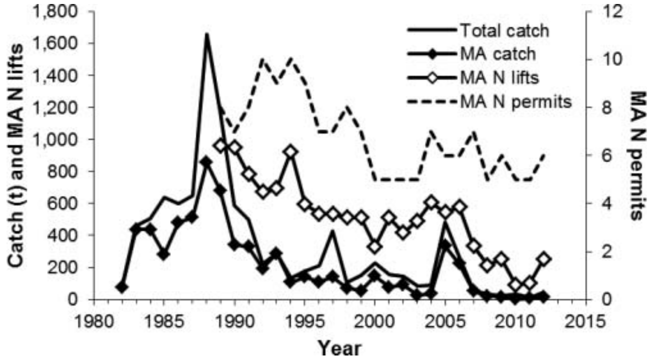

Figure 13. *Doryteuthis pealeii* catch (t) and fishing effort data (numbers of weir lifts and permits) for the coastal Massachusetts (MA) weir/trap fishery and total *D. pealeii* catches in weir/trap fisheries for all states during 1982–2012.

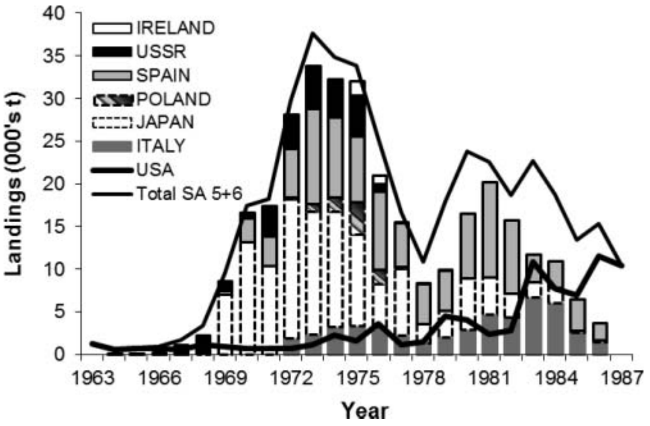

Figure 14. Landings (000's t) of *Doryteuthis pealeii* in NAFO Subareas 5+6, by country, during 1963–1987.

Beginning in 1977, when the USA began managing the squid fisheries within their 200-mile territorial waters, international fleets were subject to catch and bycatch allocations, gear limitations, and time-area restrictions. During 1977, the international squid fleets consisted of 95 factory vessels (jiggers, bottom trawlers, and off-bottom trawlers) that ranged in size from 34 to 87 m and from 298 to 3697 GRT (Kolator and Long, 1979). During 1978–1999, total landings exhibited two rise-and-fall periods. During the first period (1978–1986) landings during most years were from the international fleets, averaging 18,217 t, and during the second period (1987–1999) most of the landings were from the domestic fishery (Figure 12). Total landings averaged 18,217 t during 1978–1986, and after reaching a peak of 23,746 t in 1980, declined to 13,448 t in 1985 along with reductions in squid quota allocations for the international fleets. International allocations were reduced in order to develop a domestic offshore fishery which began during the early 1980s (Figure 12). During the fall of 1985, closure of a portion of the international longfin squid fishery also occurred when Spain exceeded its butterfish bycatch quota (Lange and Waring, 1992).

4.2.8. *USA Fisheries*

A small-vessel (<50 GRT), bottom trawl fishery for longfin squid initially developed inshore during 1973–1976; a period of time when catch-per-unit-effort increased from 1.3 to 5.9 t per day fished, respectively (Lange and Sissenwine, 1980). During 1970–1976, most of the USA landings occurred on the inshore spawning grounds where 58% and 25% of the landings were taken during May and June, respectively, with the remainder taken incidentally in other bottom trawl fisheries during the rest of the year. USA landings averaged 336 t during 1970–1976 and 4,043 t during 1977–1986. Since 1987, total landings have essentially been taken by the USA bottom trawl fishery. During 1987–1999, landings averaged 18,453 t and reached a peak of 23,738 t in 1989. Landings of longfin squid from joint-ventures between international "processor" vessels and USA "catcher" vessels occurred during 1981–1991.

The USA fishery occurs year-round primarily between sunrise and sunset. The modal tow duration is 3.0 hr (range = 1.0–5.2 hr) and the modal towing speed is 5.6 km/hr (Hendrickson, 2011). The depth range and duration of the fisheries reflect the species' annual migration patterns. An inshore fishery occurs on a portion of the spawning grounds, between western Long Island and the east coast of Cape Cod (NEFSC, 2011), at depths less than 50 m (mode = 20 m) during May–August (Figure 15). During September–November, the fishery follows the species' southward and offshore migration which results in a spatial overlap at depths of 140–220 m with the *I. illecebrosus* fishery (Figure 15). The offshore longfin squid fishery occurs near the shelf edge, primarily between Georges Bank and Maryland (41°–38°N), but some fishing also occurs as far south as 36°N (NEFSC, 2011) during November-April at depths of 110–200 m (mode = 150 m). During 2000–2012, in-season longfin squid quotas were attained at least once per year, with the exception of 2010, resulting in inshore and offshore fishery closures. Landings gradually declined between 2000 and 2010, from 17,540 t to 6,913 t, respectively (Figure 12). Landings during 2012 (13,236 t) were slightly above the 2000–2011 average of 13,206 t.

Since 2000, the distribution of monthly landings has been affected by in-season longfin squid quotas, and since 2011, by trimester-based butterfish catch quotas which, with the exception of 2010, have led to one or more directed fishery closures per year. Monthly landings were the least variable during 1987–1995, with no peak and a low of 6% during August, but reporting of landings was not mandatory until 1996. The 1996–1999 landings trend resembled the trend for 2001–2006 (the period of quarterly-based quotas) and generally declined from a peak in February through June then increased through October (Figure 16). During the current management regime of trimester-based squid quotas (2007–2012), the landings peak shifted to July and October, and landings totaled 36%, 37%, and 28% during Trimesters 1–3 (T1-T3), respectively (Figure 16). The 2007–2012 quota allocations for T1–T3 were

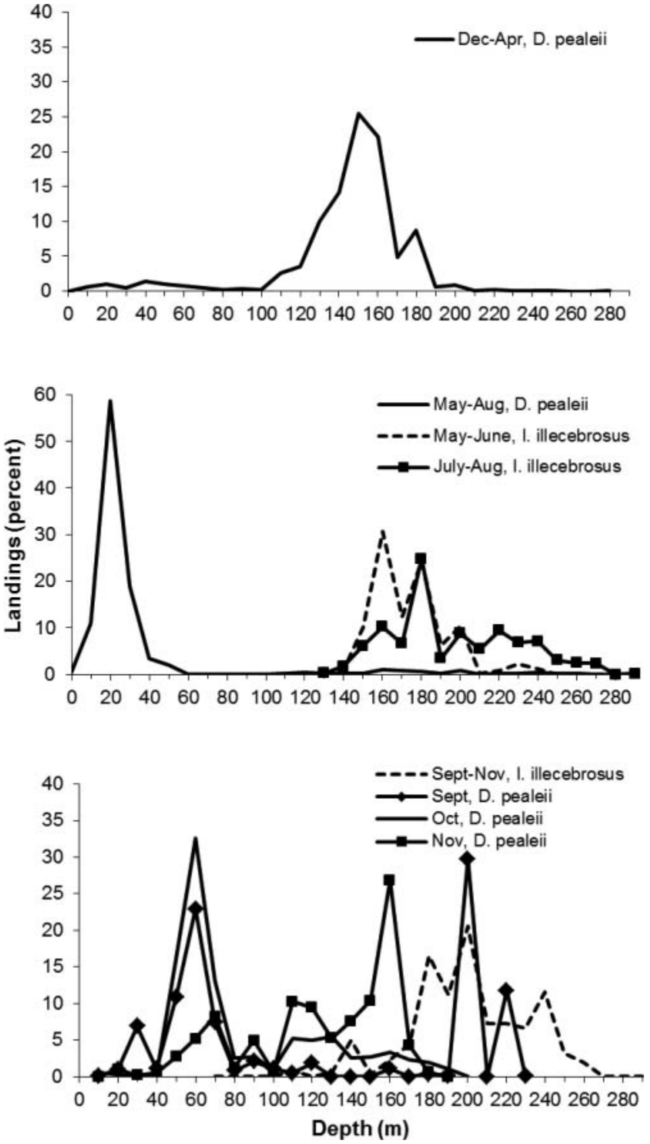

Figure 15. Landings (% by time period) of *Doryteuthis pealeii* (year-round fishery) and *Illex illecebrosus* (generally June–October fishery) in the directed fisheries (i.e., landings of *I. illecebrosus* and *D. pealeii* > 45,359 kg and 1134 kg per trip, respectively), by depth (m), during 1997–2004. The inshore regulatory depth limit of the *I. illecebrosus* fishery is 91 m.

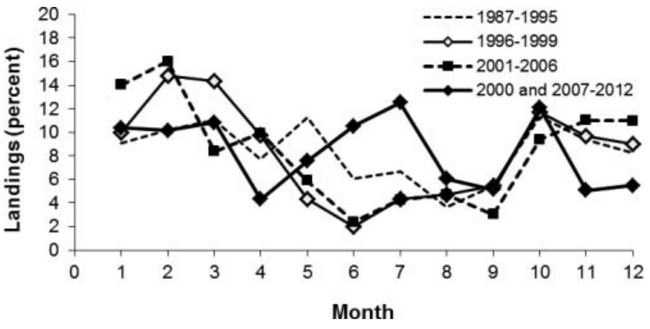

Figure 16. Landings (%) of *Doryteuthis pealeii* in the directed fishery, by month, during four fishery management periods: annual quotas without (1987–1995) and with (1996–1999) mandatory landings reporting; quarterly quotas (2001–2006); and trimester quotas (2000 and 2007–2012).

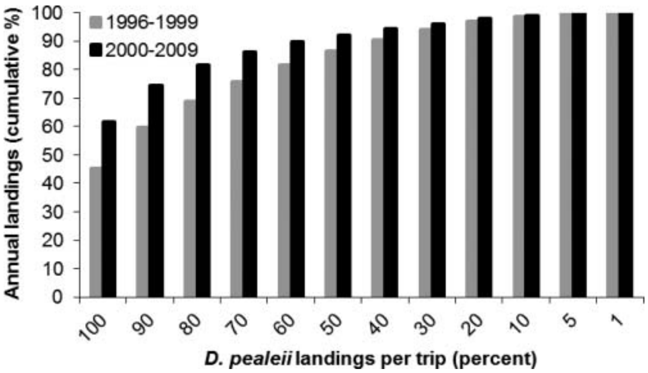

Figure 17. Landings (% by weight) per trip of *Doryteuthis pealeii* as a cumulative percentage of the annual landings during a period of annual quotas (1996–1999) versus a period of in-season quotas (2000–2009).

set at 43%, 17%, and 40%, respectively, but as of 2010, allowed for a T2 quota increase of up to 150% when a comparable underage of the T1 quota exists.

Since the implementation of in-season quotas, fishery directivity has also changed. In-season fishery closures, which trigger a trip possession limit of 1,134 kg (i.e., the regulatory definition of a directed trip), resulted in increased directivity (i.e., the percentage of the landed trip weight composed of longfin squid). Most (90%) of the longfin squid landings prior to the in-season quota period (1996–1999) were from trips where longfin squid comprised 31–40% of the total trip weight (Figure 17). However, most (90%) of the longfin squid landings during the in-season quota period (2000–2009) were from trips where longfin squid comprised 51–60% of the total trip weight.

Fishery selectivity of longfin squid likely varies by season due to differential growth rates (Hendrickson, 2011). Landings length compositions were similar (modal size = 120 mm ML) during periods of annual (1996–1999) and in-season (2000–2010) quotas when minimum mesh sizes of 48 mm (codend) and 114 mm (strengthener) were required. However, during 2011–2012 (when minimum mesh sizes of the codend and strengthener increased to 54 and 127 mm, respectively), an apparent modal size increase occured (to 130 mm ML), the proportion of squid larger than 160 mm ML doubled, and the proportion of squid smaller than 100 mm ML, most of which are discarded (Hendrickson, 2011), was reduced (Figure 18).

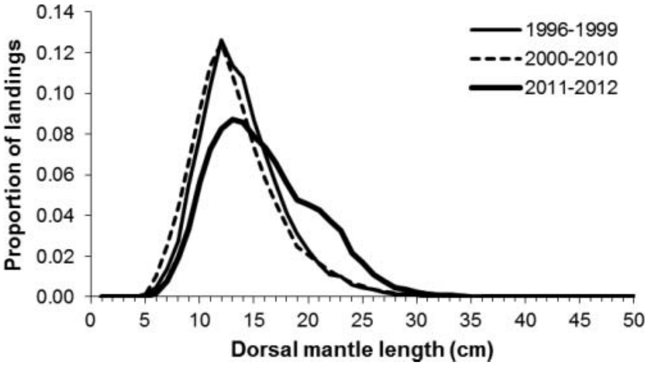

Figure 18. Length compositions of *Doryteuthis pealeii* landings in the directed bottom trawl fishery during three fishery management periods: 1996–1999 (annual quotas); 2000–2010 (in-season quotas; minimum mesh sizes of codend and strengthener = 48 and 114 mm, respectively, during both time periods); and 2011–2012 (minimum mesh sizes of codend and strengthener = 54 and 127 mm, respectively).

4.2.8.1. USA fishing fleets. The USA bottom trawl fleet consists of single- or multi-day trip vessels, onboard which squid are retained in refrigerated sea water or on ice, and larger, multi-day trip vessels onboard which squid catches are frozen (NEFSC, 2011). During 1997–2000, the numbers of vessels involved in the May–October inshore fishery (trips with longfin squid landings >1134 kg) were much higher (149–190 vessels) than during the 2001–2012 period of in-season quota management (72–120 vessels). Fleet size declined from a peak of 190 vessels in 2000 to 72 vessels in 2005 then increased again and ranged between 95 and 120 vessels during 2006–2012 (Figure 19A). Most of the inshore fleet consisted of vessels within the 51–104 GRT class, which declined in size during 1999–2005 then increased through 2012 (Figure 19B). During 1996–1999, the numbers of vessels involved in the November–April offshore fishery were also higher than during 2000–2012. The fleet size of the offshore fishery peaked at 197 vessels in 1998 then rapidly declined to 46 vessels in 2012 (Figure 19A) due to a rapid decline in the numbers of vessels within the three largest GRT classes (Figure 19C). During 1996–2007, landings were predominately from the offshore fishery (72%) then reached equal proportions during 2008, but were predominately from the inshore fishery (59%) during 2009–2012.

A small recreational jig fishery for longfin squid also occurs at night aboard party and charter boats, primarily during late April–June. Vessel logbooks indicated that the average numbers of trips and catches of longfin squid tripled between 1994–2003 and 2004–2012, from 15 trips and 2 t to 42 trips and 6 t, respectively. During 2012, the number of people jigging longfin squid from piers was unusually high in Massachusetts, but catches from shore are not recorded.

4.2.8.2. Economic importance. Fishing effort in the USA longfin squid fishery is affected by squid availability, abundance, and ex-vessel price. Most of the landings are sold domestically for food and the remainder is exported. Ex-vessel price is influenced by the global squid market (e.g., frozen *D. gahi* from the Falkland Islands and *D. opalescens* from the western USA coast), but to a lesser extent than *I. illecebrosus* prices, because a smaller percentage of longfin squid landings (averaging 6% and 17% during 1991–2005 and 2006–2012, respectively) are exported (NMFS, 2013). Foreign trade statistics for the New England and the Mid-Atlantic Customs Districts combined indicate that *D. pealeii* products were primarily exported to Italy (29%), China (19%), Spain (16%),

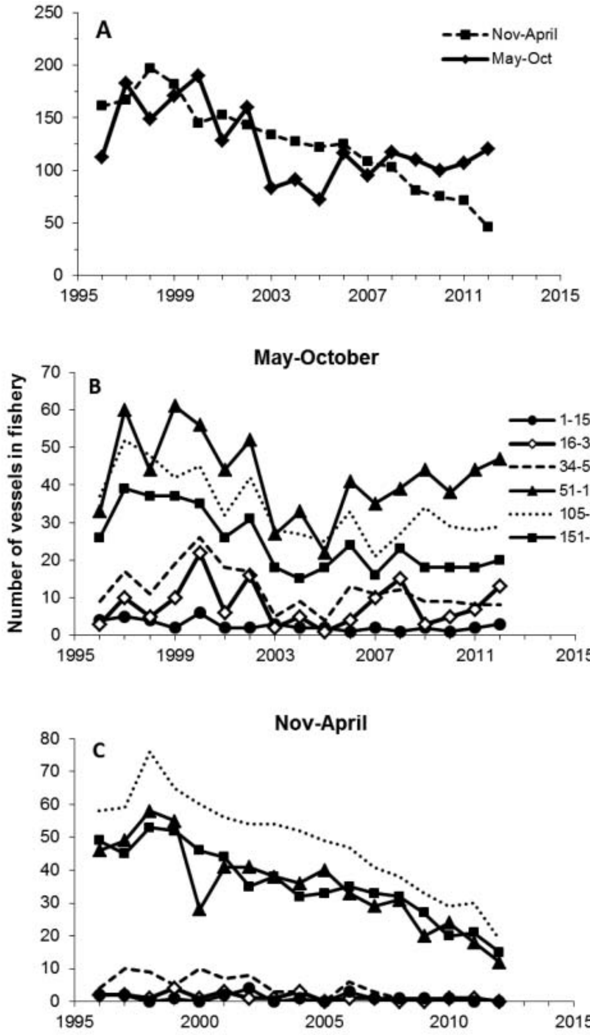

Figure 19. Numbers of vessels, by fishery (A) and by gross registered tonnage class during the May–October (B) and November–April (C) *Doryteuthis pealeii* fisheries (trips with longfin squid landings >1134 kg) during 1996–2012.

Greece (6%), and Japan (4%) during 1991–2012 (NMFS, 2013).

The average annual prices (in 2012 \$ per t) and gross revenues (in 2012 \$) for *D. pealeii* and *I. illecebrosus* were adjusted for inflation using the USA Producer Price Index. The average price of *D. pealeii* generally increased with the development of a domestic offshore fishery, from \$1,070/t in 1984 to a time series peak of \$2,769/t in 1998, but then declined by \$600/t between 1999 and 2000 (Figure 20). Despite a general decline in landings, the average price remained fairly stable, between \$2,147/t and \$2,422/t, during 2000–2009 and the mean of \$2,308/t was similar to the mean of \$2,235/t during 1990–1999 (Figure 20). The price stability from 2000 onward coincides with the management change from annual to in-season quotas but is not the only determinant of average price. During 1982–2012, trends in gross revenues were similar to the landings trends and ranged from \$3.7 million in 1982 to \$53.6 million in 1994 with an average of \$30.5 million.

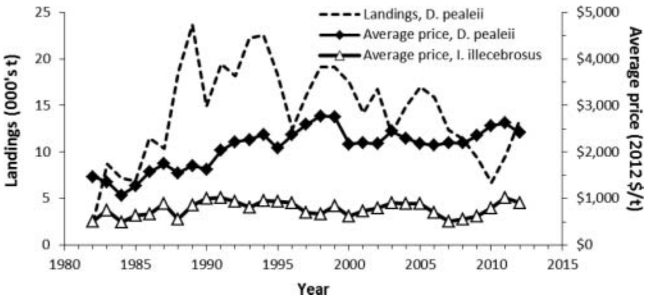

Figure 20. Landings (000's t) and average price (2,012 \$/t, adjusted for inflation using the USA Producer Price Index), of *Doryteuthis pealeii* in the USA directed fishery during 1982–2012. The average inflation-adjusted price of US landings of *Illex illecebrosus* is also shown for comparison.

4.2.9. Fishery Management and Stock Assessment

An initial TAC of 71,000 t (for *I. illecebrosus* and *D. pealeii* combined) was established for Subareas 5+6, by ICNAF during 1974–1975, as a preemptive measure to limit expansion of the international squid fisheries (Lange and Sissenwine, 1983). ICNAF established a separate TAC of 44,000 t for *D. pealeii* in 1976 which was then adopted by the USA as part of a preliminary Fishery Management Plan implemented in March of 1977. Since 1978, the stock has been managed by the Mid-Atlantic Fishery Management Council, in conjunction with the Fishery Management Plan for the Squid Fishery of the Northwest Atlantic Ocean, during 1978–1982, and the Atlantic Mackerel, Squid, and Butterfish Fishery Management Plan thereafter. The *D. pealeii* TAC was 44,000 t during 1976–1994, then was gradually reduced to 17,000 t during 2001–2008 and was about 19,000 t during 2009–2012 (Figure 12). The annual TAC was only exceeded during 2000.

Beginning in March of 1977, international bottom trawl fleets targeting either *I. illecebrosus* or *D. pealeii* were subject to the management requirements described above in the *I. illecebrosus* Section 4.1.7.2. As a result of the co-occurrence of longfin squid and butterfish, international squid fleets were also subject to butterfish bycatch allocations equivalent to 6% of their individual longfin squid quota allocations (Lange and Waring, 1992).

During 1996–2012, the primary management measures for the longfin squid resource included: TACs; mandatory reporting of landings purchased by federally permitted dealers; mandatory reporting of fishing effort, location, and estimated catch data by fishermen with federal longfin squid/butterfish permits; time-area closures; minimum codend and mesh sizes; and an incidental catch cap on a co-occurring finfish species. During 2000–2012, trimester-based quotas (2000 and 2007–2012) and quarterly quotas (2001–2006) were established to permit in-season adjustment of the harvest rate in order to maintain adequate levels of spawning stock biomass on a seasonal basis.

The longfin squid stock assessments are data-poor and are not conducted annually. A variety of assessment models have been used to compute stock biomass, fishing mortality rates, and MSY-based BRPs, or proxies thereof (e.g., F40%), as required by law and in accordance with a Fishery Management Plan. The stock was most recently assessed based on catchability-adjusted, swept-area biomass estimates for the fall and spring cohorts which were derived using daytime catches from NEFSC spring and fall bottom trawl surveys, respectively (NEFSC, 2011). Fishing mortality was evaluated using seasonal exploitation indices. Preliminary estimates of the minimum consumption of the two longfin squid cohorts were estimated as the longfin squid biomass consumed during each half-year period by the species' primary finfish predators based on food habits data from NEFSC spring and fall bottom trawl surveys. During most years (1987–2009), longfin squid consumption estimates were higher than the catches for the same half-year period (NEFSC, 2011).

5. CENTRAL-WEST ATLANTIC

At least seven species of the family Loliginidae are known to occur in neritic waters of the Central-West Atlantic from western Venezuela to Southern Brazil: *Lolliguncula brevis* (Blainville, 1823), *Sepioteuthis sepioidea* (Blainville, 1823), *Pickfordiateuthis pulchella* Voss, 1953, *D. pealeii* (Lesueur, 1821), *Doryteuthis surinamensis* (Voss, 1974), *Doryteuthis sanpaulensis* (Brakoniecki, 1984) and *Doryteuthis plei* (Blainville, 1823) (Haimovici and Perez, 1991a; Haimovici et al., 2009; Jereb and Roper, 2010). *L. brevis* and all *Doryteuthis* spp. have been commonly recorded in commercial catches throughout the area, but *D. plei* has been the only one regarded as economically important, sustaining local directed fisheries and comprising the bulk of regional squid landings in both Venezuela and Brazil (Juanicó, 1980; Arocha, 1989; Costa and Haimovici, 1990; Perez, 2002a). This review focuses on southeastern and southern Brazil, at the southern extreme of the species' latitudinal distribution range, where fishing for this coastal squid has become both socially and economically relevant, and where a significant amount of information on the species' life history, ecology, and fisheries has been produced in the last decade.

5.1. Doryteuthis plei (Slender Inshore Squid)

5.1.1. Stock Identification

No stocks have been formally identified in the main fishing areas of the Central-West Atlantic. Juanicó (1972), exploring data produced by trawl surveys covering a wide latitudinal range off Brazil (23°–30° S), showed that concentrations in the northern and southern extremes of this range differed in size-at-maturity patterns and could comprise different geographic populations. Later studies, mostly based on commercial catches of squid, found further seasonal and smaller spatial scale variations in size-at-maturity (Perez et al., 2001a; Rodrigues and Gasalla, 2008.). Such variation may simply indicate plasticity, with maturation patterns reflecting local conditions. The existence of genetically isolated stocks remains an open question yet to be addressed.

5.1.2. Distribution and Lifecycle

This is a Western Atlantic species that occurs on the continental shelf and upper slope from Cape Hatteras (36°N) to southern Brazil (34°S), occasionally being reported beyond these limits (New England and northern Argentina) (Jereb and Roper, 2010). It is a warm-water species also commonly found in the Gulf of Mexico and the Caribbean Sea. Off Venezuela, it is reported down to 185 m but most abundant on the inner continental shelf, between 20 and 55 m depths (Arocha, 1989; Arocha et al., 1991). In the Southeastern Brazil Bight (SBB, 22–28°S, *sensu* Matsuura, 1995), the species occurs over the continental shelf down to 250 m (Haimovici et al., 2009) but dense concentrations are common during the austral summer months on the inner shelf (10–40 m depths). These concentrations are often associated with the subsurface shoreward intrusion of oceanic South Atlantic Central Waters (SACW) that seasonally enhances productivity and therefore the availability of food to pelagic and benthopelagic populations (Costa and Fernandes, 1993; Rodrigues and Gasalla, 2008; Martins et al., 2004). South of 28°S, *D. plei* occurs offshore, during warm months, and under the influence of the Brazil Current that flows over the shelf break and slope (Haimovici and Perez, 1991a and b).

Jackson and Forsythe (2002), based on statolith ageing methods, estimated that *D. plei* may mature in the Gulf of Mexico after 100 days of life and live no longer than six months. Jackson (2004) included the species among "tropical loliginids with short lifespans (under 200 days)", rapid population turnover and year-round spawning. Off southern Brazil the species was found to live longer, reaching maturity after 200 days of life and probably living up to 300–350 days (Perez et al., 2006; Perez, unpublished data). It appears that the lifecycle may show considerable flexibility, for example, near the southern extreme of its distribution range the species approximates Jackson's (2004) "moderate" lifespan (200 days–1 year) group exhibited by temperate or cool-temperate species (Perez et al., 2006).

Squid caught by commercial fisheries in the SBB tend to show a pronounced size-dimorphism with both sexes concentrating around a modal size of 100–130 mm ML, but with variable proportions of large males reaching 250–350 mm ML (Perez et al., 2001a; Rodrigues and Gasalla, 2008). These large males, in general, exhibit a characteristic striped color pattern on the ventral mantle and are relatively more frequently caught during the summer and by inshore hand jigging and fish traps (Martins and Perez, 2007). Both females and males in advanced maturation stages are common in commercial catches all year round, suggesting that breeding and spawning occur throughout the year. However, a major reproductive event seems to take place during the summer months on the inner continental shelf (20–40 m depth) and in shallow waters around coastal islands (Perez et al., 2001a; Martins and Perez, 2007; Rodrigues and Gasalla, 2008). All evidence to date supports post-spawning mortality for the species.

Precise spawning grounds off Brazil are still unknown but egg capsules and newly hatched paralarvae have been recorded on 6- to 20-m-deep muddy bottoms around São Sebastião Island where there seems to be a large potential for paralarval retention during most of the year (Gasalla et al., 2011; Martins et al., 2014). Around Santa Catarina Island, newly hatched paralarvae were also recorded from plankton samples but their origin remains unclear (Martins and Perez, 2006). There is consistent evidence that young immature squid tend to concentrate offshore (100–200 m depths) all year round, and several hypotheses have been put forward regarding their connection with the coastal spawning concentrations (Haimovici and Perez, 1991b; Haimovici et al., 2008; Rodrigues and Gasalla, 2008). For example, (a) offshore juveniles may hatch in coastal areas and migrate throughout the year to the outer shelf where they remain until the onset of maturity and then return to near-shore spawning grounds, or (b) they may originate from spawning events that occur in winter and spring in deeper areas and remain offshore throughout their lifecycle. These animals would likely experience less favorable conditions and mature at smaller sizes than those recruited in shallower areas (Haimovici et al., 2008). The plasticity of life history patterns, the temporal and spatial variability of growth, and survival conditions on the SBB and the high mobility of the *D. plei* may contribute to the occurrence of a variety of possible lifecycles in the area, including: short versus long (6–10 months), migratory versus resident, spawning early in life at small sizes versus spawning late in life at large sizes. It is noticeable, however, that despite such variability, squid fishing has been mostly linked to those lifecycles that contribute to the formation of a large summer spawning event in the coastal areas of the SBB.

5.1.3. Fishing Grounds and Seasons

D. plei has been historically fished in inshore and offshore areas of the SBB. In inshore waters, fishing grounds comprise a series of discrete shallow bays (5–15 m deep) distributed along the coastline and around near shore islands, most noticeably, São Sebastião and Santa Catarina. Squid aggregate on these grounds during the summer months and become vulnerable to day and night hand jigging conducted by artisanal fisherman from coastal communities (Perez et al., 1999; Perez, 2002a; Martins et al., 2004; Gasalla, 2005; Postuma and Gasalla, 2010). *D. plei* is also a catch component of fish traps set during most of the year in the shallow sectors of these bays. Around Santa Catarina Island, trap catches were shown to "trigger" the onset of the hand jigging fishing season in different bays (Perez et al., 1999; Martins and Perez, 2008). Directed fisheries with dip nets and beach seines ("ganchos") also take place during summer in the northern coast of Rio de Janeiro state and in association with Cabo Frio SACW upwelling events (Costa and Haimovici, 1990).

Offshore *D. plei* is mostly caught by trawling operations that take place on the continental shelf from Espírito Santo (22°S) to southern Santa Catarina (29°S) (Perez et al., 2005). These operations have historically aimed at penaeid shrimps and sciaenid fish but, in the last few decades, a variety of valuable finfish and shellfish species has been both systematically retained or targeted in different areas and/or seasons (Perez and Pezzuto, 1998). At least since the early 1990's, trawlers have directed their effort during the summer months on a limited area in the center of the SBB (∼25–26°S), between the 14 and 45 m isobaths, to take advantage of profitable concentrations of mature/spawning *D. plei* (Perez, 2002a; Perez et al., 2005).

D. plei catches are highly seasonal. At the two main ports of the SBB, Itajaí and Santos, 87–92% of the biomass captured by trawlers between 1998 and 2012 was landed from early December and to late March. During the rest of the year catches are reduced, scattered and mixed with *D. sanpaulensis*, which tends to be more abundant at both extremes of the SBB (south of 29°S and north of 23°S) (Costa and Fernandes, 1993; Perez and Pezzuto, 1998). Squid fishing in inshore areas is also conducted during summer between December and March (Perez, 2002a; Postuma and Gasalla, 2010). Around Santa Catarina Island most hand jigging catches are taken in pulses of 2–3 weeks that tend to occur in different bays at different times (Perez et al., 1999). It is suggested that such spatial and temporal patterns of catches reflect the foraging displacement of schools of *D. plei* around the island's coastline and intermittent SACW upwelling events that concentrate small pelagic fish prey in different bays where these schools become available for local artisanal fishing (Martins et al., 2004).

5.1.4. Economic and Social Importance

Squid fishing by artisanal fishermen has been regarded as socially relevant, and one amongst several activities that sustain traditional fishing communities spread along Rio de Janeiro, São Paulo and Santa Catarina coastlines. These activities include a variety of near shore fishing practices, mussel culture and agriculture among others (Diegues, 1983; Medeiros et al., 1997). Fishing villages around Santa Catarina Island may rely on fish trap catches as their main source of income throughout the year (Medeiros, 2001); in the summer, cutlass fish (*Trichiurus lepturus*) and *D. plei* comprise over 80% of the traps catches (Martins and Perez, 2008). On the other hand, jigging may only take place during short periods within the season, when schools "invade" and stay in the shallow bays feeding on small clupeids (Perez et al., 1999; Martins et al., 2004). Because *D. plei* is valuable, income per squid fishing day (∼US$ 30.00) tends to be high in comparison with income from fishing other local resources. However the contribution of squid to each fisherman's overall income is usually low and sporadic (Medeiros, 2001). In some fishing villages in Santa Catarina fishermen conduct 1- to 3-day fishing trips following schools around the islands. Income estimates are not available but catch rates per day of these fishermen are significantly higher than those obtained by fishermen that only fish for squid when they approach the village's nearshore area (Perez et al., 1998).

Medeiros (2001), analyzing the fishing dynamics of "Pântano do Sul" bay, Santa Catarina Island, found that the *D. plei* hand jigging fishery is more socially than economically important. In fact, when it is established during the summer season, many people of the community are involved, even the ones who do not fish throughout the year. A similar situation was reported along the coast of São Paulo and southern Rio de Janeiro, where most of the families of fishermen, particularly women and children, are recruited during summer to hand jig for *D. plei*. An increase in the family income seems to occur during this season because catches can be sold directly, and at high prices, to summer tourists who concentrate in the coastal towns (Gasalla, 2005).

Offshore, *D. plei* has been by-caught by trawlers that operate in the SBB for nearly 60 years. Because traditional targets, such as the pink shrimp and sciaenid fish, have shown important biomass reductions at least since the 1980s (Haimovici et al., 2006), marketing of (previously) nontarget species has become increasingly valued by fishermen as a strategy to increase overall income (Perez et al., 2001b). That process involved the development of particular spatial and seasonal strategies that have diversified catches and taken advantage of valuable finfish and shellfish concentrations. The species taken included flatfishes (*Paralichthys* spp.), scallops (*Euvola ziczac*), octopus (*Octopus vulgaris*), scampi (*Metanephrops rubellus*), slipper lobster (*Scyllarides deceptor*), loliginid squids (mostly *D. plei*) and, more recently, the argentine shortfin squid (*I. argentinus*) (Perez and Pezzuto, 1998; Perez and Pezzuto, 2006). Because they are generally short-lived and semelparous, squids become abundantly available to bottom trawling in limited areas and seasons and therefore have stimulated seasonal directed fisheries both in the inner shelf (*D. plei*) and on the slope (*I. argentinus*) waters. Therefore, apart from contributing to the general income of trawlers operating in the SBB throughout the year, squid species can have a seasonally variable but critical importance.

Benincá (2013) measured the contribution of an array of catch components to the monthly landings and incomes of a large group of trawlers based in Santa Catarina during three consecutive years (2008–2010). Overall *D. plei* ranked 10th among catch components contributing to the total income of pink shrimp trawlers that stored their catch on crushed ice and 2nd of those that stored the catch in freezers. Squid prices varied between US$ 0.86 and 2.40/kg, less than 1/5 of prices attained by the pink shrimp. Despite this, for these trawlers *D. plei* were consistently the main target between December and March, a period when shrimp catch rates tend to be low. During this season, the relative contributions of squid to the landed biomass and the total income increased by 2–4 times and 2–6 times, respectively, varying widely between years (Figure 21). In 2010, when a catch peak was reported (following a trough in 2008, Figure 22), squid attained a maximum of 44.2% and 50.3% of the biomass landed and the income, respectively, for the "freezer" fleet (Figure 21).

5.1.5. *Fishing Fleet*

Hand jigging in near shore waters often takes place from canoes or from small motor boats (8–11 m long, 16–30 HP) generally used for sea-bob shrimp (*Xiphopenaeus kroyeri*) trawling. Fishing is conducted both during the day and at night, when a light source is used for attraction (Perez et al., 1999; Gasalla, 2005). Quantitative data describing this activity in the region are fragmented. In fishing communities along the São Paulo State coastline, where there has been consistent monitoring since 2009, 11–156 boats have been recorded

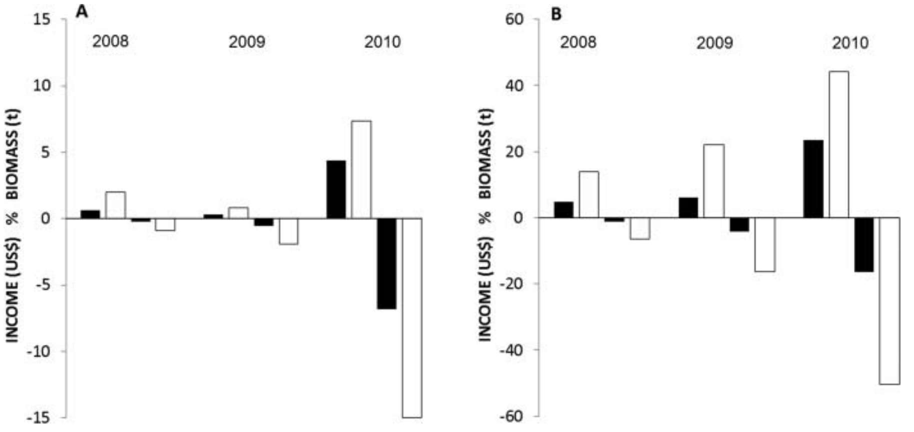

Figure 21. Relative contribution (%) of squid in the landed biomass (positive values) and income (negative values) of double-rig trawlers that store catches in ice (A) and freezers (B) in 2008, 2009, and 2010. Total annual values (dark bars) are contrasted with values calculated only for the summer squid fishing seasons (December–March) (empty bars).

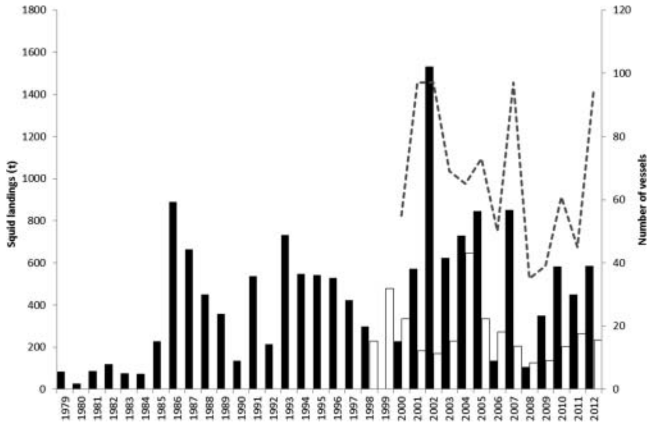

Figure 22. Squid catches landed in the fishing ports of Santa Catarina (dark bars) and São Paulo (empty bars) states. The latter are only available from 2000 onward. The number of double-rig trawlers reporting squid catches during the summer months in Santa Catarina are shown (dashed line) as a measure of effort. Sources: "Instituto de Pesca/ APTA/ SAA/ SP" (www.pesca.sp.gov.br) and "Grupo de Estudos Pesqueiros/ Universidade do Vale do Itajaí" (www.univali.br/gep).

fishing for squid each month of the squid season (Instituto de Pesca, 2013). Their squid catches have been significant in the state, reaching 10–40% of the biomass reported by trawlers in the port of Santos. Similar data obtained in Santa Catarina between 1991 and 1995, recorded 41–96 boats from 5 to 8 villages reporting squid jigging catches each season (Table 3) (IBAMA, unpublished data). In the same period squid landings were also recorded from 9 to 21 fish traps from different fishing villages along the coastline (Table 3). Hand-jigging and fish traps were jointly responsible for the bulk of artisanal *D. plei* catches every summer, reaching from 7% to 15% of total squid catches reported by trawlers in the ports of Santa Catarina.

D. plei is caught in the continental shelf area of the SBB mostly by double rig, stern, and pair trawlers. These are approximately 10- to 25-m-long vessels made of wood or steel and powered by 100–500 HP engines (Perez et al., 2007; Tomás et al., 2007; Castro et al., 2007). Squid landings are concentrated in the harbor towns of Itajai (Santa Catarina State) and Santos (São Paulo State), where the relative contribution of different types of trawlers to total squid catches has changed over the years. In São Paulo state, reports of squid in the bycatch of shrimp and fish trawlers date back to 1959 (Gasalla et al., 2005a). Throughout the 1990s, and until now, over 80% of summer squid landings have been produced by double-rig shrimp trawlers (Tomás et al., 2007; Instituto de Pesca, 2013). In Santa Catarina, between 30 and 60 trawlers operated during the squid fishing seasons in the 1990s, most of them geared with double rigs and originally built to fish for shrimps. Pair trawlers were also common in that period, producing a large proportion of the total squid catches each season (Perez, 2002a). In the 2000s, the pair trawler fleet was greatly reduced, whereas the number of double-rig trawlers targeting squid during the summer seasons nearly doubled (Table 3) and produced 50% to 90% of the landed biomass.

5.1.6. *Catch and Effort Data*

Catch statistics in southeastern and southern Brazil do not discriminate *D. plei* from *D. sanpaulensis*. However, because nearly 90% of the squid landings occur in the summer season when *D. plei* is highly dominant (approximately 90% of the landed biomass), total numbers tend to be little affected by *D. sanpaulensis* catches (Gasalla et al., 2005b). Such an assumption is probably not valid for landings in Rio Grande do Sul and Rio de Janeiro states, where the latter species predominates (Juanicó, 1981; Costa and Fernandes, 1993). Inshore and offshore catches reported in São Paulo and Santa Catarina states between 1979 and 1998 fluctuated between 100 and 1200 t annually (Perez et al., 2005). In general, catches increased after 1986, remaining mostly above 600 t per year. However, records of total annual squid catches after that period are underestimates, because artisanal landings in Santa Catarina state have not been monitored since 2000 (Figure 22). Between 2000 and 2012, these estimates varied from 230 t in 2008 to a peak of 1702 t in 2002 (Figure 22).

The evolution of fishing effort directed at *D. plei* was investigated between 1990 and 1997, considering only the trawl fleets that operated during the summer months from the ports of Santa Catarina (Perez, 2002a and b). It was shown that

Table 3. Summary of *Doryteuthis* spp. fishing activity in the South Brazil Bight (SBB). Data presented were recorded in Santa Catarina State, southern Brazil, in two periods, 1990–1997 and 2000–1912. They correspond to mean, maximum and minimum number of boats, number of landings, and landed biomass reported by different gears per month during the summer fishing season (December–March). Although catch statistics do not discriminate species, more than 90% of catches during this season refer to *D. plei* (see text).

	Double-rig trawl	Stern trawl	Pair trawl	Hand jigging	Fish trap
1990–1997					
Number of boats	32 (15–46)	0	16 (5–32)	79 (42–96)	18 (9–21)
Number of landings	48 (18–90)	0	49 (7–108)	377 (150–559)	126 (66–183)
Landed biomass (t)	131.8 (54.7–278.6)	0	244.0 (28.8–512.0)	22.8 (7.9–37.9)	25.0 (11.6–38.5)
2000–2012					
Number of boats	65 (35–97)	6 (4–19)	9 (2–15)	–	–
Number of landings	110 (48–197)	15 (3–28)	12 (6–31)	–	–
Landed biomass (t)	405.2 (95.0–833.2)	110.4 (0–613.4)	57.1 (6.5–205.7)	–	–

standardized fishing effort (measured as "fishing trips") increased until 1995 and decreased in the two following years when (less numerous) pair trawlers prevailed (Table 3). Landings were highest in 1993, reaching 718 t and decreased to 453 t in 1993 (Perez, 2002b). Between 1998 and 2000, catches reached very low levels, increasing again in the following years as double rig trawler effort increased in the summer fishing grounds and the pair trawl fleet shrunk (Table 3). Catches produced by trawlers operating from Santa Catarina after 2000 fluctuated according to the number of double rig trawlers and their landings during the fishing seasons (Figure 22). These findings suggest that the summer *D. plei* fishing in the SBB is opportunistic and related to the relative success of fishermen operating double rig trawlers in profiting with other valuable targets (Perez and Pezzuto, 1998).

Assessments of effort in the inshore fisheries are unavailable in the region. However Postuma and Gasalla (2010) described an increase in numbers of boats and of days dedicated to hand jig fisheries around São Sebastião Island between 2005 and 2009, in association with a sharp decrease in catches (21 to 9 t per season).

5.1.7. *Stock Assessment and Management*

Biomass assessments have been attempted on a nonregular basis by both fishery-dependent and independent methods and in different areas. Perez (2002a) analyzed standardized trawl catch per unit effort (CPUE) and showed that the summer fishing season is generally enclosed within a 17-week period during which squid biomass builds up gradually, peaking between the 6th and 14th week, and decreases sharply thereafter due to postspawning mortality. Using an extended Leslie depletion model, Perez (2002a) estimated the *D. plei* biomass available at the week of biomass peak during five fishing seasons, which varied between 210.5 and 1583.3 t, and the escapement rate, which varied between 20% and 69% of the biomass depending on the amount of effort directed by different trawlers each season.

Interseasonal abundance variation in the SBB was studied using Generalized Linear Model applied to a trawl CPUE series available in Santa Catarina from 1990 to 1997 (Perez, 2002b). Biomass was shown to oscillate apparently on 4-year cycles. Biomass peaks revealed by the model were poorly correlated to the catch peaks previously described, which suggested that the trawl fleet may not necessarily identify seasons with particularly favorable concentrations of squid (Perez et al., 2005). A similar analysis was carried out for the hand jigging fishery off São Paulo by Postuma and Gasalla (2010), who showed that abundance index (CPUE) correlated positively with surface temperatures and chlorophyll-a.

Haimovici et al. (2008), estimated a total biomass of 1,442 t (±49%) and 9,474 t (±66%), respectively during two trawl surveys covering outer shelf and upper slope areas off southeastern and southern Brazil in winter-spring 2001 and summer-autumn 2002. *D. plei* was caught in an area of approximately 108,000 km^2, along the entire latitudinal range surveyed (34°40′S–23°S) between 100 and 200 m. Because the species concentrates along the inner shelf during the summer months, these values are probably underestimates of actual biomass. However it is important to note that nearly 53% of estimated biomass concentrated between latitudes 28° and 24°S where most summer squid fishing takes place.

There are three types of trawl fishing permits available in Brazil, as defined by their main fishing targets: the pink shrimp (*Farfantepenaeus* spp.), the sea-bob shrimp (*Xiphopenaeus kroyeri*) and "demersal fish" (*M. furnieri*, *Umbrina canosai*, *C. guatucupa*, *M. atricauda*, *Paralichthys* spp., *Urophycis* spp., and *Prionotus* spp.). These permits also define an array of species that can be captured and landed as "predictable bycatch," although with no quotas or maximum proportions of the total catch formally determined. In practice, because loliginid squids are included in this predictable bycatch list, a large trawl fleet (over 300 units) is authorized to catch *D. plei* with no specific controls, and with only a few, mostly shrimp-oriented, management measures in place (e.g., annual fishing closure between April and June, valid for pink and sea-bob shrimps permits only). Along the coast of São Paulo and Santa Catarina, MPAs have been established (e.g., Arvoredo Biological Reserve, "Litoral Norte" Environmental Protection Area) which tend to limit fishing and other human activities in the coastal spawning grounds of *D. plei*.

5.1.8. *Conservation Measures, Biological Reference Points*

The current demersal fishing management model in Brazil fails to recognize the importance or protect a variety of target species that were gradually incorporated into the former shrimp and sciaenid fish trawl fisheries. These have been shown to represent a significant part of the total income of most trawlers' owners (Benincá, 2013) but are still regarded as bycatch and therefore remain without any specifically oriented conservation measures. *D. plei* is one of these components whose importance seems critical in an eventual reform of the current management model (Perez et al., 2001b), not only because it sustains dedicated and uncontrolled effort in a relatively limited area during the summer, but also because it is an important component of the neritic food webs in the SBB, upon which several economically important predator fishes seem to rely (Gasalla et al., 2010).

To date, no specific conservation measures or reference points have been established for *D. plei* off Brazil. Nevertheless, most of the above-mentioned studies proposed management recommendations whose fundamental concepts can be summarized as follows.

D. plei currently constitutes both a bycatch component and a major target in the SBB. In that sense the species should be subject to both (a) more stringent multi-species management strategies (Rodrigues and Gasalla, 2008) and (b) a single target-species management regime applied to trawlers that operate specifically during the summer fishing grounds (Perez, 2002a).

Fishing mortality exerted on *D. plei* off Brazil is largely concentrated in population groups that spawn along the inner shelf of the SBB between December and March. Because the species is semelparous, defining escapement thresholds during this season should be of major value in the process of building reference points for the species (Perez et al., 2005). In shallow coastal areas, "MPAs" can be critical for protection of localized spawning grounds.

Abundance tends to vary widely from season to season, partly associated with oceanographic fluctuations. Sustainable catch limits are therefore uncertain and recruitment-dependent. Any management action aiming at squid should prioritize conservation during low productivity years (Perez et al., 2005; Postuma and Gasalla, 2010).

D. plei has been characterized as a keystone species in the food webs of the SBB ecosystem, and therefore should figure prominently in any ecosystem-based management (EBM) actions in the area (Gasalla et al., 2010).

6. SOUTHWEST ATLANTIC

In their comparison of the relative importance of cephalopods in fisheries of large marine ecosystems around the world during 1990–2004, Hunsicker et al. (2010) noted that the relative (direct) contribution of cephalopods to landings varied widely between areas, being highest on the Patagonian shelf (around 40% of landings).

In 1999, according to FAO figures (FAO, 2011), cephalopod landings from the Southwest Atlantic reached 1.2 million t, a figure only ever exceeded in the Northwest Pacific. However, it was only at the end of the 1970s, when landings of *I. argentinus* first exceeded 10,000 t, that squid fisheries assumed major importance in this area and annual landings then steadily increased until their 1999 peak. Argentina is the most important fishing nation in the region (taking almost 25% of cephalopod landings between 1950 and 2010). Other important fishing nations include Taiwan, Korea, Japan, China, Poland, Spain, and (since the establishment of conservation zones around the islands in the mid-1980s) the Falkland Islands (Malvinas). Squid catches in the region are dominated by the Argentine shortfin squid *I. argentinus* (84.5% of cephalopod landings from the region between 1950 and 2010), although landings fell by almost an order of magnitude between 1999 and 2004. The fishery has experienced a further boom and bust cycle since then, with overfishing almost certainly to blame, reflecting a lack of international collaboration in the region (Pierce and Portela, 2014). The only other significant catch identified to species level in the FAO data is that of the Patagonian squid *Doryteuthis* (formerly *Loligo*) *gahi* (8.9%) Two additional squid species are identified in catches, albeit in small amounts: the sevenstar flying squid (*Martialia hyadesi*) (0.34%) and greater clubhook squid (*Onykia ingens*) (0.002%). These, and squid landings not identified to species, make up 99.75% of cephalopod landings from the area, the remainder being octopuses. Other squid species of potential commercial value occurring in the region include *O. bartramii*, for which exploratory surveys have been performed (Brunetti and Ivanovic, 2004).

The high squid biomass in the region is reflected in the high importance of these species in energy and nutrient transfer. As such, overfishing could have catastrophic effects. As noted by Arkhipkin (2013), the variable nature of squid populations increases their vulnerability to overfishing and environmental change. Failure of these critical biological pathways, for whatever reason, could result in irreversible long-term consequences for biodiversity and resource abundance.

6.1. *Illex argentinus (Argentine Shortfin Squid)*

6.1.1. *Distribution*

The Argentine short-finned squid, *I. argentinus* is the most abundant commercial species of squid in the Southwest Atlantic. This squid is a widespread neritic species occurring in waters off Brazil, Uruguay, Argentina, and the Falkland Islands (Nesis, 1987). It is associated mainly with temperate waters of the Patagonian Shelf. Its distribution extends over the shelf and individuals have also been caught in the open ocean as far east as the Antarctic Polar Front (Anderson and Rodhouse, 2001; Rodhouse, 1991). The highest concentrations of this squid are observed on the shelf to the north-west of the Falkland Islands and on the shelf and shelf edge at 45–47°S (Haimovici et al., 1998).

6.1.2. *Population Structure and Life History*

It has been assumed that the species consist of two populations with different spawning seasons and sites: an abundant winter spawning population (more than 95% of the total stock) and a small summer spawning population (Hatanaka, 1988). Brunetti (1988) subdivided the winter spawning squid into two stocks (groups), the Bonaerensis North Patagonian stock and the more abundant South Patagonian Stock, distinguished by their feeding grounds (north and south of 46°S, respectively) and size of adults (medium and large, respectively). The taxonomic status of these groups remains unclear. Analyses of length frequency compositions showed that the lifecycle of all *I. argentinus* populations was approximately 1 year (Hatanaka, 1986). This was later confirmed by statolith ageing studies (Arkhipkin, 1990; Rodhouse and Hatfield, 1990).

The winter-spawned South Patagonian stock has the longest ontogenetic migrations. The postlarval period takes place in the open ocean and above the continental slope of Brazil and Uruguay in August and September (Leta, 1987; Santos and Haimovici, 1997). Then, juveniles migrate to the shelf off Uruguay and Argentina in September–December (Brunetti, 1988; Parfeniuk et al., 1992), and continue their feeding migrations on the Patagonian Shelf in January–April (Brunetti, 1988; Hatanaka, 1988). During the feeding period, the stock structure is quite stable. During each 10 day period, four to five monthly age classes (microcohorts) are usually observed (Uozumi and Shiba, 1993). The relative importance of different monthly age classes changes gradually, from mainly June-hatched squid in February to mainly July-hatched squid in March–April. After their maturation in April-May, prespawning schools of squid descend to deep water (600–800 m) over the continental slope to the north of the Falkland Islands and migrate along the slope off Argentina and Uruguay in May–July (Arkhipkin, 1993; Hatanaka, 1986, 1988). Spawning takes place on the shelf and slope off northern Argentina, Uruguay and Brazil in July–August (Brunetti, 1988; Santos and Haimovici, 1997).

The South Patagonian Stock has been further subdivided into two groups, the "matured at medium sizes shelf group" and the "matured at large sizes slope group" (Arkhipkin, 1993). The shelf group of *I. argentinus* has a neritic type of lifecycle, characterized by spawning in warm shelf waters of the northern part of the species range (27–36°S), southward feeding migrations of juveniles <100–150 mm ML over the Patagonian shelf, medium maximum sizes of mature squid (males of 180–260 mm ML, females of 220–320 mm ML) and northward pre-spawning migrations along the shelf. The slope group of *I. argentinus* has an oceanic slope type of lifecycle characterized by spawning on the slope in the northern part of the species range (27°–36°S), southward feeding migrations of juveniles <100–150 mm ML in the open part of the Argentine Basin, large maximum sizes of mature squid (240–340 mm ML, females up to 280–400 mm ML) and northward pre spawning migrations along the slope.

6.1.3. *Fishing Fleets, Seasons, and Catches*

Argentinean trawlers regularly had "calamar" as a bycatch in hake fishery since the 1930s. After the description of the species by Castellanos (1960), *I. argentinus* appeared separately in FAO catch statistics. The first large annual catch of this squid was taken by the Soviet trawl fleet that worked in the then just-established Argentine EEZ in 1967 (12,000–15,000 t; Prosvirov and Vasiliev, 1969; Vovk and Nigmatullin, 1972). After 1967, the Soviet fleet did not take any more licenses to fish within EEZ, and *I. argentinus* were mainly taken as minor bycatch by Argentinean and Uruguayan hake trawlers in the northern part of the Patagonian Shelf (1,000–8,000 t per annum) (Brunetti, 1990). At the end of 1970s, several fishing companies started to target aggregations of *I. argentinus* on the Argentinean and Patagonian Shelves, achieving annual catches of 73,000 t in 1978 and 122,000 t in 1979 (Csirke, 1987). In 1979, a Japanese research vessel, "Shinkai Maru," carried out a major trawl survey of the Patagonian Shelf and estimated a minimum standing biomass of 0.9 million t of the winter-spawning (South Patagonian) stock of *I. argentinus* prior to their pre-spawning northward migrations to the continental slope (Sato and Hatanaka, 1983).

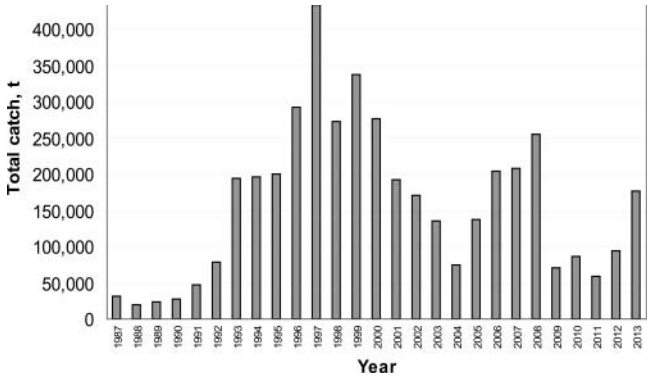

Figure 23. Total annual catches of *Illex argentinus* by trawlers and jiggers combined in the Argentinean EEZ (SagPaya, 2013).

The development of the macroscale international fishery for *I. argentinus* took place between 1980 and 1986, especially in so-called "high seas areas" outside the Argentinean EEZ (between 41° and 47°S and further south around the Falkland Islands) at depths ranging from 105 m to 850 m. In total, from 40 to 90 large factory trawlers and 50–120 jigging vessels, belonging to 10–14 countries, operated annually in these areas (Sato and Hatanaka, 1983; Csirke, 1987). Japanese catches gradually increased from 6,900 t in 1978 to 73,700 t in 1986 (Sato and Hatanaka, 1983; Brunetti, 1990). Catches by the Polish fleet (trawlers and combi-vessels) rapidly increased from 4,300 t in 1978 to 113,400 t in 1984, but then decreased to 28,300 t in 1986. One of the important innovations of Polish fishermen was to equip the trawlers with jigging machines that enabled them to fish effectively throughout the day, trawling during daylight hours and jigging at night (Karnicki et al., 1989). Large Soviet factory trawlers (2,000–4,000 GRT) took from 17,000 t in 1982 to 73,700 t in 1984 (Nigmatullin et al., 1995). The fleets followed the ontogenetic migrations of squid on the Patagonian shelf. In January to early March, feeding aggregations were targeted on the shelf at 130–160 m depth, mainly during daytime when squid schools were near the bottom. In April–June, prespawning aggregations were fished at 600–650 m over the continental slope, initially at 47°–48°S, then at 45°–47°S, and then further north at 42°S at depths 700–750 m. As squid concentrations were well above the bottom, trawlers fished with large pelagic trawls with the ground gear almost touching the bottom and with a vertical opening of 40–50 m. Inside the Argentinean EEZ, *I. argentinus* was fished as bycatch during the hake fishery and also in February–July by a specialized fishery with total annual catches up to 300,000 t (Brunetti, 1990; Figure 23).

A substantial change in the *I. argentinus* fishery occurred in 1986, when the Falkland Islands Interim Fishery Conservation and Management Zone (FICZ) was established, extending to 150 nm around the Falkland Islands. Before that, Polish, Japanese, and Soviet trawlers fished for the squid close to the islands without any restrictions. The establishment of a

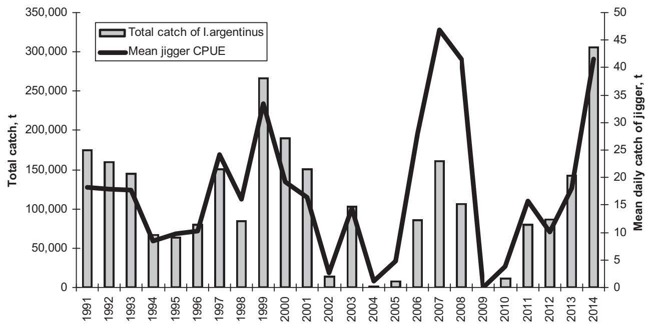

Figure 24. Total annual catch (t) and mean daily CPUE (t per night) in *Illex argentinus* jigging fishery within Falkland Conservation Zones.

regulated fishery in the FICZ has drastically changed the participants in the fishery. Licenses were taken mainly by Asian jigging fleets (up to 170 per year) with 100–120 jigging vessels fishing for squid between February and June. The total annual catch of *I. argentinus* in the FICZ fluctuated between 102,000 t and 224,000 t between 1987 and 1992 (Falkland Islands Government, 2012; Figure 24). The collapse of the Soviet Union and Eastern socialist block heavily impacted on far seas squid fisheries, ultimately reducing the trawler fleet in the Southwest Atlantic to a few dozen vessels by 2000. Since then, mainly Spanish and Korean trawlers have caught *I. argentinus* in shallow waters (130–160 m) as an important bycatch of the hake fishery. The trawl fishery in deep water no longer exists.

In 1993, the Argentinean Government facilitated access for foreign vessels to fish in the Argentinean EEZ together with establishment of the domestic jigging fleet. From 1993 to 2000, this fleet increased from 40 to 90 vessels. In 1993, a fishing ban was introduced to prevent fishing on squid to the north of 44°S between 1 February and 30 April, and to the south of 44°S from 1 July to 31 January. These regulatory measures enabled an increase in the Argentinean catch of squid to 203,200 t in 1993 and 432,000 t in 1999 (Brunetti et al., 2000). Since then, catches have ranged from 73,400 t to 270,000 t (Secretaria de Pesca, 1993–2013).

In 1998–2013, catches of squid around the Falkland Islands varied widely from a mere 44 t in 2009 to 161,000 t in 2007. Each year, licenses were issued to 43–125 vessels (mean 80 vessels). Jigging vessels belonging to 15–20 countries fished for squid, mainly from Taiwan and South Korea, but also Japan (until 2004) and China (until 2007) (FIFD, 2012; Figure 24). On the high seas (41°–47°S), a large international fleet of about 30–40 trawlers (mainly from Spain and Korea) and 120–150 jigging vessels (mainly from Taiwan, South Korea and China) worked for the whole period from January to June, taking at least 200,000 t of squid per annum (Nigmatullin, 2007). Uruguayan fishermen also took from 1600 t to 20,800 t of squid from their waters (FAO, 2010). A local fishery for *I. argentinus* (several thousand t per annum) is also being developed in the southern parts of Brazil (Perez and Pezzuto, 2006; Perez et al., 2009).

The Japanese fishery for *I. argentinus* began as a trawl fishery in the late 1970s. In the 1980s, the trawlers operated extensively in the High Seas area, and the catches increased. Squid jigging began in 1985 and expanded in 1987 and 1988, when the annual catches reached nearly 200,000 t (Figure 25). Around that time, Japanese fishers were prohibited from entering Argentine Exclusive Economic Zone (EEZ). The main fishing grounds were between 43° and 47°S on the continental shelf and offshore, and near the Falkland Islands. In 1993, fishers were allowed access to the Argentinean EEZ through "a formal charter system," and the main fishing grounds moved into the EEZ (Japan Large Squid Jigging Boats Association, 2008). In 2002, a bareboat charter contract system, which imposed strict restrictions on foreign squid jigging vessels in the EEZ, was initiated. During 1985–2006, maximum of 117 Japanese vessels were fished in 1987. Then, jigging fleet remained stable (around 50 vessels) in 1990s but further decreased from 2002 onward. In 2006, only 4 vessels worked in the region, which was the final year of the Japanese jigging fishery for *I. argentinus* (Figure 26). After 2007, the Japanese jigging fleet witrhdrew completely from the Argentine waters due to the Argentine policy of the development of their own jigging fishery (Japan Large Squid Jigging Boats Association, 2008). The mean CPUE of the Japanese squid jigging vessels was around 10–15 t per day with some annual variations (Figure 27). In 2000, mean CPUE was 26.8 t per day, the highest in history, but then dropped steeply to 5.9 t per day in 2004, the lowest since 1985. In 2005 and 2006, CPUE increased, and it was considered that the resource had recovered.

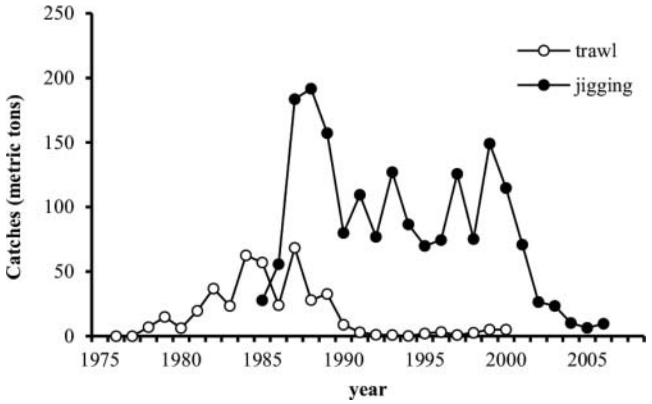

Figure 25. Catches of *Illex argentinus* by the Japanese trawl and jigging fisheries (based on Sakai, 2002).

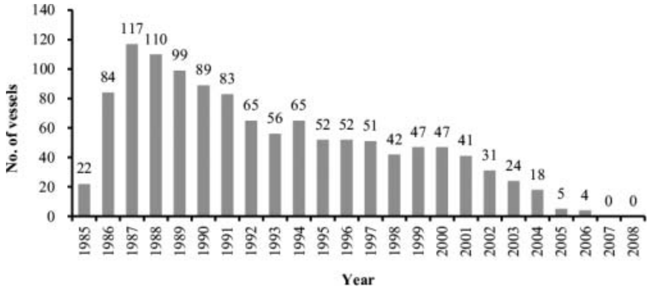

Figure 26. Number of Japanese squid jigging vessels in the *Illex argentinus* fishery in the Southwest Atlantic (based on Sakai and Wakabayashi, 2010).

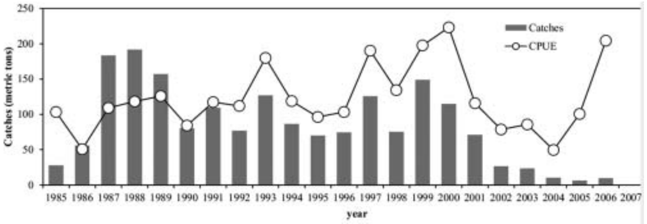

Figure 27. Catches and the mean daily CPUE for the year of *Illex argentinus* by Japanese squid jigging vessels during 1985–2006 (adapted from Sakai and Wakabayashi, 2010).

The Chinese jigging fishery began exploiting *I. argentinus* for the first time in 1997, both on the high seas and later in the Argentinean EEZ. In 1999, more squid fishing vessels entered into this area, and the annual output reached 60,000 t (Wang and Chen, 2005). In 2001, the catch increased to 99,000 t, with an average catch of 1,044 t per vessel. In 2004, as its recruitment fell, the squid production decreased dramatically, and the total Chinese catch was only 13,400 t. After 2005, the catch greatly increased to 184,000 t in 2007 and 197,000 t in 2008, respectively. However, the annual catch fell sharply to 12,000 t in 2011 (Figure 28).

Taiwanese jigging vessels mainly fish on the high seas around 45°–46°S and north of the Falkland Islands between December and June. Some fishing vessels operate within the Argentinean EEZ and FICZ under local licenses. When low squid production occurred, such as in 2004 and 2009, fishing fleets left as early as May and moved to the Southeast Pacific to fish for *D. gigas*, or to the Northwest Pacific for Pacific saury (*Cololabis saira*).

The annual production of *I. argentinus* by Taiwanese jiggers varied from 9,000 (2004) to 284,000 t (2007) between 1986 and 2011, with an annual average production of about 120,000 t, which accounted for 20∼30% of the global production of *I. argentinus*. The annual number of vessels ranged from 8 to 132 and with an annual average around 80 vessels in recent years (Figure 29).

Altogether, despite substantial fluctuations in abundance, the total catch of *I. argentinus* in the Southwest Atlantic was high between 1987 and 2003 (410,117–1,153,300 t), although catches had declined every year since 1999. In 2004–2005, the total catch dropped sharply to 178,900–287,600 t, probably due to low abundance triggered by overfishing and/or unfavorable environmental conditions. After a return to high abundance in 2006–2008 (total catch of 703,800–955,000 t), there was another drop in abundance in 2009–2011 (190,000–261,200 t). In 2012–2013, another recovery of *I. argentinus* populations was observed with total catch approaching ∼500,000 t.

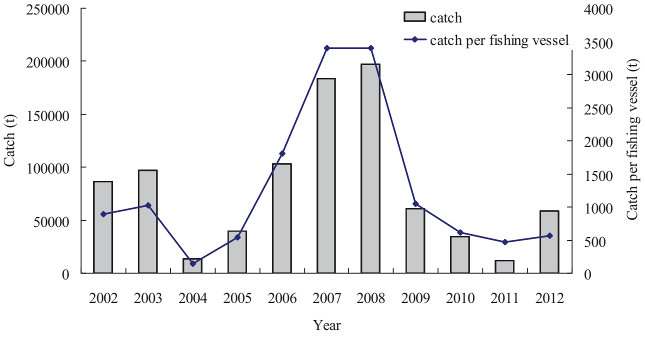

Figure 28. Total catch and catch per fishing vessel of *Illex argentinus* for Chinese squid jigging fleets in the southwest Atlantic.

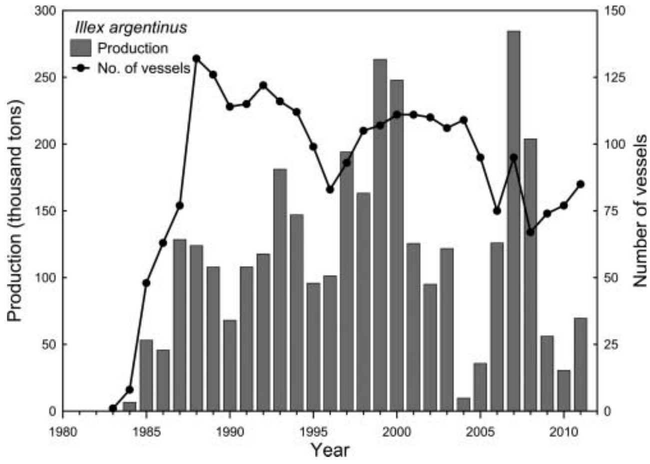

Figure 29. Production of *Illex argentinus* and number of vessels for Taiwanese distant-water squid fishery in the Southwest Atlantic between 1983 and 2011.

6.1.4. Stock Assessment

The Argentine short-finned squid is a typical “straddling” or transboundary stock that, during its ontogenesis, migrates through the EEZs of several countries including Brazil, Uruguay, Argentina, as well as Falkland Conservation Zones. It also occurs in the unregulated High Seas fishing area around 42°S and 45°–47°S. Stock assessment of this squid is challenging because it requires the data from several fishing zones under different (or no) jurisdiction in the Southwest Atlantic.

Before the start of large-scale commercial exploitation, several biomass surveys were carried out on the entire Patagonian Shelf by R/V Walter Herwig (1978), Shinkai Maru (1978/79) and Dr Holmberg (1981/82). The biomass estimated by the swept-area method varied between 635,968 t (Otero et al., 1981) and 2,605,000 t (Sato and Hatanaka, 1983). In 1990, a bilateral South Atlantic Fisheries Commission (SAFC) was established that included Argentina and the United Kingdom. One of the main aims was to exchange data on *I. argentinus* catches and locations with further recommendations on stock conservation. The SAFC organized joint trawl surveys to estimate the recruitment of the winter spawning stock on the Patagonian Shelf before the start of the fishing season in February. Abundance and biomass were estimated by swept-area method using Argentinean research vessels.

During the fishing season, stock abundance was estimated using a modified DeLury model (Beddington et al., 1990; Rosenberg et al., 1990) under the assumption that in March–April squid remain in the same area (Southern Patagonian

Shelf) with no substantial immigration or emigration. Later, Basson et al. (1996) improved the depletion model by considering the progressive (i.e., asynchronous) immigration of squid to the fishing ground after the season starts. It was established that if the Spawning Stock Biomass fell below the threshold limit of 40,000 t for the Southwest Atlantic, the SAFC should recommend early closure of the *Illex* fisheries both in Argentina and the Falkland Islands. Such early closures were implemented in a number of years. Unfortunately, since 2005, the SAFC has been inactive because the Argentine Government reduced cooperation, declined to attend meetings and suspended joint scientific activities. Currently, the Southwest Atlantic region suffers from lack of any effective regional management and conservation of straddling *I. argentinus* stocks because there is no regional fisheries management organization (RFMO). An RFMO should include all or the majority of countries whose fleets are exploiting those stocks. To date no such organization exists, making the Southwest Atlantic unique in having no comprehensive fisheries management programme. Countries with fishing waters in which *I. argentinus* occurs now impose conservation measures separately. This situation has undoubtedly increased the vulnerability of *I. argentinus* stocks. Since 2000, *I. argentinus* abundance has become more variable (Falkland Islands Government, 2012), probably reflecting both climatic variation and overexploitation.

6.2. *Doryteuthis gahi (Patagonian Squid)*

6.2.1. Distribution

The Patagonian squid *D. gahi* (Orbigny, 1835) inhabits the continental shelves of South America from southern Peru and Chile in the Pacific to southern Argentina and the Falkland Islands in the Atlantic (Jereb and Roper, 2010). It is a relatively small squid, typically attaining 130–170 mm ML. *Doryteuthis gahi* is the coldest water species among loliginids that lives in waters of Sub-Antarctic origin mixed with shelf waters. In the Pacific, the squid is distributed as far north as 4°S on the shelf of northern Peru, in shallow waters derived from the Humboldt Current (Villegas, 2001). The abundance of squid in Peruvian waters was quite low, with the total annual catch not exceeding several thousand t per year along the whole Peruvian coast. In Chilean waters, *D. gahi* is encountered from Valparaiso in the north to Cape Horn in the south (Arancibia and Robotham, 1984) in very low abundance, probably too low to support any specialized fishery. It is assumed that the populations off Peru and Chile are connected by squid that occur in the northern part of Chile (Jereb and Roper, 2010). However, there are no records of *D. gahi*'s occurrence in the region between 20° and 34°S.

In the Southwest Atlantic, *D. gahi* is widely distributed on the whole Patagonian Shelf, and found within waters of the Falkland (Malvinas) Current up to 38°–40°S on the Argentinean Shelf. The squid is most abundant to the south, south-east and north-east of the Falkland Islands, where it is the subject of a specialized bottom trawl fishery (Patterson, 1988; Hatfield et al., 1990). Its distribution and abundance on the Falkland Shelf are closely associated with the "Transient Zone" representing the mixing of Shelf Waters with the sub-Antarctic Superficial Water Mass of the Falkland Current (Arkhipkin et al., 2004b).

6.2.2. Population Structure and Life History

Two main seasonal cohorts of unclear taxonomic status, namely, a spring-spawning cohort and an autumn-spawning cohort, were identified around the Falkland Islands (Patterson, 1988). Recruitment of the autumn-spawning cohort occurs in the feeding grounds from October until January, that of the spring-spawning cohort in March and April. Squid of both cohorts have an annual lifecycle (Patterson, 1988; Hatfield, 1991) but, because of difference in spawning and hatch dates (Arkhipkin et al., 2004a), their similar ontogenetic phases occur at different times of the year and are subject to different environmental conditions. The squid that hatched in summer (at higher temperatures) were significantly larger than squid of the same age but hatched in winter (Hatfield, 2000). Ontogenetic growth in *D. gahi* is characterized by two-stage growth patterns with positive acceleration of growth during the juvenile period and negative acceleration of growth during the adult period. The inflection point of the Shnute growth curve was observed at the same age as the inflection point of the maturity ogive in males, but much earlier in females (Arkhipkin and Roa, 2005).

Genetic studies of *D. gahi* using allozyme markers found no evidence of genetic differentiation among samples collected monthly over 1 year, suggesting that all seasonal cohorts of *D. gahi* belonged to one single interbreeding population (Carvalho and Loney 1989; Carvalho and Pitcher 1989). Subsequent studies on the *D. gahi* population occurring around the Falkland Islands revealed no significant genetic differentiation among subpopulations (Shaw et al., 2004). This suggests extensive genetic interchange between spawning cohorts and geographical areas, that is, that there is interbreeding between the cohorts (Patterson, 1988; Agnew et al., 1998; Arkhipkin and Middleton, 2003).

Squid of both cohorts occur in the warmest water available in near-bottom layers of the Transient Zone between shelf waters and the Falkland Current (Arkhipkin et al., 2004b). The extent of the distribution of *D. gahi* aggregations on their feeding grounds may be predicted by determining the location of the Transient Zone on the shelf (Arkhipkin et al., 2004b). These areas comprise their feeding grounds on the Falkland Shelf. In summer, immature squid of the autumn spawning component are found in the warmer waters of the inshore boundary of the Transient Zone, moving to shallow Shelf Waters as soon as they start to mature. In autumn, emigration of the autumn-spawning cohort from their feeding grounds ends and these squid are replaced by immature squid of the spring-spawning cohort, which are just arriving on the shared feeding grounds. Late autumn homogeneity in temperatures from inshore to 200 m depths enables the spring-spawning squid to penetrate deeper into the Transient Zone. Winter cooling of the Shelf Waters and formation of the warm water layer between 150 and 250 m depths in the Transient Zone restricts squid almost exclusively to this zone, their movement being limited by colder waters situated both shallower and deeper. Thus, the whole spring-spawning cohort stays in the deepwater feeding grounds in winter, and continuous growth and maturation is evident in biological sampling. As soon as the spring warming starts at the end of October, the spring-spawning squid begin to move to shallow water to spawn, disappearing first from the deeper parts of the Transient Zone.

The squid spawn in shallow waters with egg masses occurring in kelp beds (Arkhipkin et al., 2000). The first (autumn-spawning) and second (spring-spawning) cohorts of *D. gahi* differ in the duration of embryonic development. Squid of the autumn-spawning cohort have their peak spawning in May–June (austral autumn) (Hatfield and des Clers, 1998), their egg masses develop slowly throughout the winter, and their hatchlings appear in early spring. Squid of the spring-spawning cohort spawn in the austral spring (October–November), their egg masses develop rapidly in warmer water conditions, and their hatchlings appear in early summer. Thus, the 5–6 month difference in spawning time between the two cohorts diminishes to only 2–4 months difference in hatching time (Arkhipkin and Middleton, 2003). This strategy enables recruits of both cohorts to target the pronounced spring-early summer zooplankton bloom in the Southwest Atlantic (Boltovskoy, 1999), presumably enhancing their survival.

6.2.3. *Composition and Numbers of the Fishing Fleet*

The fishery for *D. gahi* around the Falkland Islands started in the beginning of 1980s, when both Polish and Spanish trawlers discovered dense aggregations of squid on the shelf near the Beauchêne Island. The fishery has been carried out exclusively by trawlers operating bottom nets with small mesh liners. The fishery by several dozen factory trawlers was totally unregulated with the declared annual catch around 40,000 t (Csirke, 1987). The establishment of the 150-nm FICZ around the Falkland Islands in 1986 introduced a management regime for all commercial resources within the Zone. Since then all trawlers had to fish for *D. gahi* under licenses issued by the Falkland Islands Fisheries Department. In 1988–1990, up to 46 trawlers belonging to ten countries (mainly Spanish, 50–70%) were licensed to fish for Patagonian squid. The numbers of licenses gradually decreased to 21 in 1998, with the composition of fishing fleet changing to mainly Falkland flagged vessels (70–80%). Since 2000, the fleet has consisted of 16 factory trawlers (almost exclusively Falkland flagged vessels).

6.2.4. *Fishing Grounds, Duration of Fishing Period*

The *D. gahi* fishery is restricted spatially, limiting the trawling fleet to an area to the east and south of the Falkland Islands. The so called "*Loligo* box" extends about 10,000 square nautical miles on the shelf and shelf edge between 100 and 350 m depths. Two fishing seasons were established, the first running from February to May, and the second running from August to October. Since 2003, the seasons were shortened for conservation reasons. Currently, the first season is scheduled for 50 calendar days of fishing from February 24 to April 14, and the second season is scheduled for 78 calendar days of fishing from July 15 to September 30. During the first season, the squid exploited mainly belong to the first, autumn-spawning cohort, whereas during the second season the squid exploited mainly belong to the second, spring-spawning cohort.

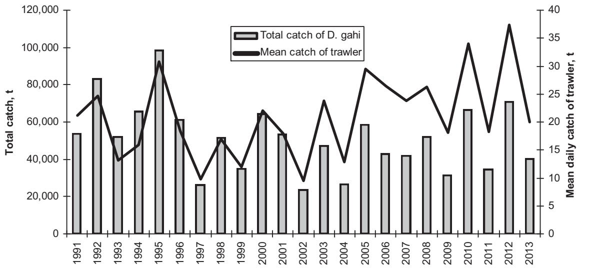

Figure 30. Total annual catch (t) and mean daily CPUE (t per day) in *Doryteuthis gahi* fishery within Falkland Conservation Zones in the Southwest Atlantic.

6.2.5. *Amounts and Dynamics of Catches*

Over the last two decades, total annual catches of *D. gahi* in the Falkland Islands have ranged from 24,000 to 98,000 t (Figure 30) with a mean of 51,000 t (Arkhipkin et al., 2013). CPUE has also been variable, with a negative interannual trend observed in the 1990s and a positive trend observed since 2000 onward (Figure 30). Occasionally, catches of *D. gahi* are also taken in the high seas at 46°–47°S outside the Argentinean EEZ in August–September, but they usually do not exceed 5,000 t per annum.

6.2.6. *Stock Assessment*

There is a rare opportunity in the Falkland Islands to use a depletion model for stock estimations of *D. gahi* as all ontogenetic stages of squid occur in one management area. A modified standard Leslie–Delury method is focused on the use of catch and effort data from the commercial fishery (Rosenberg et al., 1990). Instead of the usual assumption of negligible mortality, a fixed mortality rate was introduced, together with an extension to consider multiple fleets instead of a single catch-effort series. Assessments are carried out over the period following a peak in CPUE (where catch is expressed in numbers of squid). In practice, assessments using this method (Rosenberg et al., 1990) did not work in all fishing seasons, primarily because the time series of weekly CPUE deviated in some years from the assumed pattern of a continuous decline following an initial peak (Agnew et al., 1998). This has been a particular problem in the first season where recruitment of the second cohort often masks the depletion of the first cohort. Deviations from the assumed pattern of CPUE may also arise for other reasons including spatial structuring of the population on the fishery grounds (Arkhipkin and Middleton, 2002). The combined modeling of *D. gahi* stocks employs a stochastic biomass projection model for preseason and postseason assessment, and a stock depletion model (SDM) that assesses the stock during the fishing season period (Roa-Ureta and Arkhipkin, 2007). Additionally, it was shown that the spatio-temporal dynamics of the fleet was a useful component of the stock assessment of the *D. gahi* stock by the SDM. This is because more than one depletion episode, some of them quite short-lived, may occur in a given season, either in distant regions within the fishing grounds (as in the second seasons of 2004 and 2005) or even at short distances within the same region (the first season of 2005) (Roa-Ureta and Arkhipkin, 2007).

6.2.7. Management

The fishery management of *D. gahi* is based on the strict control of fishing effort rather than the more common policy of limiting catches (TAC). The choice of effort limitation as the primary management tool was made taking into account an annual lifecycle and high variability in abundance from year to year. With a very weak stock-recruitment relationship the management target has been to maintain spawner escapement biomass above a level that appreciably decreases the probability of poor recruitment (currently 10,000 t for each cohort). As the numbers of recruits cannot generally be estimated until the fishery is actually underway, Beddington et al (1990) argued that management should aim for constant proportional escapement via a constant harvest rate. In-season monitoring remains important to allow the possibility of reducing effort in years when a low recruitment implies that a constant harvest rate will not be sufficiently conservative. The aim of a constant proportional escapement has been implemented via the setting of allowable fishing effort, estimating the catchability coefficients and likely time spent fishing of groups of vessels, and thereafter issuing appropriate numbers of licenses (Beddington et al., 1990). The issuing of licenses, which are based on predetermined estimates of a vessel's fishing power and do not restrict the actual catch taken, has the advantage of reducing the incentive to mis-report catch (Beddington et al., 1990), which can be a serious problem in catch-limited fisheries.

Several management measures are currently in force to conserve the *D. gahi* stocks (Arkhipkin et al., 2008). Temporal restrictions (in the form of the early closure of the fishery season) may be used in cases when in-season estimations of stock size show that the stock is approaching a minimum escapement level. Spatial restrictions (in the form of areas temporally or permanently closed for fishing) may be used to prevent the fishing of dense schools of small juvenile squid during their offshore feeding migrations. The locations and timings of closed areas may vary interannually depending on environmental conditions, which determine the distribution of young squid. Reductions in fishing effort could be used in case of predicted poor recruitment of *D. gahi* for a given fishing season, though predictive ability is limited at present. If assessments indicate that minimum spawning stock biomass targets were not met then effort may be reduced in following seasons to take account both of the fact that recruitment may have been reduced and that fleet performance may have been underestimated. The current management practice, in the form of fishing effort regulation by restrictions in number of licenses, together with in-season spatial and temporal restrictions of the fishery, is flexible enough to conserve the stocks of short-lived *D. gahi* around the Falkland Islands at a sustainable level.

7. NORTHEAST ATLANTIC

The ICES divides the Northeast Atlantic, FAO area 27, into 14 fishery areas (Figure 31). Within this area, most catches of cephalopods arise from areas IV to IX, on the Continental shelf. Cephalopod fisheries remain relatively unimportant in the northeast Atlantic, a fact highlighted in reviews by Caddy and Rodhouse (1998) and Hunsicker et al. (2010). Indeed, according to Caddy and Rodhouse (1998), the only region of the world covered by their study where total cephalopod landings had not increased significantly over the previous 25 years was the Northeast Atlantic[1]. This area is only the 11th most important FAO fishing area for total cephalopod catches since 1950; with peak annual landings of just over 60,000 t compared to a peak of almost 1.5 million t for the Northwest Pacific (FAO, 2011).

The continuing pressure on finfish stocks has led several authors to propose that cephalopods, especially squid, would become increasingly important as a fishery resource (e.g., Boyle and Pierce, 1994). However, except for a brief period during 1980–1985, when *T. sagittatus* supported an important fishery in Norway, squid have remained less important than octopus and cuttlefish in this region; and the general upward trend in cephalopod landings since 1979 (peaking in 2004 at just over 60,000 t) has been driven by increasing landings of cuttlefish.

In the northern Northeast Atlantic, expansion of cephalopod fishing has probably been held back by the limited local consumption of cephalopods. For example, most squid landed in Scotland is exported to southern Europe (e.g., Pierce et al., 2010). Nevertheless, there has been intermittent interest in directed squid fishing in UK waters over the years and directed fishing on squid occurs on Rockall Bank and in the Moray Firth (see Hamabe et al., 1982; Pierce et al., 1994a; Young et al., 2006a; Hastie et al 2009a; Smith, 2011).

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[1] Note, however, that the time window selected affects the trends seen in the Northeast Atlantic. Total cephalopod landings increased from 1950 to 1970 but fell sharply to a low in 1979, trends driven by the rise and fall of Spanish octopus landings. The general increase seen since 1979 (at least until 2004) mainly reflects an increase in French cuttlefish landings, aside from the short-lived *Todarodes* fishery in Norway (see FAO, 2011 and Pierce and Portela, 2014).

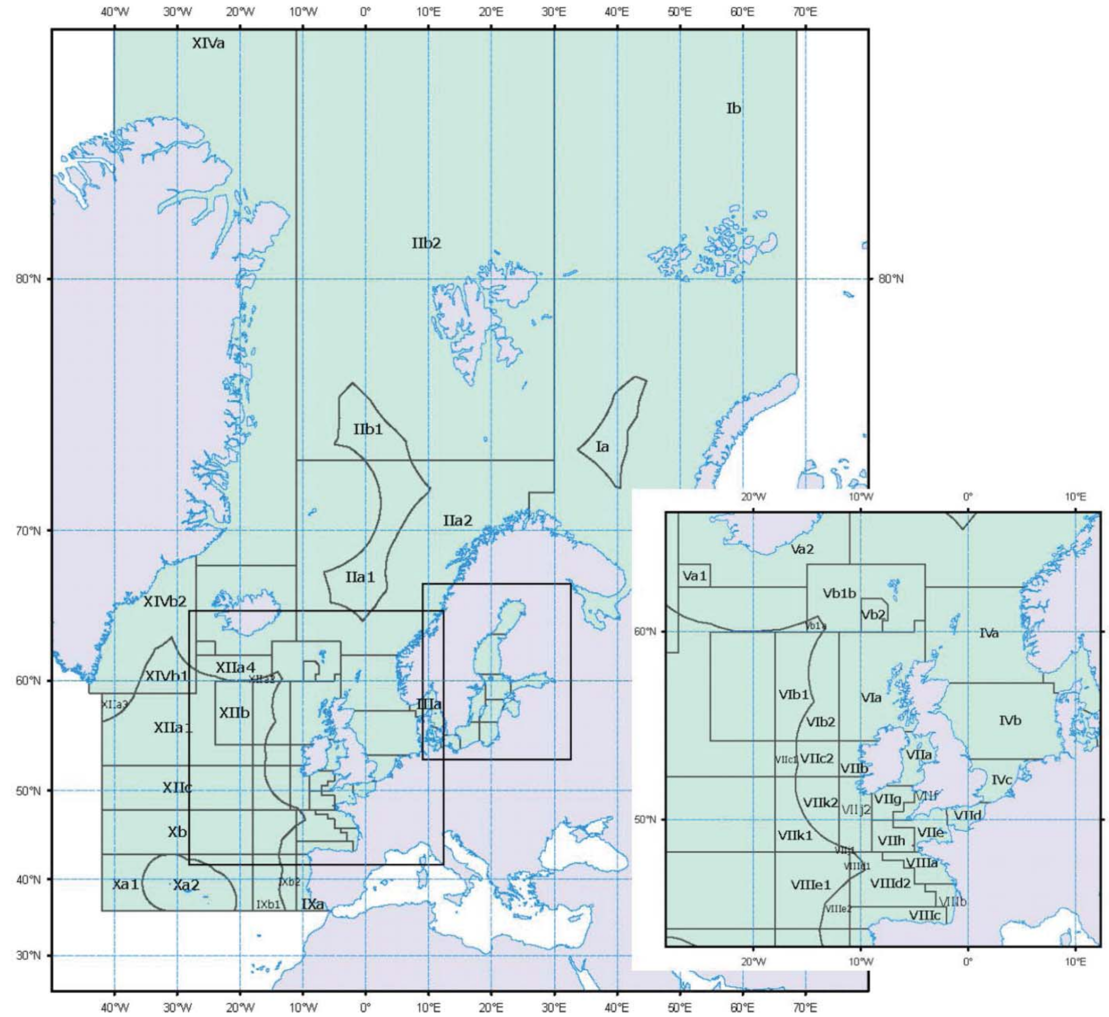

Figure 31. The division of the Northeast Atlantic, FAO area 27, into 14 fishery areas by the International Council for the Exploration of the Sea (ICES).

From the English Channel southward, cephalopods assume much greater importance as resource species, with commercial and artisanal fishing for cuttlefish, octopus and, to a lesser extent, squid. However, it is only very recently that there appears to have been more widespread commercial targeting of squid, for example, by Spanish trawlers in the Bay of Biscay, reflecting the poor state of the hake stock (ICES, 2013).

In the northern Northeast Atlantic, the most important cephalopod fishery resource is currently the loliginid squid *Loligo forbesii*. From the English Channel southward, other cephalopods, notably the cuttlefish *Sepia officinalis* and the octopus *Octopus vulgaris*, are more important in terms of both weight and value of catches, and *L. forbesii* is increasingly replaced in catches by *L. vulgaris*. There is some evidence that *L. forbesii* abundance declined markedly in the south of its range in the early 1990s, leading to increased dominance of *L. vulgaris* (Chen et al., 2006). The English Channel cuttlefish fishery is currently the most valuable Northeast Atlantic cephalopod fishery (ICES, 2012; Pierce et al., 2010).

Two other loliginid species, namely *Alloteuthis subulata* and *A. media*, are of minor fishery importance in the Northeast Atlantic. These species are landed and marketed as a secondary target or bycatch in Spain and Portugal; however, they are not distinguished from each other and are also likely sometimes landed with *Loligo* catches (Moreno, 1995; García Tasende et al., 2005; Jereb et al., in press).

Unlike in many parts of the world, the most important squid resources in the Northeast Atlantic are loliginids although, as mentioned above, historically, the ommastrephid *T. sagittatus* supported an important, if short-lived, fishery, in Norway (FAO, 2011). Two other ommastrephids, *Todaropsis eblanae* and *Illex coindetii*, are landed in small amounts as bycatch in the northern NE Atlantic, occasionally along with third species, *O. bartramii* (Pierce et al., 2010; ICES, 2012; Jereb et al., in press).

Clarke (1963) proposed that ommastrephid squids could provide an important future fishery resource in the eastern North Atlantic, for human consumption, animal feed, and fertilizer. He cited the seasonal exploitation of *Todarodes sagittatus*, *Stenoteuthis pteropus* and *S. caroli* (the latter now recognized as a synonym of *O. bartramii*) in Madeira. The Arctic and sub-Arctic gonatid squid *Gonatus fabricii* is considered to have some fishery potential (Bjørke and Gjøsæter, 1998). It is caught for use as bait in Greenland and has been the subject of unsuccessful experimental fisheries (Frandsen and Wieland, 2004). As Clarke (1963) observed, ommastrephids are generally considered less palatable than loliginid squid, but it remains possible that economically important fisheries for various oceanic squid species could be developed in the future. Nevertheless, the evidence for the existence of a high biomass of these species, that is, their importance in oceanic food webs, is also a reason to take a precautionary approach since uncontrolled exploitation could have important and unpredictable consequences for oceanic ecosystems.

Most information on abundance of the commercially exploited species arises from fishery landings and, in some cases, trawling surveys. Usually, at best these provide an indication of relative abundance; even where swept area estimates have been derived (as for *L. forbesii*, Pierce et al., 1998), they are essentially minimum estimates due to uncertainty about gear selectivity. In the last two decades, some model-based estimates have been derived (e.g., Young et al., 2004), although these also suffer from uncertainty about natural mortality. What is evident is that there are wide interannual fluctuations in abundance, generally thought to be environmentally driven although effects of fishing cannot always be ruled out.

7.1. The Loliginid Squids: Loligo and Alloteuthis

The so-called long-finned (loliginid) squid in this region comprise four species, *Loligo forbesii* (veined squid) and *L. vulgaris* (European squid) and *A. subulata* (European common squid) and *A. media* (midsize squid). Fishing focuses mainly on the former genus.

7.1.1. Biology, Ecology, and Stock Structure

7.1.1.1 Loligo forbesii. The range of *L. forbesii* extends along the eastern Atlantic continental shelf from Norway to north Africa; it is absent from the Baltic Sea and the southern boundary of its range in the Atlantic is poorly defined. It also occurs around the Azores and the Canary Islands groups, and throughout the Mediterranean (Jereb et al., in press). It appears to be most abundant in the northern part of its range, particularly around the United Kingdom (see Chen et al. 2006). *L. forbesii* is a temperate and subtropical neritic species, usually found in continental shelf waters at temperatures exceeding 8.5°C and with a vertical range from 50 to over 700 m along the mainland coast, although apparently generally found in deeper waters than *L. vulgaris* in areas where the two species co-occur. In the Azores, where deep waters are found close to the shore it can be found at depths up to 1000 m.

Males reach much larger sizes and weights than females, although females are usually heavier at any given length (e.g., Pierce et al., 1994c). Males can reach over 900 mm in length while maximum female size is around 460 mm, with the most common adult sizes being in the range 200–300 mm. Size at maturity is very variable; two or more size modes of maturity can exist in both sexes, but these separate modes are more pronounced in males (Collins et al., 1999). In Portuguese waters the smallest mature male measured 80 mm ML, and the smallest mature female 103 mm. However, on the mainland coast, most males start to mature at a minimum size around 150 mm ML and females around 170 mm ML. In the Azores, minimum sizes at maturity are larger, at 240 and 200 mm ML for males and females respectively (Jereb et al., 2010).

The lifecycle is annual, as indicated by generally consistent seasonal peaks of reproduction and recruitment, although statolith readings suggest that individuals can live up to around 16 months and there has been speculation the lifecycle could sometimes take two years (e.g., Boyle et al., 1995). In Scotland, the species is typically winter-spawning, with young animals recruiting to the fishery mainly in summer and autumn (Boyle and Ngoile, 1993a; Pierce et al., 1994b; Boyle et al., 1995; Rocha and Guerra, 1999; Jereb et al., in press). However, some spawning may occur all year round and the seasonal peaks differ between areas; secondary spawning peaks may also occur, for example, in the summer in the English Channel (Holme, 1974). Following the classification of Rocha et al. (2001) the species is an intermittent terminal spawner.

It shows an onshore-offshore ontogenetic migration, typical of loliginids, moving from the shelf edge (at 100–200 m) in summer toward inshore waters to spawn in the winter. In some years a West-East migration apparently occurs in autumn in Scottish waters (Waluda and Pierce, 1998). In the Moray Firth, Scotland, the smallest individuals are caught close inshore in summer and there seems to be a subsequent ontogenetic migration away from the coast and a later return of mature animals into coastal waters to spawn (e.g., Viana et al., 2009).

Several studies in Scotland have reported two main recruitment periods, in April and November, with small numbers of recruits present throughout most of the year, despite there apparently being a single main breeding season (Lum-Kong et al., 1992; Boyle and Pierce, 1994; Pierce et al., 1994b; Boyle et al., 1995; Collins et al., 1997, 1999). The phenology of lifecycle events appears to be very variable, both between years, apparently reflecting sensitivity to varying environmental conditions (see Sims et al., 2001; Pierce and Boyle, 2003; Pierce et al., 2005) and also within years, since between two to four microcohorts may be identifiable in landings at any one time (Collins et al., 1999). It is generally unclear whether variability in life history characteristics is environmentally driven, genetic, or a mixture, but it has given rise to suggestions that more than one stock may be present (see below). Several studies on squid landings in Scotland have identified an apparently predictable seasonal pattern, with highest landings from coastal waters usually occurring in autumn, as might be expected from the predominant seasonality of recruitment and growth. However, examining data over several decades, it becomes evident that the seasonal pattern of landings has actually varied considerably over the years, possibly reflecting a shift in relative dominance of winter and summer breeding populations (Pierce et al., 2005). Thus while peak landings in the 1990s were usually in October and November, in 2012 and 2013 the peaks occurred in August and September, respectively (Wangvoralak, 2011). Further research is needed on this topic, preferably underpinned by routine monitoring of month-to-month evolution of size distributions, as indeed would be needed for any formal stock assessment.

Fishery landings and survey catch data suggest wide fluctuations in abundance of this species (e.g., Pierce et al., 1994b; 1998), a conclusion also supported by the few (project-based) attempts to carry out a formal stock assessment (e.g., Young et al., 2004). Many studies have demonstrated links between cephalopod abundance and environmental conditions, often related to sea temperature and/or large scale indices such as the NAO Index, as is the case for *L. forbesii* (e.g., Pierce and Boyle, 2003); there are many hypotheses about mechanisms but most authors propose effects on food availability, metabolism, growth and survival, especially during early life stages (see Pierce et al., 2008 for a review). Environmental drivers may also have strong influences on distribution and (as mentioned above) lifecycle phenology. Results from spectral analysis of Scottish *Loligo* landings data suggested an underlying cyclic pattern of abundance with a periodicity of around 15 years (Pierce et al., 1994a). However, in recent years the peaks have been closer together. This, coupled with increased landings in recent years (see Section 7.1.2), suggests that the boom-bust cycle may be at least partly fishery driven.

L. forbesii is an active predator, older animals being largely piscivorous; seasonal shifts in the diet are consistent with opportunistic feeding (Pierce et al., 1994c; Collins and Pierce, 1996; Wangvoralak et al., 2011). It is itself eaten by a variety of marine predators, including fish, seabirds, seals and cetaceans (see Daly et al., 2001; Jereb et al., in press).

Given that most squid species are highly mobile and undertake sometimes extensive ontogenetic migrations, it is not expected that the distribution range of *L. forbesii* would be divided into very many separate stocks. However, various studies of life history and morphometric variation in *L. forbesii* have indicated the existence of different forms, sometimes occurring sympatrically. Thomas (1973) proposed that the variable patterns of squid availability, particularly the difference between coastal waters and the offshore Rockall area (ICES subdivision VIb), were consistent with the existence of at least two stocks with different migratory patterns. Further evidence of differences between animals from Rockall and coastal waters arises from results on the phenology of maturation (Rockall animals apparently mature earlier in the year) and on morphometric characters (Boyle and Ngoile, 1993b, Pierce et al., 1994 d,e). As previously mentioned, Holme (1974) identified winter and summer breeding populations of this species in the English Channel, which gives rise to the suggestion that Rockall animals are summer breeders, as opposed to the more usual winter breeding modality (see also Pierce et al., 1994a, b, 2005). Another phenomenon that has led to suggestions of alternative lifecycles is the existence of (at least) two distinct modes of male maturity (Boyle et al., 1995), although this seems to be linked to selection for alternative mating strategies (mate guarders vs. sneakers; c.f. Hanlon and Messenger (1996)), rather than implying the existence of reproductively isolated stocks.

Genetic evidence of stock differentiation within continental shelf waters of the European Atlantic remains inconclusive: a study based on allozyme data indicated no differences (Brierley et al., 1995), while Shaw et al. (1999) reported no significant differences between samples from different coastal areas but some genetic differences between inshore and offshore (Rockall and Faroe Islands) animals.

One geographically isolated and genetically distinct stock of *L. forbesii* certainly exists; that in the Azores. Its distinct morphometric, allozyme, and genetic characteristics indicate that these animals comprise a highly isolated population, based on a founder event occurring up to 1 million yr ago (Shaw et al., 1999). Brierley et al. (1995) suggested that the Azorean population should be regarded as a separate subspecies.

7.1.1.2. Loligo vulgaris. The geographical distribution of *L. vulgaris* extends from 20°S, off the south-western coast of Africa, to approximately 55°N, extending into the North Sea, the Skagerrak, the Kattegat and the western Baltic Sea—although currently it is rarely recorded north of the English Channel. It occurs off the Canary Islands and Madeira but is absent from the Azores (Jereb et al., in press). On the continental shelf, ontogenetic migrations are thought to occur. Animals which overwinter in deeper waters of the French coast and in the Bay of Biscay apparently migrate northward in summer to spawn in shallow waters of the North Sea and English Channel respectively. Southward migrations take place in the autumn.

Loligo vulgaris typically lives up to 12 months of age (Rocha and Guerra, 1999), although a shorter lifespan (9 months) has been suggested in southern Portuguese waters. As is the case for *L. forbesii*, its lifecycle appears to be annual and it shows similar variability and sexual dimorphism in growth and maturation. No major changes in the general morphology occur with sexual maturity; males attain larger sizes and weights and mature earlier than females, but females generally exhibit higher weights than males at any given length. Size at maturity is variable. Two modes in size at maturity are reported for males from most Atlantic areas. Spawning extends all year round in most of its distributional range, usually with two seasonal peaks that occur earlier in southern waters; it is mainly a winter breeder in the north of its range (Guerra and Rocha, 1994; Arkhipkin, 1995; Jereb et al., in press). Following the classification of Rocha et al. (2001) the species is an intermittent terminal spawner.

Using microsatellite data, Garoia et al. (2004) showed that Atlantic specimens of *L. vulgaris* differed consistently from

Eastern and Western Mediterranean samples, which also differed from each other.

Like *L. forbesii*, *L. vulgaris* shows an ontogenetic shift in feeding habits, from a diet dominated by small crustaceans to a mainly piscivorous diet (Rocha et al., 1994). Most published records of predation on loliginid squid refer to fish and cetacean predators; because identification is often based on examination of beaks, the squid are often identified only to genus level (Jereb et al., in press).

7.1.1.3. Alloteuthis subulata and A. media. The ranges of the two *Alloteuthis* species differ from those of *Loligo* in that they do not extend so far from the coast; in addition, both are absent from the Canary Islands and the Azores, while the occurrence of *A. media* further north than the Irish Sea and southern North Sea is doubtful (see Jereb et al., in press). *Alloteuthis* spp. have a maximum age of around 12 months (Rodhouse et al., 1988; Moreno et al., 2007). The lifecycle lasts between 6 and 12 months; there may be several spawning seasons (Rodhouse et al., 1988; Moreno, 1990, 1995; Arkhipkin and Nekludova, 1993; Hastie et al., 2009b; Oesterwind et al., 2010).

Like *Loligo* spp., *A. subulata* show an ontogenetic shift in feeding habits, from a diet dominated by small crustaceans to a mainly piscivorous diet. The diet of *A. media* is less well documented. In terms of their role as prey, most published records of predation on these loliginid species refer to fish and cetacean predators; because identification is often based on examination of beaks, the squid are often identified only to genus level (Jereb et al., in press).

There is currently no information on the existence of different stocks in the *Alloteuthis* species; however, larger taxonomic issues remain unresolved for this genus, specifically the number and identity of extant species and their relationship to the recognized "*A. subulata*" and "*A. media*" morphotypes (see Anderson et al., 2008; Jereb et al., in press).

7.1.2. Fisheries

Loliginid squid are fished throughout shelf waters of the Northeast Atlantic as well as around offshore banks (e.g., Rockall) and islands (e.g., the Azores), usually all year round although with seasonal peaks reflecting the timing of the lifecycle. Across the region, much of the catch of loliginids is taken as a bycatch by demersal trawling, although some artisanal fishing does occur, especially in the south. Squid tend to be caught year round, with clear seasonal peaks for some species, and represent an important source of income for fishers in the region. Official fishery landings data normally identify squid only to family level. Information on the proportion of different species present may to some extent be inferred from the known distributions of the species and the size of squid landed (hence loliginid squid landed in Scotland are normally *L. forbesii* and larger loliginid squid landed in the Iberian Peninsula are mainly *L. vulgaris*) although some additional information on the proportions of different species is available from project-based studies and regional fishery monitoring programmes (e.g., fishery monitoring by the Galician government in Northwest Spain).

Data on total landings of loliginids from the Northeast Atlantic are available from the ICES WGCEPH (see reports from 1995 to 2013 available at www.ices.dk), but must be viewed as approximate due to gaps in reporting by various countries, and indeed the frequent revision of the figures. Between 1988 and 2012, reported annual landings of loliginid squid ranged from 7,124 t to 12,464 t. The underlying trend since 1990 is downward. Currently, the southern part of the region (ICES areas VIII and IX) is more important for squid fisheries than the northern region: in 2012, around 5,550 t out of 9000 t declared landings of long-finned squid from the European ICES region came from areas VIII and IX (ICES, 2013). However, a decade previously, landings from these areas made up only around 1/3 of a total of approx. 9,800 t. The increased importance of the southern areas for squid landings in recent years is driven mainly by increased catches in the Bay of Biscay reported by France and Spain (ICES, 2013).

7.1.2.1. *Loligo forbesii. Loligo forbesii* is fished all year round, currently mainly as a bycatch in demersal trawl fisheries in UK waters, with seasonal peaks in landings related to the lifecycle (see Section 7.1.1). United Kingdom landings of *Loligo* spp. (probably dominated by *L. forbesii*) ranged from around 1,500 t to 3,500 t in the period 2000–2012 while French landings in the same period ranged from approximately 2,800–6,400 t (ICES, 2012, 2013).

The importance of directed fishing may be limited by the wide fluctuations in abundance reported (Young et al., 2004; 2006a) but in fact *L. forbesii* has been targeted in various locations over the last 70 years. *Loligo forbesii* supported a directed fishery by Denmark and Sweden in the North Sea and Skagerrak in 1948–1953, while targeted fishing from small boats emerged in the English Channel in the mid-1970s (Arnold, 1979). In his review of the economic status of European squid fisheries, Shaw (1994) described fisheries in UK waters for *L. forbesii*, noting that directed fishing occurred off southwest England from late summer to autumn. The most important British port for squid landings was usually Brixham in Devon, from which as many as 45 boats with crews of two or three undertook day-trips to trawl for squid within 20 miles of the coast. In addition, 8 to 10 boats with crews of three or four sailed from Newlyn or Mevagissey in Cornwall. Elsewhere, vessels targeted squid if there were reports that they were available in substantial numbers.

A directed trawling fishery for *L. forbesii* developed at Rockall, 480 km west of mainland Scotland, during the 1980s, involving boats that usually targeted haddock and other whitefish (Shaw, 1994) but which switched to squid when this was abundant. Catches of *L. forbesii* at Rockall occurred mainly in July and August (Pierce et al., 1994a), a time when only the smallest recruits are normally caught in coastal waters, thus supporting the idea that this was a different stock. The Rockall squid fishery yielded high landings in 1986, 1987, and 1989 but subsequently almost disappeared (Pierce et al., 1994a, 2005), although since 2008 there has been something of a resurgence, with 700 t landed in 2011 (ICES, 2012).

A small directed trawl fishery for squid now exists close inshore in the Moray Firth (North Sea, Scotland). This fishery is strongly seasonal (mainly September–November) and initially involved around 20 trawlers of between 10 and 17 m in length. In the mid-2000s, the number of boats taking part in the fishery increased dramatically (from around 20 boats in 2000 to as many as 65 in 2003; Young et al., 2006a). However, high catches were not sustained and interest subsequently decreased again (Smith, 2011).

Stroud (1978) reported that squid were caught in UK waters mainly as a bycatch of trawling or seining for white fish, as also shown by more recent analyses (e.g., Pierce et al., 1994a). He further noted that, since squid tend to swim off the bottom, the best catches were obtained with midwater trawls or high headline bottom trawls, and that a high proportion of the smaller squid could readily escape through the meshes of a typical trawl. Boyle and Pierce (1994) described specially designed squid trawls used in Scotland, which had small mesh cod-ends and higher head ropes than those normally used to catch fish. In the Moray Firth, vessels change to small mesh gear in late summer when the squid become abundant (Young et al., 2006a). Use of jigs to catch squid in UK waters was advocated by Hamabe et al. (1982) but various unsuccessful trials of commercial jigging machines in the UK in the 1970s and 1980s appear to have discouraged further use of this gear (see Pierce et al., 1994a).

Loliginid squid are caught throughout UK waters, notably in the English Channel, Celtic Sea, and in the Moray Firth, although the spatial distribution of catches varies from year to year. In some years, there are high catches on the offshore Rockall Bank while, historically, the species was caught on Faroe Bank and in the Bay of Biscay by UK vessels. Within this area, Scottish landings can be assumed to be mainly *L. forbesii* but further south *L vulgaris* is increasingly important and squid landed in England, Wales, and France likely normally comprise a mixture of both *Loligo* species. Market sampling of French landings has been used to estimate the proportion of the two *Loligo* species present in catches, results suggesting that these species have different seasonal cycles (Robin and Boucaud, 1995).

In Scotland, available landing records for squid (as mentioned above, presumed to be mainly *L. forbesii*; Figure 32) go back to at least 1904 (Thomas, 1969), although the fishery only became significant in the mid-1950s, perhaps facilitated by the advent of deep-freeze facilities (although most squid caught in Scottish waters continue to be landed fresh, on ice) and exports to continental Europe. To some extent, landings will reflect abundance: this is plausible for a valuable nontarget species for which there is no quota (Pierce et al, 1994a). However, even though fresh undamaged squid fetch a good price they are not always landed since, as noted previously, they are often damaged when caught in a trawl along with fish and, in addition they cannot be kept on ice for many days (not withstanding the somewhat optimistic appraisal of the condition of squid after a week on ice by Stroud (1978)). Furthermore, fishing effort has undoubtedly increased since the early 1900s, and other human factors such as two world wars have clearly had an effect on squid landings. Nevertheless, it can be suggested that abundance trends are characterized by recurrent peaks and troughs.

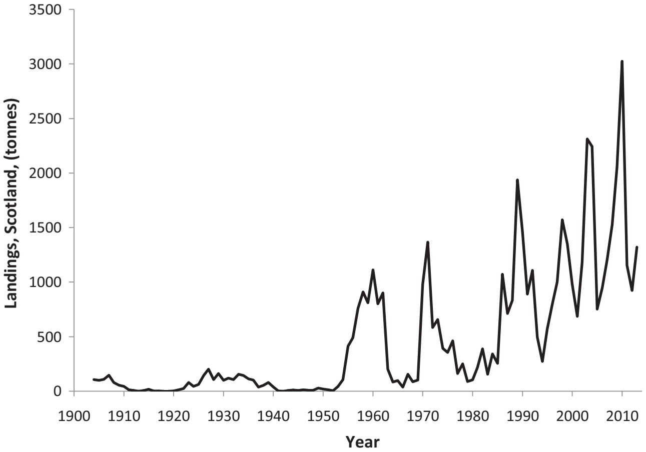

Figure 32. Landings of loliginid squid in Scotland (1904–2013).

Major peaks in Scottish loliginid landings broadly correspond to those in total loliginid landings for the region (ICES 2013) although in Scotland the trend since 1990 has been upward, opposite to that for the whole region. This could suggest that *L. forbesii* has become more abundant while *L. vulgaris* has been declining.

L. forbesii is also caught in waters of the mainland coast of the Iberian Peninsula, both by trawling and artisanal fisheries, but, as elsewhere, is not normally distinguished from *L. vulgaris* in official landings data. Previous studies and recent observations by the authors and colleagues suggest that it forms only a small proportion of long-finned squid landings in the area. In the Azores islands, *L. forbesii* is fished exclusively by an artisanal fleet equipped with hand-lines and home-made jigs (Martins, 1982; Porteiro, 1994). It is also fished in Madeira, where it is used both for human consumption and as bait.

7.1.2.2. *Loligo vulgaris and Alloteuthis spp*. *Loligo vulgaris* is fished all year round throughout its distributional range. It is caught together with *L. forbesii* as a bycatch of French trawlers operating in ICES areas VIII and VII; the species are not separated in official landing statistics. During 2001–2010, the average annual French landings of long-finned squid were 5705.5 t (range 4690–6292 t).

In southern Europe, while loliginids (mainly *L. vulgaris* but also *L. forbesii* and sometimes *Alloteuthis* spp.) are caught by trawling, there are also important small-scale fisheries, using jigs and hand-lines, beach seines, gill nets or trammel nets, which target loliginid squid when they enter coastal waters in autumn and winter to spawn (e.g., Cunha and Moreno, 1994; Guerra et al., 1994).

In Galicia (NW Spain), official annual total landings of *L. vulgaris* were on average 418.9 t (range 292–560 t) for the period 2004–2012. Trawler landings accounted for approximately 95.5% of the total and the remainder were caught by small-scale fisheries, using artisanal gears such as hand-jigs and beach seines, mainly during the summer; beach seining is permitted during July and August. The sale price at auction of this species in Galician ports varied from 5.67 to 19.70 € per kilo during the period 2001–2013. The beach seine fishery takes squid below the legal minimum size (100 mm ML), along with *Alloteuthis* spp. European squid is mainly sold fresh and reaches a high market value. In the coastal rías of southern Galicia (northwestern Spain), *L. vulgaris* is targeted during July–September using boat seines ("boliche") and makes up around half of the catch; *Alloteuthis* spp. are a secondary target in this fishery and are also taken using trawls and purse-seines in grounds outside the rías (Tasende et al., 2005).

In the Gulf of Cadiz (SW, Spain), *L. vulgaris* is mainly caught by the multi-species bottom trawl fishery. Bottom trawl catches from 1994 to 2010 ranged from 300 to 575 t (average 497 t), which represent 99% of the total landings in the Gulf of Cadiz. This squid fishery shows a clear seasonal pattern, with higher landings occurring in October and November. Both *Alloteuthis* spp. are also caught as a bycatch of the bottom trawl fleet in this area, with recorded annual landings of between 55 and 290 t during 1996–2006 (Pierce et al., 2010).

The catches of long-finned squid in Portugal potentially combine three different species, which are not distinguished in the markets: *L. vulgaris*, *L. forbesii*, and *A. subulata* although most are probably *L. vulgaris*. There is a MLS for *L. vulgaris* of 100 mm ML, which effectively covers the three species. In the 1990s, only *L. vulgaris* entered the market because *L. forbesii* was not available in significant numbers, and *A. subulata* is a small species that is almost always under the MLS. For the period 2001–2010, the Portuguese official landings for this category were 514 t per year on average. On the west coast, off Aveiro (Central Portugal), large trawlers which mainly target horse mackerel also have well-defined fishing strategies for taking cephalopods. They catch common octopus (*O. vulgaris*) and *L. vulgaris*, switching between these species seasonally and year to year depending on abundance (and hence ultimately depending on the interannual recruitment variation of these species) (Fonseca et al., 2008).

7.1.3. Stock Assessment

There is presently no routine stock assessment for European cephalopods and (in consequence) there is no routine market sampling of biological characteristics and few directed surveys for this species in the northern Northeast Atlantic. Nevertheless, several research projects and the ICES WGCEPH have carried out exploratory assessments (Robin and Denis, 1999; Denis et al., 2002; Royer et al., 2002; Young et al., 2004; Challier et al., 2005; ICES, 2010, 2011, 2012).

Various characteristics of species such as *L. forbesii* make it difficult to apply traditional stock assessment approaches; these include the short lifespan, the fact that age determination is difficult and time-consuming, variable growth rates (resulting in weak length-age relationships, the lack of synchronization of lifecycle events (reflected in the presence multiple microcohorts) and year-to-year differences in the timing of lifecycle events, reflecting high sensitivity to variation in environmental conditions (Boyle and Pierce, 1994; Pierce and Guerra, 1994; Young et al., 2004; Pierce et al., 2008). The lack of stock-recruitment relationships, reflecting short lifecycles and high environmental sensitivity means that postseason assessments have limited predictive value. In fact, the difficulty of predicting abundance is a fundamental issue for managers in all cephalopod fisheries (Rodhouse, 2001).

Options for stock assessment in squid include forecasting, surveys for recruits, in-season assessment (e.g., using depletion models), and postseason assessment (e.g., using production models or models more explicitly based on population dynamics) (Pierce and Guerra, 1994). The existence of relationships between abundance and environmental conditions suggest the possibility of forecasting abundance (Rodhouse, 2001), although the predictive power of such relationships may be weak (e.g., Pierce and Boyle, 2003).

In the Northeast Atlantic, only Portugal has routinely carried out trawling surveys directed at cephalopods (see Pereira et al., 1998). Data collected from standard trawling surveys for fish can generate abundance indices, the value of which is supported by the positive correlation between indices of abundance derived from trawling surveys and annual fishery landings (Pierce et al., 1998). It may also be possible to provide absolute abundance estimates by applying to trawl survey data a swept area method. However, both relative and absolute abundance estimates are presently difficult to achieve. The timing of many such surveys (directed at fish) is inappropriate to allow recruitment strength to be predicted; in any case the timing of loliginid lifecycles is known to vary both within and between years (e.g., Pierce et al., 2005). Gear selectivity needs to be understood so that an appropriate mesh size can be chosen. Furthermore, bearing in mind the apparently highly patchy distribution of the species, important concentrations may easily be missed by surveys, or indeed suffer high additional mortality due to research trawling (see Hastie, 1996; Pierce et al., 1998). There is also the issue of the difficulty of distinguishing small *Loligo* from adult *Alloteuthis.*

Royer et al. (2002) applied depletion methods and monthly cohort analysis to both *Loligo* species in the English Channel. With the depletion method, assuming a natural mortality value of 0.2, initial population size (recruitment) ranged from 3.7 to 19 million for *L. forbesii* and from 2.1 to 10 million for *L. vulgaris.* Cohort analysis gave figures of 2.4 to 14 million for *L. vulgaris* and 6.3 to 22.3 million for *L. forbesii*. For both *Loligo* species, exploitation levels in the English Channel were above the optimum. Assessments can be improved by introducing age data and accounting for variability in individual growth rates (Challier et al., 2006), although the necessary data collection is labor intensive.

Young et al. (2004) estimated abundance of *L. forbesii* in Scottish waters in the 1990s using a depletion method, obtaining figures that varied from a maximum of around 6 million (in the 1990–1991 season) down to a few thousands in 1995–1996. In addition, an approach to estimating fishing effort and landings from interview surveys of fishermen has been attempted for *Loligo* fisheries in Scotland (Young et al., 2006b).

Key challenges include obtaining standardized CPUE indices, estimating the ratio of the two *Loligo* species in areas of overlap, estimating recruitment strength, and linking length to age.

7.1.4. Fishery Management for Loliginid Fisheries

Management of cephalopod fishing in Europe is largely limited to MLS regulations in southern Europe. In Spain and Portugal, the MLS for *Loligo* spp. is 100 mm (Fonseca et al., 2008). In Galicia, there is a MLS (60 mm) for *Alloteuthis* (Tasende et al., 2005). Collins et al. (1997) proposed that a directed fishery for *L. forbesii* could be managed by a combination of controlled opening, to prevent growth overfishing, and curtailment of fishing during spawning, to prevent recruitment overfishing. However, the authors recognized that this would leave a fairly narrow window within which fishing could take place.

The need for management is indicated by analyses that suggest exploitation levels are above optimum, and the occurrence of boom and bust dynamics in landings. In addition, loss of eggs either due to trawling over spawning grounds or egg laying on fixed gear may be important and there has been evidence of growth overfishing (high catches of very small squid followed by lower catches later in the season) in the Moray Firth. Large numbers of eggs are laid on fixed gear (e.g., trammel nets) off western Portugal and this may represent a significant cause of mortality (A. Moreno, pers. comm).

Perhaps the most realistic approach, considering the continued dominance of landings from bycatch fisheries, is for management to focus on protection of essential habitat such as spawning areas rather than on generic catch or effort limitations. Recent modeling work has attempted to define habitat and movements of *L. forbesii* in Scottish waters (Viana et al., 2009; Smith et al., 2013) but the main spawning areas of this species remain to be identified. Many records exist of *Loligo* spp. eggs on traps, pots and creel lines (Holme, 1974; Lum-Kong et al., 1992; Porteiro and Martins, 1992; Martins, 1997; Craig, 2001; Pham et al., 2009; Smith, 2011). Lordan and Casey (1999) argue that *L. forbesii* probably spawn mainly over rocky bottoms where opportunities to attach eggs to the substrate are more numerous and, indeed, damage by bottom trawling is less likely. In the case of *L. vulgaris*, some spawning grounds have been identified, for example, off southwest Portugal (Villa et al., 1997). Habitats of English Channel fish, cephalopod and macrocrustacean communities, including a subcommunity demarcated by the two *Loligo* species, were described by Vaz et al (2007).

7.2. The Ommastrephid Squids

7.2.1. Biology, Ecology, and Stock Structure

Three ommastrephid species are caught regularly by commercial fisheries in the Northeast Atlantic, if rarely as target species, namely the European flying squid *T. sagittatus*, the lesser flying squid *T. eblanae* and the broadtail shortfin squid *I. coindetii.* Several other species of this family may be caught occasionally. All three species show apparently wide fluctuations in abundance, with sporadic occurrences of very high abundance; further details appear in Section 7.2.2.

7.2.1.1. Todarodes sagittatus. The European flying squid, *T. sagittatus*, occurs in the Eastern Atlantic Ocean from Iceland, the Barents and Kara Seas southward to Guinea, and westward to the mid-Atlantic Ridge as well as throughout the Mediterranean. It is a nerito-oceanic species, inhabiting not only mostly slope waters from the surface down to >1000 m, but also occurs on the shelf and in the open ocean.

As has been the case for many other squid species, the availability of age data from statoliths led to a downward revision of the lifespan, and the conclusion that it is basically an annual species. The maximum recorded age is around 14 months (assuming that growth increments on statoliths are daily; Lordan et al., 2001). Off West Africa, spawning was recorded all year round but with a winter peak (Arkhipkin et al., 1999), while Lordan et al. (2001) found evidence of summer and winter breeding peaks.

The European flying squid takes a wide range of prey species but is mainly piscivorous, with small mesopelagic fishes (e.g., pearlsides and lanternfishes) making up a high proportion of the diet. It is in turn eaten by a range of fish and cetaceans, as well as seabirds and seals (Breiby and Jobling, 1985; Piatkowski et al., 1998; Lordan et al., 2001; Jereb et al., in press).

Within the species range there are at least three populations—a migratory Northeast Atlantic population that reproduces at the mid-Atlantic Ridge and forages as far north as off Iceland and Norway, and resident Mediterranean and Northwest African populations (Dunning and Wormuth, 1998; Nigmatullin et al., 2002; Vecchione et al., 2010). Status of these stocks is unclear as genetic comparisons between them have not been researched. No specific management measures are presently applied to the species.

7.2.1.2. Illex coindetii. The broadtail shortfin squid has a widespread and disjunct geographic distribution. In the eastern

Atlantic, it occurs from the Norwegian coast at around 60°N to Namibian waters (20°S). Unlike *T. sagittatus*, it is restricted to shelf waters, and is absent from waters around Iceland (Jereb et al., in press). It also occurs throughout the Mediterranean Sea. In the western Atlantic, the northernmost records are from off the Virginia coast (37°N). The southern limit of its western Atlantic distribution is unknown but it occurs in the Gulf of Mexico and the Caribbean Sea and has also been reported from French Guiana.

This species is a demersal, neritic species of the continental shelf and upper slope, occurring from the surface down to over 1000 m, with maximum concentrations between 150 and 300 m in the eastern Atlantic. The lifecycle is probably approximately annual, with a maximum age around 15 months (González et al., 1996). Breeding occurs all year round, albeit with seasonal peaks which vary between areas (Jereb et al., in press). It is mainly piscivorous, although smaller animals take more crustaceans, and takes a wide range of fish species, both pelagic and demersal (Rasero et al., 1996). Predators include fish and cetaceans, as well as seabirds and other cephalopods (Jereb et al., in press). There appears to be only a single stock of *I. coindetii* in the northeast Atlantic region (Martínez et al., 2005a, b).

7.2.1.3. Todaropsis eblanae. The lesser flying squid exhibits a very wide distribution, occurring in shelf waters of the Eastern Atlantic Ocean from 61°N to 36°S, as well as the Baltic Sea and the entire Mediterranean Sea. Its range extends as far north as that of *T. sagittatus*, beyond the north of Norway (Golikov et al., 2013). However, it also occurs in the western Indian Ocean, western Pacific Ocean, South China Sea and Australian waters, the Timor Sea, along the western and eastern Australian coasts, to Tasmania on the eastern side.

The lesser flying squid is a medium-sized demersal species usually associated with sandy and muddy bottoms, within a temperature range from 9 to 18°C in depths between about 20 and 850 m. Typically, it is associated with the shelf break zone where boundary currents and associated mesoscale oceanographic events such as downwelling eddies and upwelling cells promote rich food supplies. No clear evidence exists of seasonal migrations or any other type of major migration. It is probably the least mobile of the ommastrephid squids in terms of migratory habits (see Jereb et al., 2005).

The sex ratio is usually 1:1 in the populations studied to date. There is sexual dimorphism in body size with females growing larger than males (a maximum of 290 mm ML in females and 220 mm in males) and maturing at slightly larger sizes. The smallest mature females measure around 120 mm ML compared to 100 mm ML in males. In addition, maturing and mature males have bractae (leaf-like plates) on both ventral arms (see Sabirov et al., 2012). The lifecycle is probably approximately annual although the maximum recorded age in *T. eblanae* is only 255 days (Robin et al., 2002). Breeding occurs all year round, albeit with seasonal peaks which vary between areas. In Atlantic waters south of 44°N, hatching extends all year round but with peaks at the end of the summer and the beginning of autumn. (González et al., 1994; Hastie et al., 1994; Robin et al., 2002; Zumholz and Piatkowski, 2005; Jereb et al., in press).

Like *I. coindetii*, it is mainly piscivorous, opportunistically on fishes, crustaceans and other cephalopods, in decreasing order of importance; cannibalism also occurs (Rasero et al., 1996). Predators include fish and cetaceans, as well as seabirds and other cephalopods (Jereb et al., in press).

Although there are three stocks of *T. eblanae* in the eastern Atlantic, only one occurs in the Northeast Atlantic (Dillane et al., 2005).

7.2.2. Fisheries

Abundance of *T. sagittatus* is highly variable and presumably depends on a range of oceanographic factors influencing the recruitment strength. Explosions of the North Atlantic population when the squid invaded Norwegian and Barents Seas—the world's largest fishery grounds for this species—occurred in 1885, 1891, 1930–1931, 1937–1938, 1949, 1958, 1962, and 1965 (Zuev and Nesis, 2003). Wiborg (1978) commented that "during the years 1949–1971, it came to the·Norwegian coast nearly every autumn, failing only in 1951, 1952, 1956, and 1961," also noting that much of this catch was used as bait for long-line fisheries.

The next period of very high squid abundance occurred in 1980–1985 and led to the development of a large scale, though short-lived, fishery for this species (Sundet, 1985). This followed the similar event on the other side of the Atlantic, where another ephemeral large-scale fishery for an ommastrephid squid, in this case *I. illecebrosus* (also previously a bait species) bloomed in the late 1970s. Both events followed a decline in Japanese domestic squid catches, and so led to the development of a huge market for frozen whole and dried squid (O'Dor and Dawe, 2013). Currently, *T. sagittatus* is taken as bycatch throughout its range, though it has periodically occurred in Norway in sufficiently large numbers to support a moderate target fishery (Pierce et al., 2010).

The lesser flying squid and *I. coindetii* are landed as bycatch throughout the year, mainly from trawling. These species are normally not distinguished from each other (or other ommastrephids) in official landings data. However, in Galicia, NW Spain, market sampling has been used to derive separate figures for both species; both are landed in substantial amounts, albeit with different spatial and seasonal patterns (González et al., 1994; Bruno et al., 2009). Both species are usually caught in waters 100–400 m deep (Hastie et al., 2009a; Jereb et al., in press), *T. eblanae* mainly in waters of around 200 m depth according to Robin et al. (2002). However, in some years in Scotland *T. eblanae* has been caught adjacent to the coast (Hastie et al., 1994). *Illex coindetii* is generally more important in French and northern Spanish landings than *T. eblanae* (Robin et al., 2002; Bruno and Rasero, 2008). Nigmatullin (1989, 2004) comments that consistently occurring concentrations of *O. bartramii* have not been found in the North Atlantic; there are no data on landings of this species. A fourth species, *O. bartramii*, whose distribution extends throughout the Mediterranean and Northeast Atlantic as far north as Iceland, may represent a very small proportion of ommastrephid landings.

7.2.3. Fishing Methods

Fishing methods used to catch *T. sagittatus* depend on the area, and were often originally designed to catch something else. In Norway, the main fishing method, used when the squid enter the fjords, is the use of jigging machines (Wiborg and Beck, 1984; Sundet, 1985). In 1984, as many as 1800 vessels participated in this fishery (Sundet, 1985). Across Europe as a whole, however, the most important fishing method is bottom trawling, in which this species is taken as a small bycatch from Greece to Scotland, Norway and Iceland (Wiborg and Beck, 1984; Joy, 1990; Jonsson, 1998; Roper et al., 2010). This squid is also recorded in catches from pelagic trawls and purse seines off Norway, gillnets off France and northern Spain, purse-seines and Scottish fly-seines off the United Kingdom, gill-nets and trammel nets off Portugal, hand-jigs in the Canary Islands and Italy, and hand-jigs, purse-seines and trammel nets in Greece (Wiborg and Beck, 1984; Pierce et al., 2010; Escánez Pérez et al., 2012).

There have been several attempts to develop specialized fisheries for the species. In the 1980s *T. sagittatus* was caught as bycatch during the commercial purse seine fishery for pollock, mackerel and herring off Norway and in the northern North Sea. Amounts caught varied from several kilograms to 50 t per day. However, an experimental target fishery in Norway in October–November 1981 was a failure. Squid were located by echosounder and concentrated with lights mounted on a small anchored skiff. Unfortunately, they were attracted in low numbers, and the maximum catch was ∼200 kg (Wiborg et al., 1982). The traditional method of squid jigging proved to be more successful. In autumn 1981, a prawn trawler was equipped with five jigging machines with double line drums. During six weeks of fishing the maximum daily catch was 3.3 t, whereas another trawler equipped with eight single-line drum jigging machines caught 100 t of squid during one month with maximum catches of 10–12 t per day (Wiborg et al., 1982). An experimental jigger fishery in Soviet waters of the Barents Sea in autumn 1981 resulted in 1–10 t of squid per night (PINRO, 2011). Attempts to use Japanese drift nets for the squid fishery in Norway, as used for the *O. bartramii* fishery in the North Pacific, were not successful (Wiborg et al., 1982; Wiborg and Beck, 1983).

In April–May 1982, the Soviet trawlers fishing for blue whiting took up to 4 t of squid per week as bycatch, but attempts to launch a specialized trawl fishery either in Norway or in Soviet waters in the 1980s failed due to low catches (Wiborg and Beck, 1983, PINRO, 2011). It appears pelagic nets do not concentrate *T. sagittatus* into the trawl path as they do with *Illex* and *Loligo* (PINRO, 2011). Most of the squid (210–470 mm ML) in catches of research hauls by a semi-pelagic commercial blue whiting trawl, were found in meshes of the wings of the trawl, and very few in the codend (Wiborg and Beck, 1983). The same situation occurred during Russian research surveys off Northwest Africa when a semi-pelagic net (vertical opening ∼30 m, horizontal opening 40–50 m, mesh size 10–34 mm) was used. Squid size in catches was mostly 120–240 mm ML, and most of the catch was stuck in the wings.

Off Northwest Africa, *T. sagittatus* was occasionally fished as an important bycatch of Russian trawl fisheries for pelagic and demersal fish (chub mackerel, horse mackerel, hake, and others) from Cap Blanc to 23°N–23°30 N. Normally catches peaked at 300–500 kg/d in June–July, though in years of high abundance some vessels could achieve 2–6 t/d and even 10–15 t/d. The best catches were obtained on the bottom between 10.00 and 17.00 hr. Because fish predominated in catches, particularly horse mackerel, commercial freezing of whole squid was often hampered by intensive skin damage. Production of canned pieces of mantle and arms turned out to be an optimum solution to the problem. In 1992, Russia recognized Moroccan jurisdiction of these waters, and the sporadic squid fishery was stopped (Nigmatullin et al., 1998). The species was also taken occasionally by the Russian fleet in Mauritania before 1983, when the country introduced a prohibition on cephalopod bycatch.

The lesser flying squid (*T. eblanae*) is mainly landed by trawlers but is also caught using gill nets and trammel nets, long lines, and jigs. The broadtail shortfin squid (I. *coindetii*) is taken by bottom and pelagic trawls, and, to a lesser extent, by gill nets, trammel nets, and hooks (Jereb et al., in press).

7.2.4. Catches

As is the case with the loliginids, reported landings of short-finned squid are often not identified to species and there are doubts as to the veracity of the landings data submitted to ICES and FAO, although national data may be more reliable. Thus, according to ICES data, total landings of these species for the European ICES area ranged between around 970 and 5600 t annually during 2000–2012 (ICES, 2012, 2013). For the same period, FAO data indicate annual landings into Europe from Area 27 ranging between 835 and 10270 t (FAO, 2014). Although both sources agree that Spain has the majority of European landings for this group, otherwise correspondence between the two datasets is poor, with the minima occurring in 2007 in the ICES data and in 2004 in the FAO data. In addition, although the FAO database distinguishes between the different ommastrephid species caught in the northeast Atlantic, it indicates that by far the largest proportion of the landings in Spain are of northern shortfin squid, in other words *I. illecebrosus*, a species which does not occur in the northeast Atlantic!

There were just two cases of a target fishery for *T. sagittatus* in periods of its high abundance. One of them was in waters off Northwest Africa in 1974 and another in 1981–1985 in Norway. In 1974, Russian trawlers took around 18,000 t around Cape Blanc (21°–23°N). Aggregations of immature squid of 140–200 mm ML (70–150 g BM) appeared in May of that year and peaked in June–July; occurring between 100 and 300 m depth. This situation was likely related to a sudden explosion of *T. sagittatus* abundance as a particular generation entered the shelf for foraging. Intensive surveys by the Russian R/V "AtlantNIRO" in 1995–1998 carried out between 18 and 32°N demonstrated that squid of this size occur mostly between 400 and 800 m, whereas waters shallower than 300 m are occupied by different ommastrephids:

I. coindetii and *T. eblanae*.

The *T. sagittatus* fishery in Norwegian and Barents seas in 1980–1985 developed gradually. From 1977, when 1683 t were taken, the squid *T. sagittatus* invaded the Norwegian coast and adjacent areas every year with increasing intensity. The introduction of the squid into the Norwegian food market was successful, and there was an increasing demand. The squid were generally large, with their size in inshore waters increasing during the fishing season from ca. 280–350 mm ML in October to 390–450 mm ML in March (Wiborg, 1978; Wiborg et al., 1982; Wiborg, 1987). In oceanic and bank waters, squid were 20–30 mm smaller (Wiborg et al., 1982). The fishery used a variety of gears, but in coastal and bank waters jigging appeared to be the best fishing method for *T. sagittatus*. The fishery was based on immature squid with females representing 92–100% of catches. The abundance of males was slightly higher in oceanic waters (sometimes up to 20–25%), and on Viking Bank at the border between the Norwegian and North Seas, they represented >80% of the total catch in March–April 1982 (Wiborg et al., 1982). The maximum catches, of 18,385 and 18,025 t, were taken in 1982–1983. Catches gradually declined with intensive interannual fluctuations until the disappearance of this species in 1986. This was followed by a short-term return of scarce commercial aggregations in 1987–1988 (total catch of 3,936 and 1,183 t, respectively).

Nowadays, the species is taken only as a valuable bycatch. In the Northeast Atlantic in recent years most catches have been reported by Spain (around 2,500 t in 1997, declining to 373 t in 2004, since then amounts have increased again slightly). The United Kingdom has also reported landings of this species, falling from 293 t in 1998 to only 6 t in 2010 (FAO, 2011). Landings of *T. sagittatus* are variable throughout the species' range and, historically, peak catches generally lasted just a few years followed by long periods of low squid abundance. During the last 60 years, reported catches varied from nil to ~20,000 t (Figure 33), mean 2,934 t for a period 1950–2009. The maximum reported catch in Norwegian waters was ~ 18,000 t in 1982–1983, and after 1988 commercial aggregations disappeared from the area (FAO, 2011).

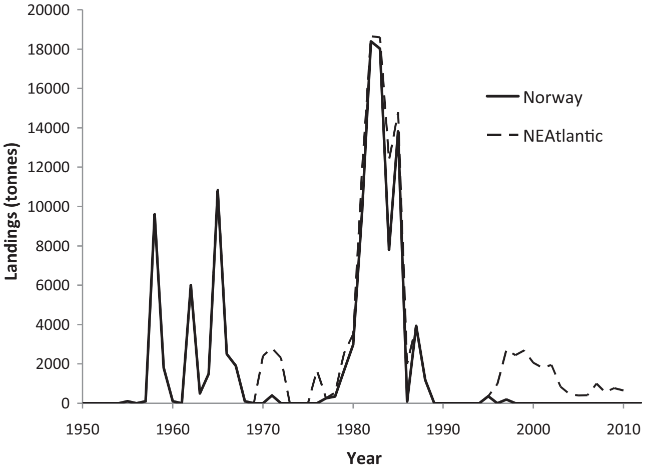

Figure 33. Landings of *Todarodes sagittatus* landings by Norway and in total for the Northeast Atlantic (adapted from FAO (2011)).

I. coindetii and *T. eblanae* are caught by the French, Spanish, and Portuguese trawling fleet as bycatch in fisheries targeting teleosts (e.g., hake, moonfish, etc.) and crustaceans (e.g., Norway lobster). Fishing occurs year round. Landings, however, only reflect retained catches and discards are unknown and can depend on the market price and the amount of target species that have been caught. In Spain, the average price of these two species from 2002 to 2012 was 1.5 €/kg, which represents a total first sale income of around 6–8 million euros per year. The Spanish bottom trawl and pair trawl fleet was composed in 2012 of around 85 industrial vessels and an unknown number of boats engaged in small-scale fishing with hooks and trammel nets.

The monthly mean percentage by weight of *I. coindetii* in ommastrephid squid landings from Spanish bottom trawlers in the last 10 years varied between 56% and 88%, as compared to 12–44% for *T. eblanae*. For pair trawlers, the relative importance of the two species was reversed: *I. coindetii* represented 11–28% of landings, and *T. eblanae* 72–89%. It seems these differences can be mainly attributed to fishing fleet behavior, although differences in species biology and oceanographic conditions may contribute.

French catches of *I. coindetii* represent around 8–10% of the total catch, mainly caught in the ICES Divisions VIII a, b, and c. Spanish catches represent 76–80% of the total catch, and Portuguese catches from ICES division IXa represent 12–14%. Within the Spanish catch, Galician ports receive around 78% of short-finned squid caught in the ICES Divisions VIIIc West and IXa North. Of these, 75% are caught by the bottom trawl fleet, 22% by pair trawl, and 3% by hooks and gillnets. For the Bay of Biscay (ICES Division VIIIc East), bottom trawling provides 49% of ommastrephid squid landings, pair trawls 37%, and 14% arise from hooks and gillnets.

Landings of *I. coindetii* in Spain show a high interannual variation, but a seasonal pattern can be observed for most years, mainly due to the seasonal trend in landings along the

Galician coast, with higher mean annual values in spring (30%) and autumn (26%), and lowest values in summer (19%). A seasonal pattern in the monthly body weight distribution of *I. coindetii* was observed in landings from the Spanish bottom trawl fleet. Larger specimens (average of 90–100 g; subadult and adult individuals) are more abundant in winter and spring than in the summer and autumn (average 50 g, new recruits and juveniles). *I. coindetii* from pair trawl landings are generally bigger than those from Spanish bottom trawl; in pair trawl landings *I. coindetii* $\geq$ 120 g represented 42% of the total number, as compared to only 24% for bottom trawl.

Although the seasonal trend in monthly body weight distribution of *T. eblanae* is not very clear in most years, the data show increases in recruitment in the period January–May (this period includes 75% of individuals with a body weight of less than 50 g).

7.2.5. Stock Assessment and Management

There is currently no stock assessment of any of the ommastrephid species in European waters and no regulation of fishing on these species. This reflects the usual issues with cephalopod stocks (as described above for the loliginids), exacerbated in the case of the ommastrephid squids by the sporadic nature of the catches and the fact that they are generally less appreciated than loliginids by consumers. In addition, the data available to carry out assessments are limited. Aside from issues with landings data already mentioned (including the unknown proportion of discards), since there is little or no directed fishing, fishing effort data for these species are not available. Lastly, they are not included among the species for which there is routine market sampling (except at regional level; as seen above good data are available for Galicia, e.g., Bruno, 2008; Bruno and Rasero, 2008; Bruno et al., 2009).

8. MEDITERRANEAN SEA

Though sometimes considered as part of the Atlantic Ocean, the Mediterranean Sea constitutes a distinct and separate entity due to its geographical, ecological, historical, social and economic peculiarities. Almost completely enclosed by land, a characteristic which determines distinct environmental parameters and events, which, in turn, affect fishery resources biology, with about 46,000 km of coastlines, the Mediterranean Sea offered the best and most suitable environment for fisheries activities to coastal populations since the colonization of Mediterranean lands.

The exploitation of marine living resources started several thousands years ago and since remote antiquity the Mediterranean Sea has been the object of studies and descriptions in which “marine activities and fishing hold a paramount place” (Margalef, 1989, in Farrugio et al., 1993). Interest in Mediterranean cephalopods is well documented since the studies of Aristotle (about 23 centuries ago) and continued in old Greek and Roman times (see Section 2 of this review). The Mediterranean Sea became a core area in cephalopod research at the beginning of the 20th century till recent years (see Boletzky, 2004 for a review), due to the Zoological Station at Naples, Italy, the Laboratoire Arago, at Banyuls-sur-Mer, France and other important institutions subsequently. Along with excellent working facilities, Neaples offered two main series of publications: the “Publications of the Zoological Station at Neaples” and the monographs of the “Fauna and Flora of the Gulf of Neaples.” Among the monographs, Giuseppe Jatta’s one on the cephalopod fauna of Neaples (Jatta, 1986), represents a milestone in cephalopods study and some of the superb illustrations by Merculiano included in that book are still used in modern publications (e.g., Orsi Relini et al., 2009). The Swiss zoologist Adolf Naef visited Neaples in the early 1900s, completed his PhD Thesis there and remained to continue Jatta’s work. Naef’s monograph (1921/23) created the basis for modern systematic studies on cephalopods and still represents the most comprehensive systematic presentation of Mediterranean cephalopods and squids.

As for Mediterranean squids biology, the monograph of Katharina Mangold-Wirz (1963), “Biologie des Cephalopodes bentiques et nectoniques de la Mer Catalane,” still constitutes a fundamental reference for main Mediterranean squid species such as *L. vulgaris*, *I. coindetii* and *T. eblanae,* but also *T. sagittatus* and *A. media*.

Squids appear depicted in several fisheries scenes in Mediterranean mosaics from the first centuries after Christ, such as those preserved in the archeological Museum of Sousse (Tunisia) (Figure 34A,B; Donati and Pasini, 1997). Also, a beautiful squid image, clearly a *Loligo*, is portrayed in an apsis mosaic illustrating the god Ocean and its main creatures (Figure 34C; Donati and Pasini, 1997), indicating that squids were considered an important component of marine coastal life.

Squids, especially *L. vulgaris*, still constitute an important component of Mediterranean populations diet, particularly in Spain, Italy, and Greece, and play an important role in the local fish markets, both for their specific value (*L. vulgaris*) and their abundance (*I. coindetii* and *T. eblanae*) (Jereb and Roper, 2010).

Although only a few targeted fisheries for these species exist in the Mediterranean, squids are fished throughout the Mediterranean basin, both by small-scale and artisanal coastal fisheries as well as by larger multi-species trawl fishing boats. Results of the detailed monitoring of major landings in southern Sicily (the Italian region contributing the highest percentage to total Italian cephalopod landings; Jereb and Agnesi 2009) in the late 1980s, indicated that cephalopods can contribute up to 37% of total estimated landings for the region, and squids (mainly *Illex* and *Todaropsis*) up to >30% of total cephalopods landings in some Sicilian ports (Andreoli et al., 1995).

Squids make up for about 1/4 of the Mediterranean recent capture production as documented by FAO database (FAO, 2011–2013). These include the long-finned squids *L. vulgaris*

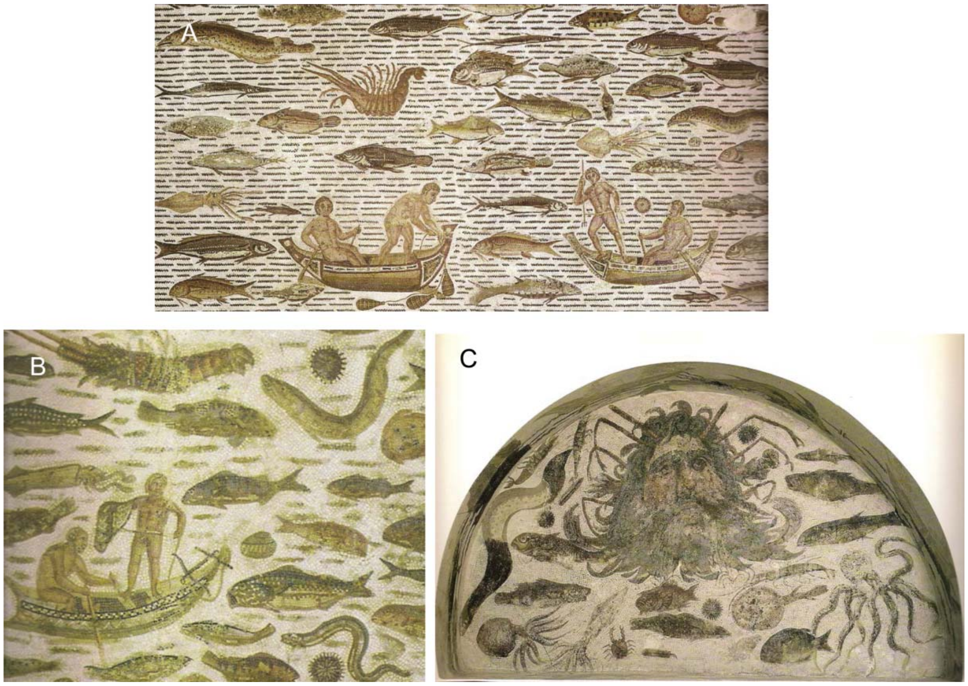

Figure 34. (A, B) Coastal fishery scenes. (C) The Ocean and its creatures Mosaic; Donati and Pasini, 1997.

and *L. forbesii*, along with *A. media* and *A. subulata,* and the ommastrephid squids *I. coindetii*, *T. eblanae*, and *T. sagittatus. O. bartramii* captures also occur, but, even though this species has been acknowledged to be more common in the Mediterranean Sea than originally thought (see Orsi Relini, 1990; Ragonese and Jereb, 1990a; Bello, 2007), it is rarely caught and seldom targeted by artisanal or sport fishers (e.g., Eolian Island, southern Tyrrhenian Sea; Potoschi and Longo, 2009).

8.1 Biological Information on Main Squid Species

8.1.1. Loligo vulgaris

The European squid *L. vulgaris* is distributed throughout the Mediterranean Sea, including the western and central Mediterranean waters, the whole Adriatic Sea, the Ionian Sea, the Aegean Sea and the Levant Basin (Jereb et al., in press). This species has also been recorded in the Sea of Marmara (Katağan et al., 1993; Ünsal et al., 1999).

It is most likely an annual species, as indicted by growth studies using statolith analysis on Mediterranean specimens (Natsukari and Komine, 1992), even though both longer (Rocha and Guerra, 1999; Arkhipkin, 1995) and shorter (Bettencourt et al., 1996; Raya et al., 1999) lifecycles have been reported from outside the Mediterranean, with a maximum age of 15 months for both sexes (Moreno et al., 2007).

In the Mediterranean Sea spawning seasons of varying length have been observed. In the western Mediterranean and the Central Adriatic Sea, the presence of mature animals all year round indicates that spawning may occur throughout the year. However, spawning concentrations from (February) March to July (August) (Mangold-Wirz, 1963; Worms, 1980), with recruitment peaks in late summer (Lloret and Lleonart, 2002) have been observed in the western Mediterranean and peaks between January and May were recorded in the Adriatic Sea (Krstulović Šifner and Vrgoč, 2004). Recent studies confirmed spawning activities all year-round with peaks in spring in the Balearic Islands (Cabanellas-Reboredo, 2014a, b).

More restricted spawning seasons were reported for the eastern Mediterranean, where data from the Thracian Sea (Lefkaditou et al., 1998) indicate a spawning concentration from February to May and additional data from Greek seas indicate a spawning season from November until April–May (Moreno et al., 2007).

Males grow larger than females, and maximum sizes up to 640 mm ML for males and 485 mm ML for females have been recorded off the West African coasts (Raya, 2001). In the Mediterranean Sea, maximum sizes of 540 mm ML for males and 340 mm for females were recorded in the Gulf of Lion (western Mediterranean; Worms, 1979), and specimens larger than 300–400 mm ML are not infrequent throughout the species distributional range.

Usually more abundant in waters shallower than 100 m, *L. vulgaris* is found from the coast to the limits of the upper slope (200–550 m) (Jereb et al., in press), the deepest record in the Mediterranean being at 545 m, in the eastern Ionian Sea (Krstulović Šifner et al., 2005). Where its distribution overlaps with that of *L. forbesii*, *L. vulgaris* tends to be found in shallower waters, the switch from dominance of one species to the other being placed at around 70–80 m (Ragonese and Jereb, 1986; Ria et al., 2005).

In the Mediterranean Sea *L. vulgaris* migrations are mainly related to sexual maturation and spawning, and thus are generally limited to on-shore/off-shore movements as mature adults reach shallow coastal waters in late winter-early spring and young individuals move back to deeper waters in fall (Mangold Wirz, 1963; Worms, 1980; Sanchez and Guerra, 1994; Valavanis et al., 2002). Vertical migrations to surface waters at night, related to feeding, also occurs. This behavior is well known and is used by commercial and recreational fishermen who concentrate on shallow water fishing grounds at night and sunset, targeting squid using line jigging (e.g., Cabanellas-Reboredo et al., 2012a).

Like most fast-growing, active swimming squids, *L. vulgaris* is an opportunistic predator, feeding mainly not only on fish, but also on crustaceans and cephalopods, with seasonal variations in diet resulting from changes in prey abundance and changes of fishing grounds. In turn, it is preyed upon by several pelagic and demersal fish, sharks, and marine mammals (Jereb et al., in press).

In the Mediterranean Sea *L. vulgaris* is mainly a bycatch of the multi-species bottom trawl fisheries, and it is landed throughout the year, along with *L. forbesii*. However, directed small-scale coastal fisheries targeting inshore spawners, using hand-jigging, beach seining, and other artisanal gears such as gill nets and trammel nets and recreational fisheries also exist (Lefkaditou and Adamidou, 1997; Lefkaditou et al., 1998; Morales-Nin et al., 2005; Adamidou, 2007; Cabanellas-Reboredo et al., 2012a, b, 2014a, b).

8.1.2. *Loligo forbesii*

The veined squid *L. forbesii* is also widely distributed throughout the Mediterranean Sea, including the western and central Mediterranean waters, the central and southern Adriatic Sea, the Ionian Sea, the Aegean Sea and the Levant Basin (Jereb et al., in press). The species has not been recorded in the Sea of Marmara.

Once relatively abundant, at least in some Mediterranean areas (i.e., the Sicilian Channel; Ragonese and Jereb, 1986), this species has undergone an abrupt decrease in its southern distributional range, including the Mediterranean, since the 1990s (Jereb et al, 1996; Chen et al., 2006). Recent studies, however, indicate that *L. forbesii* constitutes an important resource among loliginid squids of the Egyptian Mediterranean waters (off Alexandria, Riad and Werfaly, 2014), both as bycatch of artisanal trawling and as the subject of directed hand-jig fisheries.

Results from different studies on this species age and growth in the Atlantic, suggest a lifespan of about 16 months with a maximum estimate of 18 months (Rocha and Guerra, 1999), though most of the sampled individuals showed an annual lifecycle (Jereb et al., in press). Information on the biology of this species in the Mediterranean is poor, but data from the Atlantic indicate an extended spawning season, with spawning peaks variable in time, according to different geographic areas (Jereb et al., in press). Preliminary observations from the Sicilian Channel (central Mediterranean), indicated a winter spawning concentration in that area, from November-December till February–March (Ragonese and Jereb, 1986) and, possibly, a second pulse in late spring-early summer. Recent observations from the Egyptian Mediterranean indicate that spawning occurs in spring and early summer in that area (Riad and Werfaly, 2014).

In the Mediterranean Sea *L. forbesii* occurs down to depths of over 700 m (i.e., 715 m in the Ionian Sea; Lefkaditou et al., 2003a). Though records in waters shallower that 50 m do exist (e.g., Cuccu et al., 2003), major *L. forbesii* concentrations occur close to the shelf break area, between 200 and 500 m both in the eastern (Lefkaditou et al., 2003b) and the western (Quetglas et al., 2000) Mediterranean. As previously mentioned, where its distribution overlaps with that of *L. vulgaris*, *L. forbesii* tends to be found in deeper water, the switch from dominance of one species to the other being placed at around 70–80 m (Ragonese and Jereb, 1986, Ria et al., 2005). Migratory patterns have been described in the northeast Atlantic, but are still poorly understood (Jereb et al., in press).

The veined squid is a highly opportunistic predator, feeding on fish, crustaceans, cephalopods, polychaetes, and any other potential available prey, and cannibalism, also, occurs; the species is preyed upon by several pelagic and demersal fish, sharks and marine mammals (Jereb et al., in press).

In the Mediterranean Sea *L. forbesii* is mainly a bycatch of the multi-species trawl bottom fisheries and it is landed throughout the year, usually mixed with *L. vulgaris*; however it is also a target of hand-jig fisheries in some areas (e.g., Egyptian Mediterranean waters; Riad and Werfaly, 2014).

8.1.3. *Alloteuthis media* and *Alloteuthis subulata*

Alloteuthis media and *A. subulata* are widely distributed in the Mediterranean Sea (Jereb et al., in press), however, due to the still unresolved taxonomic issues related to these two species, doubts remain as to the true geographic limits and location of each of them, as well as to the true taxonomic allocation of Mediterranean specimens to either species.

Both *A. media* and *A. subulata* are considered represented in the western and central Mediterranean waters (e.g., Mangold and Boletzky, 1987; Belcari and Sartor, 1993; Jereb and Ragonese, 1994; Relini et al., 2002; Cuccu et al., 2003), in the Adriatic Sea and the eastern Ionian Sea (Krstulović Šifner et al., 2005, 2011). *Alloteuthis media* is also widely distributed in the Ionian and the Aegean Sea (Tursi and D'Onghia, 1992; Salman et al., 1997; Lefkaditou et al., 2003a, b), and it has been recorded from the western Marmara Sea (Katağan et al., 1993; Ünsal et al., 1999).

The presence of one morphometric taxa in the eastern Mediterranean, *A. media*, is supported by recent morphometric analysis (Laptikovsky et al., 2002, 2005); subsequent genetic analysis, confirming the existence of two species in the Mediterranean (Anderson et al., 2008), suggests that one species, *A.*

media, extends from the eastern to the western side of this sea, while the other, *A. subulata* is present in the Adriatic Sea; the presence of *A. subulata* in the Ionian Sea has been recently confirmed (Lefkaditou et al., 2012).

Alloteuthis media is one of the most abundant cephalopods of the shelf community throughout the Mediterranean Sea, from the western side (González and Sánchez, 2002; Massutí and Reñones 2005) through the central waters (Mannini and Volpi, 1989; Sanchez et al., 1998), the Adriatic Sea (Ungaro et al., 1999; Krstulović Šifner et al., 2005) and the Aegean Sea (Katsanevakis et al., 2008). It is found from shallow waters down to about 600 m (585 m, Aegean Sea; Lefkaditou et al., 2003b).

Little information on the biology of *Alloteuthis* species in the Mediterranean Sea is available, the most comprehensive information still being data collected in the Catalan Sea for *A. media* (Mangold-Wirz, 1963). Lifecycle is probably 1 year (e.g., Mangold-Wirz, 1963; Auteri et al., 1987; Rodhouse et al., 1988) even though a slightly shorter lifespan has been estimated by direct ageing for *A. media* in the Aegean Sea (Alidromiti et al., 2009) and as short as six months for *A. subulata* off the African coast (Arkhipkin and Nekludova, 1993).

According to observations on *A. media* in the Gulf of Naples (Lo Bianco, 1909; Naef, 1921/1923) and more recent information from the eastern Mediterranean (Laptikhovsky et al., 2002), spawning occurs year round, even though a more restricted spawning season (March-October) has been reported from the Catalan Sea (western Mediterranean; Mangold-Wirz, 1963).

Both *Alloteuthis* species are caught as bycatch in bottom trawl and beach-seine fisheries and, even though these species are discarded in some areas (e.g., Machias et al., 2001), they are considered of variable commercial interest in others (Ragonese and Jereb, 1990b; Sartor et al., 1998) and are landed and marketed in Spain and Italy. In southern Sicily, they are marketed under the commercial category "calamaretti."

8.1.4. *Illex coindetii*

The broadtail shortfin squid *I. coindetii* occurs throughout the Mediterranean Sea, including the western and central Mediterranean waters, the whole Adriatic Sea, the Ionian Sea, the Aegean Sea, and the Levant Basin (Jereb et al., in press). The species has been recorded in the Sea of Marmara (Katağan et al., 1993; Ünsal et al., 1999).

In the Mediterranean Sea the lifecycle is most likely annual (i.e., 14–16 months, Sicilian Channel; Jereb and Ragonese, 1995; 10–15 months, Greek Sea; Arvanitidis et al., 2002; 13–14 months, north Aegean Sea; Lefkaditou, 2007; 12–15 months, Ligurian Sea; Cavanna et al., 2008) even though shorter and longer lifespans have been estimated by using different age techniques and by geographic areas. A lifecycle as short as 6–7 months (Sicilian Channel; Arkhipkin et al., 2000) and as long as 18 months (western Mediterranean; Sanchez et al., 1998) has been estimated by statoliths reading, while modal progression analysis resulted in a lifespan between 17 and 18 months (Sanchez, 1984) and 2 years (Mangold-Wirz, 1963) in the Catalan Sea.

The broadtail shortfin squid is a medium-sized squid, commonly reaching 200–250 mm ML throughout its distributional range (see Jereb et al., in press). Females are larger than males. Very large specimens up to 300 mm ML have also been recorded in the Mediterranean Sea (Ceriola et al., 2006; Profeta et al., 2008; Perdichizzi et al., 2011); these represent extremes in the population and it has been hypothesized that they are late-hatching members of the previous year class or individuals that do not reach maturity and continue to grow (see Jereb et al., in press).

Spawning occurs year-round for this species in most of its distributional range (Sanchez et al., 1998; Arkhipkin et al., 2000; Arvanitidis et al., 2002; Ceriola et al., 2006), however, spawning peaks have been observed throughout the Mediterranean, such as in spring and summer in several Italian seas (Maragliano and Spedicato, 1993; Soro and Paolini, 1994; Jereb and Ragonese, 1995; Gentiloni et al., 2001; Ceriola et al., 2006).

In the Mediterranean Sea *I. coindetii* has been recorded from surface waters to over 700 m (i.e., 776 m, South Aegean Sea; Lefkaditou et al., 2003), with highest densities found between 100–200 and 400–600 m (e.g., Tursi and D'Onghia, 1992; Jereb and Ragonese, 1995; Salman et al., 1997). It lives close to muddy, sandy, and debris-rich bottoms and it is often associated with decapod crustacean such as the deep-water rose shrimp (*Parapenaeus longirostris*) and the European hake (*Merluccius merluccius*) (Jereb and Ragonese, 1991), the lesser flying squid (*T. eblanae*) (e.g., Mangold-Wirz, 1963; Lumare, 1970; Gentiloni et al., 2001; Ciavaglia and Manfredi, 2009), the horned octopus (*E. cirrhosa*) and the midsize squid (*A. media*) (Krstulović Šifner et al., 2005, 2011).

Juveniles and adults share the same depth ranges in some Mediterranean areas (Sanchez et al., 1998; Ceriola et al., 2006), though juveniles/small specimens show a major concentration in waters shallower than 200 m. Adults undergo vertical migrations from the bottom to the upper layers at night and seasonal migrations have been observed in the western and central Mediterranean waters (Mangold-Wirz, 1963; Soro and Paolini, 1994; Sanchez et al., 1998; Gentiloni et al., 2001) with the bulk of the population approaching shallow waters (70–150 m) in spring, to spread again over a wider bathymetric range in autumn.

In the Mediterranean Sea *I. coindetii* is taken throughout the year as bycatch in bottom and pelagic trawls, and, to a lesser extent, with gill and trammel nets, at depths between 100 and 400 m.

8.1.5. *Todaropsis eblanae*

The lesser flying squid *T. eblanae* is widely distributed throughout the Mediterranean Sea, including the western and central Mediterranean waters, the whole Adriatic Sea, the Ionian Sea, the Aegean Sea and the Levant Basin (Jereb et al., in press). The species has been recorded in the Sea of Marmara (Katağan et al., 1993; Ünsal et al., 1999).

The information on the biology of this species in the Mediterranean is limited to the Catalan Sea (Mangold-Wirz, 1963) and to few other studies in Italian waters (e.g., Belcari et al., 1999; Lelli et al., 2005; Cavanna et al., 2008). In the Mediterranean Sea, the lifecycle is most likely annual, as a recent direct ageing study evidenced (12 months; Ligurian Sea, Cavanna et al., 2008), even though a lifespan up to 2 years has been estimated by indirect age observations on the species in the Catalan Sea (Mangold-Wirz, 1963).

Todaropsis eblanae is a medium-sized squid. In the Mediterranean Sea maximum ML was 210 and 200 mm for females and males from the Sicilian Channel (central Mediterranean waters; Ragonese and Jereb, 1990). The spawning season probably extends year-round, mature females having been found from March through November in the Catalan Sea (Mangold-Wirz, 1963).

This squid inhabits mainly the lower sublittoral and upper bathyal throughout the Mediterranean waters (Mangold-Wirz, 1963; Ragonese and Jereb, 1990; Belcari and Sartor, 1993; Salman et al., 1997; Giordano and Carbonara, 1999; Quetglas et al., 2000; Gonzales and Sanchez, 2002; Cuccu et al., 2003; Lefkaditou et al., 2003a, b; Krstulović Šifner et al., 2005). Deepest records occurred in the northeastern Ionian Sea (848 m; Lefkaditou et al., 2003a), but the species is particularly abundant between 200 and 500 m (e.g., Belcari and Sartor, 1993; Krstulović Šifner et al., 2005) and in highly productive areas such as the shelf-break (100–200 m; Colloca et al., 2004).

In the Mediterranean Sea *T. eblanae* is taken throughout the year as bycatch in bottom and pelagic trawls, and, to a lesser extent, with gill and trammel nets, in depths between 100–200 and 600–800 m.

8.1.6. *Todarodes sagittatus*

The European flying squid *T. sagittatus* occurs throughout the Mediterranean Sea, including the western and central Mediterranean waters, the whole Adriatic Sea, the Ionian Sea, the Aegean Sea and the Levant Basin (Jereb et al., in press). Old references to the presence of the species in the Sea of Marmara exist (Demir, 1952, in Ünsal et al., 1999); however, the species has not been recorded by recent investigations in those waters (Katağan et al., 1993; Ünsal et al., 1999).

The biological information on this species in the Mediterranean Sea is mainly restricted to the western Mediterranean (Morales, 1958; Mangold-Wirz, 1963; Quetglas et al., 1988, 1999; Cuccu et al., 2005). The European flying squid is a typical strong, muscular ommastrephid, with common sizes ranging between 350 and 400 mm for females and 200 and 250 mm for males. Very large animals have been reported from the Mediterranean, a female of 600 mm ML and males of over 380 mm ML (south Sardinia; Cuccu et al., 2005), while a maximum ML of 418 mm is reported for a female from the Balearic Islands (Quetglas et al., 1998).

Most individuals probably live for 12–14 months, even though the lifespan of the largest individuals may approach 2 years. Spawning likely takes place on the continental slope, as suggested by Clarke for *Todarodes* species (Clarke, 1966). According to the presence of mature females and males year-round (Quetglas et al., 1998), spawning probably occurs throughout the year, even though different seasonal spawning concentrations may occur, depending on the geographic area; a major spawning season occurs in autumn-winter in the western Mediterranean (i.e., between September and November–December in the Catalan Sea and the Balearic Islands, Mangold-Wirz, 1963; Quetglas et al., 1998).

The European flying squid inhabits the water column in the open ocean as well as near the coast, and has been found from shallow waters down to 800 m throughout the Mediterranean (e.g., Jereb and Ragonese, 1990; Tursi and D'Onghia, 1992; Belcari and Sartor, 1993; Salman et al., 1997; Casali et al., 1998; Giordano and Carbonara, 1999; Quetglas et al., 2000; Gonzalez and Sanchez, 2002; Cuccu et al., 2003; Lefkaditou et al., 2003a, b; Krstulović Šifner et al., 2005). It is known to migrate between the surface at night and near bottom waters during the day and more important migrations toward deeper waters in winter may occur, according to the higher captures observed in summer in some areas of its distribution (i.e., Ionian Sea; Lefkaditou et al., 2003a; southern Tyrrhenian Sea; Potoski and Longo, 2009).

As mentioned above, artisanal hand-jigging fisheries occur in some areas of the Mediterranean Sea (e.g., southern Tyrrhenian Sea; Potoski and Longo, 2009; Battaglia et al., 2010), and the species is also taken as a bycatch in trawl fisheries. *Todarodes sagittatus* is reported as a separate category in FAO statistics; however, no data are recorded at present from Mediterranean countries.

8.2 Fisheries

The variety of squid species, the absence of large, monospecific "stocks" comparable to those inhabiting other wide areas of open oceans, the variety of small-scale fisheries operating along the coastlines and the need to coordinate 23 countries bordering its body of waters (each with its own legal approach toward marine resources management within national waters) make for the unusual circumstances of the Mediterranean fisheries (Caddy, 1993; Farrugio et al., 1993). In particular, fishing activities exhibit great variation from one area to the other, differences being related not only to geographical and ecological constraints, but to the social, economic and historical context of neighboring countries.

Cephalopod fisheries in European waters have been extensively reviewed by Lefkaditou et al., 2010. Statistical information reported therein has been updated for the Mediterranean, using FAO's database and FishstatJ (2.0.0) software (FAO, 2011–2013).

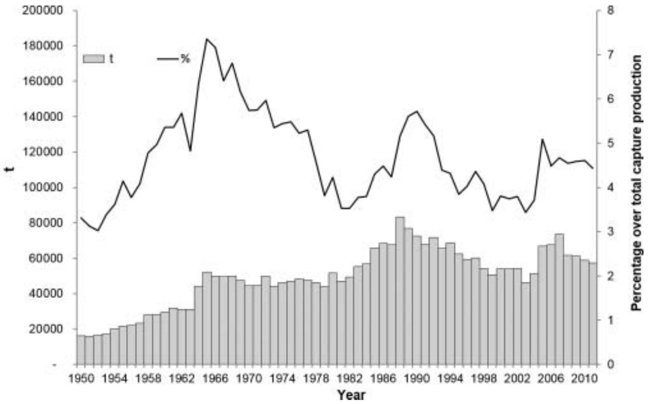

Figure 35. Total cephalopods capture production in the Mediterranean Sea and proportion over the total Mediterranean capture production (1950–2011). Bars = capture production; line = proportion over the total.

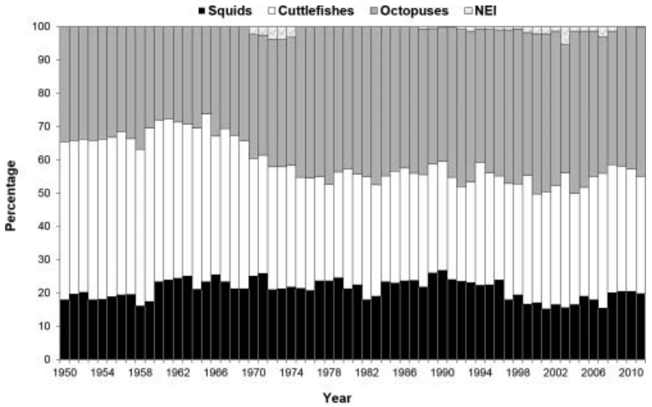

Figure 36. Percentage of squids, cuttlefishes and octopuses over the total cephalopods capture production in the Mediterranean Sea (1950–2011). NEI = not elsewhere indicated.

8.2.1 Landings

Cephalopod landings data in the Mediterranean are gathered and grouped according to the following main commercial categories:

Cuttlefishes: not only *Sepia officinalis*, but also *S. elegans* and *S. orbignyana*
Octopods: mainly *Octopus vulgaris, Eledone cirrhosa*, and *E. moschata*
Long-finned squid: mainly *Loligo vulgaris* and *L. forbesii*, but also *Alloteuthis media* and *A. subulata* species
Short finned squid: *Illex coindetii*, *Todaropsis eblanae*, and *Todarodes sagittatus*

Total fisheries capture production in the Mediterranean increased from about 500,000 t in 1950 to about 1.6 million t at the end of 1980s, fluctuating around 1.4 million t since then. Cephalopod contribution to the total Mediterranean fisheries capture production reached 7% in the middle sixties but oscillated around 4.5% throughout the time range observed (Figure 35); octopuses and cuttlefishes dominate the landings (Figure 36), and the overall trend showed a slight but constant increase since 1950 (Pearson's coefficient, $p < 0.05$ for cuttlefishes, $p < 0.01$ for octopuses).

Total squid capture production increased for about 20 years, from 1950 to the end of the sixties and remained quite stable since then, with a peak at the end of the eighties and the minimum reached at the beginning of 2000 (Figure 37). Squids contribution to total cephalopod capture production oscillates around 25%. Italy, Spain, Greece, Libya, and Turkey are the main producers (Figure 38), with recorded landings of 4971, 2629, 1551, 470, and 394 t, respectively, in 2011.

Most of the squid fisheries capture production (52–100%, 1950–2011) in the Mediterranean Sea is reported as unclassified. The remaining part is dominated by short-finned squids with a peak at the end of the eighties-beginning of the nineties and a strong reduction from 2000 onward (Figure 39). Long-finned squids capture production was first recorded as a separate category during the mid-seventies and peaked at the end of the time period considered (2011; Figure 39). However, it is not clear if this increase is related to an effective increase in capture production or to a more accurate reporting for the species.

According to a recent practical working approach by the FAO General Fisheries Commission for the Mediterranean, this body of water is divided into three main areas: western Mediterranean (Algeria, France, Morocco, and Spain), central Mediterranean (Albania, Croatia, Italy, Libya, Malta, Montenegro—before 2008 reported as Serbia and Montenegro—and Tunisia) and eastern Mediterranean (Cyprus, Egypt, Gaza Strip, and West Bank [Palestina], Greece, Israel, Lebanon, and Syria) (GFCM, 2007).

Most of the squids capture production is recorded in the central Mediterranean with a maximum (about 13,500 t) at the end of the eighties and minimum at the beginning of 2000 (about 4,000 t) (Figure 40).

8.2.2. Fishing Fleets

According to Lleonart et al. (1998) and as adopted in Sacchi (2011), Mediterranean fishing fleets can be broken down

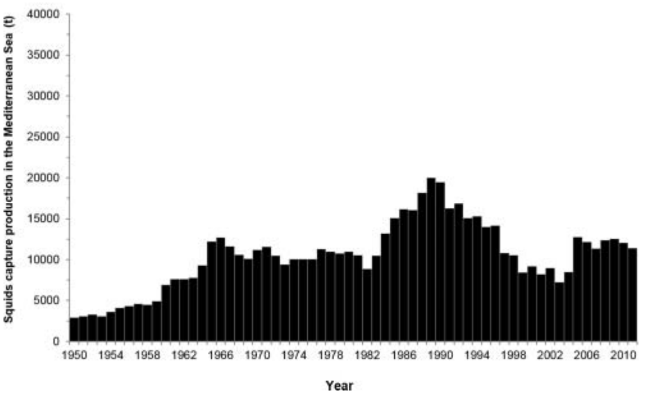

Figure 37. Squids capture production in the Mediterranean Sea (1950–2011).

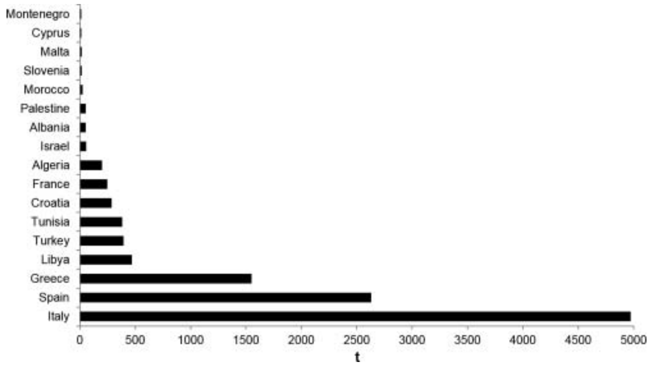

Figure 38. Reported squids capture production of Mediterranean countries in 2011.

into three main categories: industrial, semi-industrial, and small-scale artisanal fishing (Sacchi, 2011).

Industrial fleets, often described as ocean-going or long-distance fishing fleets, go out for several days at a time and use large vessels, generally over 500 GRT, to transport the catch and accommodate the crew (Folsom et al., 1993). They target large catches of certain species (such as tunas, sardines, anchovies, large gadidae, squids, or prawns) for the international fresh or frozen markets and especially for processing. This implies large investments, both in fishing vessels and gear (ship-owners) and processing (factories and fattening units), and it is only possible for industrial or financial groups.

Semi-industrial fleets. Also driven by domestic or international market demand, the management of these vessels is mainly artisanal, with the captain being also the owner of the vessel and fishing gears. The relationship with markets is either via auctions or contracts with fishing associations (such as cooperatives, producer bodies and Spanish "*cofradias*"). Like industrial fleets, they specialize and use fishing gear suitable for large catches. In the Mediterranean, this category mainly comprises trawlers, sardine seiners and vessels using equipment such as mechanical drag nets, certain long-lines and trammel nets. They generally land their catches daily or on 2–3 days basis and mainly operate on the continental shelf and around the continental slope.

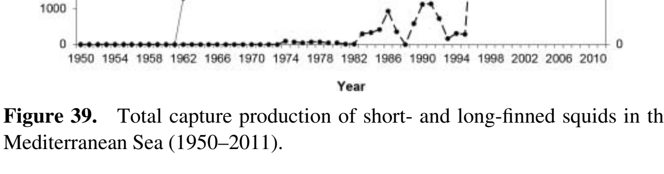

Figure 39. Total capture production of short- and long-finned squids in the Mediterranean Sea (1950–2011).

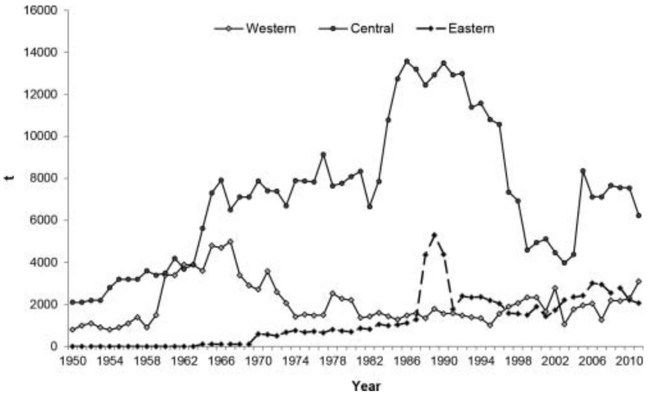

Figure 40. Squids capture production in the western (Algeria, France, Morocco, and Spain), central (Albania, Croatia, Italy, Libya, Malta, and Montenegro—before 2008 reported as Serbia and Montenegro and Tunisia) and eastern (Cyprus, Egypt, Gaza Strip, and West Bank [Palestine], Greece, Israel, Lebanon, and Syria) Mediterranean Sea (1950–2011).

Small-scale artisanal fishing fleets. These fleets mostly target local markets with varied products, mainly sold directly to consumers. However, some of them may contribute significantly to the export market. They generally operate in lagoons and in the coastal areas of the continental shelf. They mainly use low-tonnage boats with small or no engines, usually no more than 12 m long and comprise small-scale fisheries, made up of vessels that require low levels of investment. Boat length is not an absolute criterion and in certain countries polyvalent (i.e., multi-purpose) vessels longer than 12 m and specializing in longline and gillnet fishing can be considered as practising artisanal fishing. Artisanal fleets use a wide variety of fishing techniques (45 types of fishing gear have been identified in the Mediterranean), catching around a hundred different demersal species and a smaller proportion of medium-sized pelagic species. They employ a variable number of fishermen, depending on the practices of the various geographical areas, generally with one or two registered fishermen per vessel and one or two "seasonal" hands.

It is important to stress that, while "small-scale" and "artisanal" fisheries clearly differ from industrial and recreational fisheries, and even though in the preface of the draft "Voluntary Guidelines for Securing Sustainable Small-scale Fisheries in the Context of Food Security and Poverty Eradication," (FAO, 2012) it is acknowledged that the terms "small-scale fisheries" and "artisanal fisheries" are considered to relate to the same fraction and can be used interchangeably, from a technological point of view these two terms imply somewhat dissimilar concepts, relating to the size of the fishing unit (i.e., the scale) as well as to the relative level of technology (or "artisanality") expressed as capital investment/men-on-board (Farrugio, 2013).

8.2.3. Fishing Methods

Generally, all squids species are caught as bycatch of the several scale-differing trawl fisheries operating throughout the Mediterranean Sea and trawling is responsible for the main landings of these cephalopods; however, other fishing systems are also used and some species are geographically and seasonally targeted.

This is the case, for example, of *T. sagittatus*, which is the object of recreational and artisanal fisheries in southern Italy. According to a recent study carried out in the Aeolian Island (southern Tyrrhenian Sea, northeast Sicily; Battaglia et al., 2010), the artisanal fishery use the typical Aeolian hand-jig line (called "totanara," after the Italian name given to ommastrephid squid, "totano"), consisting of a crown of hooks mounted on a stainless steel cylinder, baited at its central part and empowered by the addition of a small blinking light. Larger cylinders baited but devoid of hooks are positioned near the bottom, at 400–600 m depth, to attract squid. These are then hauled to a depth of about 120 m and fishermen commence fishing with hand-jig lines. Boats are between 5.40 and 9.80 m long and engine power varies between 6.6 and 133 kW. According to the analysis of Battaglia et al. (2010), the average income per fisherman in summer may be among the highest registered for the local small-scale fisheries (comparing trammel nets, squid hand-jig line, and albacore drifting longlines).

Hand-jigs of various types named "calamarieres" in Greek, "palhacinhos" or "toneiras" in Portuguese, and "poteras" in Spanish are used by artisanal and sport-fishery vessels to catch *L. vulgaris* and *O. bartramii* (e.g., Lefkaditou et al., 2010; Battaglia et al., 2010). Typical jigs are usually lead cylinders, bearing crowns of metal hooks at one end and a metal ring on the other end, to which the fishing line is tied. Fishermen hold the fishing line, giving rhythmic movement to the gear (i.e., "jigging"). Jig fishing is carried out mostly before sunset or at night using some kind of light attraction (Ragonese and Bianchini, 1990; Potoschi and Longo, 2009; Lefkaditou et al., 2010).

Boat-seines with bags are used along the Spanish and Greek coasts, where they target *L. vulgaris* when the species concentrates in coastal fishing grounds (Lefkaditou et al., 2010). The "boliche" or "chinchorro" used in Spain has two wings, each 75 m long, and the cod-end is 10 m long with a mesh size of 18–60 mm (the minimum legal mesh size is 17 mm). *Loligo vulgaris* appears to be the most important catch of this fishery (e.g., 45.5% of catches during the years 1999–2003; Lefkaditou et al., 2010).

The "pezotrata" or "vintzotrata" used in Greece consists of a main body (or "shoulder"), two relatively long wings, the bag, and the cod-end (Katsanevakis et al., 2008; Lefkaditou et al., 2010). The total length of the net in Greek boat seines is usually between 200 and 450 m. The wings constitute the longest part of the net, having a length of 140–400 m and a stretched mesh size of 350–600 mm. The bag, which is the central part of the net, is 13–40 m long with a stretched mesh size of 20–28 mm. The rearmost part of the bag is the cod-end, which has a length of 1–7 m; the netting of the cod-end usually has a stretched mesh size between 16 and 20 mm (Adamidou, 2007). This métier is registered separately in Greek fisheries statistics and yields 25–30% of the total national catches of *L. vulgaris* (Lefkaditou et al., 2010).

Beach-seines and trammel nets are also used to fish *L. vulgaris* and *I. coindetii* (e.g., Guerra et al., 1994; Lefkaditou, et al. 1998; Colloca et al., 2004).

In the western Mediterranean an inshore recreational fishery for *L. vulgaris* occurs in the southern waters of Mallorca (Balearic Islands), as part of the recreational fishery which is one of the island's main leisure activities (Morales-Nin et al., 2005; Cabanellas-Reboredo, et al., 2012a, b). It is a seasonal activity, as local fishers concentrate on squid when they enter shallow waters for reproduction, and hand-line jigging with artificial lures are used (Cabanellas-Reboredo, 2012a). Local fishing activity is restricted to a shallow depth range (25–30 m) and fishing operations occur primarily at sunset, when squid become more active for feeding (Cabanellas-Reboredo, 2012a, b, 2014a).

8.3. Stock Assessment and Management

According to the peculiarities mentioned above, biologist and decision makers face numerous difficulties in their efforts to study and manage the Mediterranean fisheries (e.g., Caddy, 1993; Farrugio et al., 1993; Papaconstantinou and Farrugio, 2000; Scovazzi, 2011).

As for most Mediterranean cephalopods, squids stocks are not assessed. In the Mediterranean, fisheries management measures indirectly affect squids capture production as they involve the various fisheries exploiting them; thus, measures adopted at national level for bottom trawlers, such as capacity control, limitation of fishing days and restricted areas, indirectly affects the capture of squid.

In particular, management measures aimed at protecting nursery areas and improving selectivity for bottom trawling indirectly affect cephalopods fisheries; for example, prohibition of trawling within 3 NM off the coastline, at depths shallower than 50 m and on *Posidonia* beds (nursery areas for many species including cephalopods) indirectly protects cephalopod juveniles; also, the adoption of diamond 50 mm stretched or 40 mm squared mesh size in the cod-end instead of the traditional diamond 40 mm stretched enhances selectivity for octopuses and juvenile squids.

The general rules established by United Nations Convention on the Law of the Sea (UNCLOS; Montego Bay, 1982) on marine spaces division and attributes apply also in semienclosed seas, such as the Mediterranean Sea. However, in the case of this body of water, the presence of 23 bordering States creates a particularly complex situation (Scovazzi, 2011). While most coastal Mediterranean States established a 12-mile territorial sea, not all of them have established an EEZ. However, others have proclaimed fishing zones or ecological protection or both, beyond the territorial sea. Although some high seas zones still exist in the Mediterranean Sea, the area is already fractioned into several subareas under different control regimes, some of which by law implement measures not applicable in the Mediterranean Sea (i.e., quotas catch systems).

As for the high seas, the UNCLOS fisheries regime is based on an obligation to cooperate for the conservation and management of living resources, which is not devoid of legal meaning and, in principle, should favor the conclusion of agreements for the conservation of common resources to the benefit of all (Scovazzi, 2011). In practice, however, problems such as unregulated fishing, vessel reflagging to escape control, insufficiently selective gear, unreliable databases, excessive fleet size, and lack of sufficient cooperation between States frustrate and neutralize efforts toward conservation and management goals in the Mediterranean.

However, two important commissions have been established with relevance to Mediterranean fisheries management: the FAO General Fisheries Commission (formerly Council) for the Mediterranean (GFCM; 2007, amended to its actual status) and the International Commission for the Conservation of the Atlantic Tunas (ICCAT; 1996) in the Atlantic Ocean and the Mediterranean Sea. In addition, a network of FAO Projects has also been established to promote cooperation and capacity development of fisheries in the Mediterranean.

GFCM counts 24 members at present (including Japan and the European Union (EU)) and covers the high seas and marine areas under national jurisdiction, with the purpose of promoting the development, conservation, rational management, and best utilization of all marine living resources.

FAO fisheries related Projects (i.e., AdriaMed, CopeMed, EastMed, and MedSudMed) contribute to this goal by providing member countries with the necessary tools to meet national and international requirements. GFCM "adopts" ICCAT decisions related to tuna fishing and quotas on tuna fish.

Last but not least, an important role in the Mediterranean fisheries is played by the European Union (EU), through its eight Mediterranean coastal member countries (Croatia, Cyprus, France, Greece, Italy, Malta, Slovenia, and Spain).

Due to the multi-form and complex status of present maritime zones within the Mediterranean, which reflects on the fisheries, it is to be hoped that future jointly agreed fisheries management approaches will be developed by the GFCM, and that the EU fishery policy will devote more attention to the peculiarities of Mediterranean fisheries communities.

8.4. Concluding Remarks

With a production reaching about 11,000 t in 2011, Mediterranean squids landings undoubtedly contribute only a small proportion of the world squids production, estimated at over 2 and a half million t for the same year (2,564,978 t; FAO, 2011–2013).

Their contribution to the European squids fisheries by means of the coastal Mediterranean members has also decreased conspicuously in the last years, after an important peak in the mid-1960s (Figure 41). However, squids are an important resource for the Mediterranean communities and economy. Average prices for Mediterranean *Loligo* still are the highest with respect to other areas production, averaging more than twice the values of *Loligo* from other areas (i.e., 15–20 € × kg, compared to 6–8 € × kg, respectively; So.Ge. Mi. SpA, 2013).

Figure 41. Squids capture production: percentage of Mediterranean European countries (Croatia, Cyprus, France, Greece, Italy, Malta, Slovenia, and Spain) over the total European countries (1950–2010).

Also, traditionally, local demand for regional, high-quality products obtained from the artisanal fisheries still exists in some Mediterranean areas, and prices of *L. vulgaris* caught by trammel nets, for example, are double those for trawl caught squids (Guerra et al., 1994), due to the higher quality of the former. The role of squids in the economy and social structure of local communities involved in the small-scale artisanal fisheries may have been underestimated, as future investigations and studies on these fisheries are likely to prove.

9. SOUTHEAST ATLANTIC

A number of squid species are found in the Southeast Atlantic; however, few are of any commercial importance. An exception is *Loligo reynaudii*, targeted by hand jigging in South Africa as a major commercial fishery, and caught with homemade jigs in southern Angola by artisanal fishers. *Todarodes angolensis* is broadly distributed around the southern part of Africa, and is especially common and abundant in Namibian waters. Caught as a bycatch by commercial trawlers, it has in the past been sold as bait but presently is discarded as far as we are aware. *Todaropsis eblanae* is another widely distributed species present in the Eastern Atlantic, but differing genetically from other areas of distribution and is considered to be a separate population. The lifecycle of the southern African population has not been studied in any detail and is imperfectly known. In southern African waters, this species is a bycatch in the demersal trawl fishery.

9.1. Loligo reynaudii (Cape Hope Squid)

9.1.1. Distribution and Life History

The Cape Hope squid *L. reynaudii*, locally known as chokka, is distributed from Southern Angola on the west coast of southern Africa, to the Great Fish River on the east coast of South Africa (Shaw et al., 2010). Interestingly, *L. reynaudii* is rarely found on the shelf off Namibia, which lies between Southern Angola and the west coast of South Africa. This is a neritic loliginid species and is seldom found deeper than 200 m. In South African waters, although distributed along the majority of the coastline, two-thirds of the adult biomass is concentrated on the south east coast (Augustyn, 1989, 1991; Augustyn et al., 1993).

Size at maturity within this species is highly variable, particularly for males, depending on not only location but also the time of year (Augustyn et al., 1992). Males can be mature at 90 mm ML or immature at 250 mm ML. Females generally mature between the sizes of 100–180 mm ML (Augustyn et al., 1992). *L. reynaudii* spawn inshore in both protected bays and open, exposed parts of the south east coast of South Africa (Augustyn, 1989, 1990; Sauer et al., 1992). Depending on the substrate (open sand vs. rocky reef with small patches of sand), egg beds comprise of a few egg strands to large beds up to 4 m in diameter (Sauer et al., 1992). Eggs recovered from demersal research trawls (Roberts and Sauer, 1994; Roberts et al., 2012) and hydroacoustic traces of mushroom shaped spawning aggregations offshore (Roberts et al., 2002) indicate this species also spawns in the deeper colder waters between 70 and 130 m (Roberts et al., 2012). Inshore spawning peaks during the summer months (November-January) (Augustyn, 1989). In some years, a second peak in spawning occurs during the winter (Olyott et al., 2006). The environment appears to play a role in the formation of spawning aggregations (Roberts, 1998) with the initial formation of spawning aggregations possibly being triggered by upwelling (Sauer et al., 1991; Roberts, 1998; Schön, 2000; Downey et al., 2010). *L. reynaudii* are serial spawners (Sauer and Lipinski, 1990; Melo and Sauer, 2007), and as a result mortality is sporadic over a prolonged period.

The most important prey for *L. reynaudii* paralarvae is the copepod *Calanus agulhensis* (Venter et al., 1999; Roberts, 2005). On the spawning grounds, adults feed mainly at night with teleosts dominating the prey items (Lipinski, 1987). During the day, cannibalism is prominent (Lipinski, 1987). Lipinski (1992) investigated the impact of predation by *L. reynaudii* on commercial fish species. The results indicated that there may be an impact on anchovy (*Engraulis capensis*) and hake (*Merluccius capensis*) of 100,000 and 70,000 t/y respectively, but further study is needed.

9.1.2. Stock Identification

In South African waters, the population characteristics of *L. reynaudii* from the western part of its distribution differ from those of the population in the east (Augustyn, 1989). Generally, when compared to squid occurring in the east, squid from the west are slower growing, mature at a larger size, the size distribution is narrower and gonadal development is not as far advanced (Augustyn, 1989; Olyott et al., 2007). Although as yet inconclusive, results of a study by Olyott et al. (2006) suggest there may indeed be two separate stocks in South African waters. Recent genetic evidence (Shaw et al., 2010) further strengthens this hypothesis.

9.1.3. Catches and Effort

The small commercial jig fishery (6000–13,000 t caught annually) occurs mainly on the south Eastern Cape coast of South Africa. Fishermen target squid on inshore spawning aggregations, as well as using drogue anchors and strong lights to attract the squid during offshore drift fishing. In South African waters, squid are also caught as bycatch of a hake directed demersal trawl fishery (Figure 42). Initially, chokka squid was caught as bycatch of the trawl industry operating in South African waters. This species was considered a bait species and bycatch was sold as such. Between 1974 and 1985, both the South African and foreign trawl fleet were catching between ~1,800 and ~3,800 t per annum (Roel et al., 2000).

Squid targeted trawling is not possible in South African waters due to a ban on trawling within bays, introduced in 1987 (Augustyn and Roel, 1998). As a result, only 200–500 t are caught (as bycatch) annually, by the demersal trawl fisheries. Commercial jig catches vary considerably from year to year, as can be seen in Figure 43. The lowest annual catch of under 2,000 t was recorded in 1992, and the highest annual catch, over 13,000 t, was landed in 2004. Annual catches appear to have stabilized at around 9,000 t in recent years, however preliminary catch data for 2013 indicates another period of very low catches. Nominal CPUE, measured in kg per man per day, ranged from ~16 to ~38 kg/man/d during the period 1995–2008.

9.1.4. Fishing Methods and Fleet

In Southern Angola, an artisanal hand-line jig fishery occurs close to shore (Sauer et al., 2013). Fisherman use floats washed ashore to make rafts from which they operate the hand-lines (Sauer et al., 2013) (Figure 44). In South African waters, only in 1985 did a coastal jig fishery begin to develop (Augustyn et al., 1992), starting with squid being targeted by hand-line from ski-boats. The jig fishery expanded rapidly and by 1986 the squid fishing fleet comprised 17 mother vessels with freezing capacity, 95 deck boats (10–15 m) and 40 ski-boats (M. J. Roberts unpublished data). In 1987, trawling within bays along the South African coast was banned, preventing the targeting of spawning squid by trawlers (Augustyn and Roel, 1998). Although not yet used to target squid spawning concentrations, purse-seining was also banned as it was considered too destructive on the spawning habitat (Augustyn and Roel, 1998). From 1988 ski-boats in the squid fishing fleet began to be upgraded to larger vessels with on-board freezing capacity (M.J Roberts, unpublished data). This enabled vessels to remain at sea for more than a week at a time. By 1998, the number of small ski-boats within the fleet had been reduced from 128 to only 39 (M. J. Roberts unpublished data). The

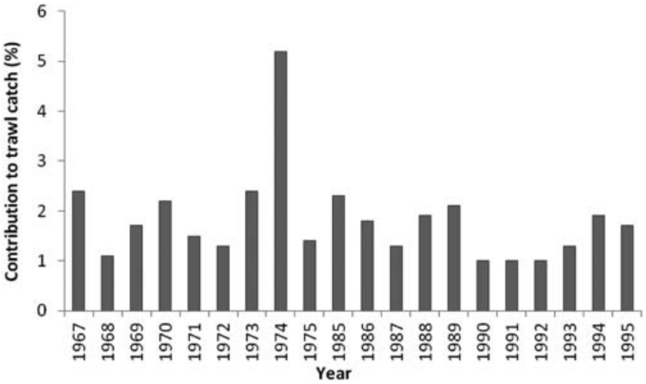

Figure 42. The contribution of *Loligo reynaudii* to the Eastern Cape demersal inshore trawl catch between 1967 and 1995, South Africa (from Booth and Hecht, 1998).

current fleet is comprised of large-decked vessels with freezing facilities (Sauer, 1995) (Figure 44).

9.1.5. *Duration of Fishing Period*

The jig fishery operates throughout the year, except for a 5 week period during the peak spawning season when a closed season is imposed.

9.1.6. *Stock Assessment*

The first formal stock assessment conducted on the *L. reynaudii* fishery in South Africa was in 1998 and indicated the resource was at risk of collapsing (Roel, 1998). Although a 33% reduction in the then effort levels (3.6 million man-hours) was advised, due to employment reasons, only a 10% reduction in effort levels was implemented (Roel, 1998). Recent stock assessment results indicate the *L. reynaudii* resource is in a healthy condition as a result of above average recruitment in successive years (Sauer et al., 2013). Currently, effort levels are capped at 136 vessels and 2422 crew (Sauer et al., 2013). In addition, effort is further reduced by an annual 5-week closed season during the peak spawning period (October-November), and a ban on fishing in the Tsitsikamma National Park area on the south coast.

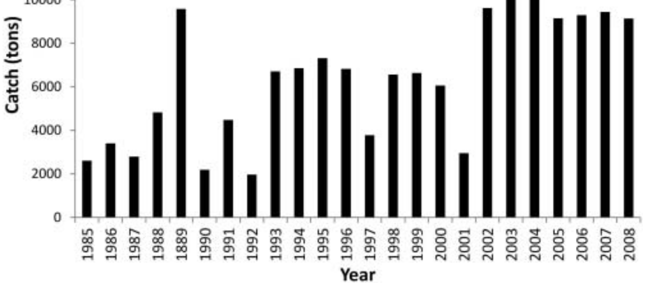

Figure 43. Commercial jig catches (tons) of *Loligo reynaudii* in South Africa from 1985–2008.

9.1.7. *Economic Importance*

The jig fishery centred on *L. reynaudii* is the third most valuable fishery in South Africa (Cochrane et al., 2012). It provides employment for ∼3000 people with catches generating R400 million per year (DAFF 2009/2010). As the majority of the fishery operates out of the Eastern Cape, it is an important economic engine for that province (Glazer and Butterworth, 2006). In fact, links have been made between increased crime levels and low squid catches in one of the main coastal towns out of which this fishery operates (Downey et al., 2010).

9.2. *Todarodes angolensis (Angolan Flying Squid)*

9.2.1. *Distribution and Life History*

Todarodes angolensis is a distinct species, broadly distributed around the southern part of Africa, and is especially common and abundant in Namibian waters (Jereb and Roper, 2010).

The lifecycle is still unclear. Spawning occurs year-round, with a peak in spring-summer (October–December). It is also the period of greatest catches by bottom trawlers during daylight hours, with female squid dominating the catch. Spawning behavior and larval biology are unknown. Juveniles grow in the epipelagic zone where they are most abundant on the Orange Banks in 200–300 m of water, feeding mainly on crustaceans. Adults feed mostly on myctophids and lightfish (Lipinski, 1992). Longevity is about one year, with fast growth (Villanueva, 1992).

9.2.2. *Stock Identification*

Stock structure has not been investigated in any detail but judging from the even distribution of catches it is likely to be a single uninterrupted stock. This species is bottom-dwelling, dominating the cephalopod fauna between a depth of 200 and 400 m in the north of Namibia (18°–28°S, mainly 23°30’–24°S) (Villanueva, 1992) and a depth of around 500 m in the south, investigated in detail in the Cape Canyon and Cape Valley by Roeleveld et al. (1992). Nocturnal vertical migrations of adult squid have not been investigated in any detail although Laptikhovsky (1989) and Villanueva (1992) confirm that they do undertake diel migrations. Juveniles, however, have not been caught in the water column during day or night trawls (Lipinski, R/V Dr Fridtjof Nansen unpublished data).

9.2.3. *Catch and Effort*

Adults of this species are caught as a bycatch of the trawl fishery in Namibian waters, aimed mainly at deep-water hake (*Merluccius paradoxus*). Between 1960 and 1980, bycatch of

Figure 44. (A) Typical squid hand jigging fishing vessels used in the earlier days of the South African chokka squid fishery, beached along the Kromme River, South Africa. (B) A typical squid hand jigging boat used today, with fishermen along the rail with jig lines in the water. (C) Squid caught on a single line with two jigs. (D) Strong lights are used to attract squid to the surface at night. (E) A raft fashioned from floats washed ashore, typically used by artisanal fishers in Southern Angola to target both squid and teleosts. (F) The current South African fleet is comprised of vessels with freezing facilities, and squid are sorted by size, packed and frozen on board. (G) The frozen catch is packaged at land-based factories, with more than 95% of the catch exported.

T. angolensis was frozen whole by trawlers belonging to the Eastern Bloc countries (Russia, Poland, Germany, and Romania) and sold as bait (e.g., to Faroe Islands). Russian trawl operations in this area began in roughly 1970, followed by other Eastern bloc countries in 1973. Spanish trawlers also fished in this area. Anecdotal evidence suggests that catches were fairly low per trawl (~30 kg/hr); however, the large number of trawlers indicates a considerable catch, estimated at 5,000–7,000 t in good years.

To the best of our knowledge *T. angolensis* are presently discarded by the fishing fleet in Namibia.

9.2.4. Stock Assessment

T. angolensis are not subject to any stock assessment and conservation measures. The only exceptions are two demersal surveys per year, conducted with a stratified random survey design in South Africa and one survey per year conducted according to transect design in Namibia. The biomass indices are calculated for all dominant demersal species, but provide only indicators of yearly changes rather than absolute measures of total biomass. Available catch and biomass data are given in Figure 45.

9.3. *Todaropsis eblanae*

9.3.1. Distribution and Life History

Todaropsis eblanae is a widely distributed species, laying claim to two hotspots of occurrence; Indo-Pacific, and Eastern Atlantic. A precise account of the biology and ecological importance is given by Jereb and Roper (2010). Stock identification was studied by Dillane et al. (2000; 2005) using microsatellite DNA analysis, concluding that the south-eastern Atlantic part of this species distribution constitutes a separate population, differing significantly from all other populations.

The lifecycle of the southern African population has not been studied in any detail and is imperfectly known. Longevity is probably one year on average, hence growth is relatively rapid (Arkhipkin and Laptikhovsky, 2000, for NE African waters), although there is evidence on the possibility of slower growth for this species in South African waters (Lipinski et al., 1993). Research conducted in Cape Valley and Cape Canyon indicated an association of this species with the slope waters (around 300 m). Feeding is conducted mainly in the water

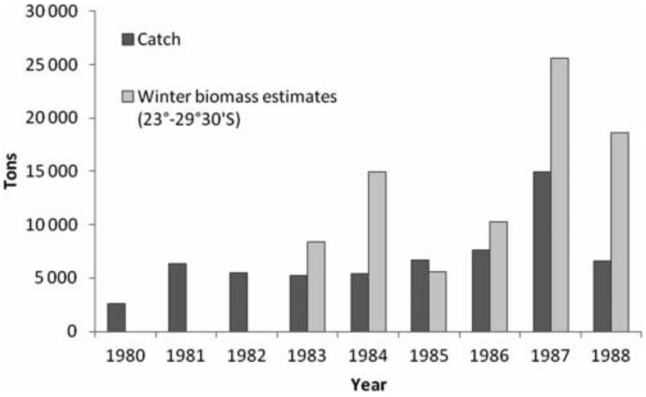

Figure 45. Catches and estimates of biomass of cephalopods in the northern Benguela ecosystem, 1980–1988. Most of the catch and all of the biomass estimates are for *Todarodes angolensis* (from Lipinski, 1992).

column, indicating some vertical movement (as adults, they feed upon lanternfish *Lampanyctodes hectoris*, lightfish *Maurolicus muelleri* and some other small fishes; Lipinski, 1992)), with feeding intensity independent on the stage of maturity. There is no evidence of geographical migrations. Spawning occurs year-round, with no distinct spawning peak. Spawning behavior and biology of paralarvae are unknown.

9.3.2. Catch and Effort

In southern African waters, this species is a bycatch in the trawl fishery for hake (both *Merluccius capensis* and *M. paradoxus*). Adult squid are caught year-round, mainly on the western Agulhas Bank and along the west coast of South Africa in depths between 200 and 400 m. The average catch is small and does not exceed 30 kg/hr trawled. Total catch rarely exceeds 100 t per year. In the years 1980–2000, this species was retained and frozen whole as there was a limited Mediterranean market for it (Lipinski, unpublished data). It is presently discarded.

9.3.3. Stock Assessment

T. eblanae are not subject to any stock assessment and conservation measures. The only exception are two demersal surveys per year, conducted with a stratified random survey design in South Africa and one survey per year conducted via transects in Namibia, providing an index of biomass.

10. WEST INDIAN OCEAN

The Western Indian Ocean region includes the western part of the Indian Ocean, the Red Sea, Persian Gulf, and Arabian Sea, and is bordered by 24 countries. There is a high dependence on marine resources in this region and fishers operate primarily at the subsistence and artisanal level (van der Elst et al, 2005). Annual landings of squid in the West Indian Ocean have increased from ~10,000 t, in 1986, to ~140,000 t, in 2001 (van der Elst et al., 2005). *Uroteuthis duvaucelii*, the most common loliginid squid in Indo-Pacific waters, is exploited throughout its range by artisanal fishers. *U. duvaucelii* also supports commercial fisheries in India, Thailand, the Andamen Sea and Gulf of Aden. *Sepioteuthis lessoniana*, another neritic loliginid, and the oceanic squid *S. oualaniensis*, are also targeted by commercial fisheries in this region. The squid are caught using a variety of gears, including purse-seining, trawling, jigging (hand and mechanical), and specialized shore seines.

10.1. Sthenoteuthis oualaniensis (Purpleback Flying Squid)

10.1.1. Distribution

The purpleback flying squid *S. oualaniensis* is distributed in the equatorial and tropical waters of the Indo-Pacific Ocean (Chen et al., 2007c), with the Arabian Sea considered one of the richest regions for this species (Mohamed et al., 2006). *S. oualaniensis* are pelagic, inhabiting the open ocean beyond depths of 250 m. Three major and two minor intraspecific forms of this species have been described by Nesis (1993). The middle-sized form is the "typical" form occurring throughout its range (Mohamed et al., 2006; 2011). Distribution is closely linked to oceanographic conditions, such as the presence of an upper-homogenous layer in areas with large scale cyclonic gyres, and sea surface temperatures within the range 25–28°C (Chen et al., 2007c). As summarized by Young and Hirota (1998); (1) the small dwarf form (the only form without a dorsal photophore) occupies equatorial waters, (2) the giant form is found in the Red and northern Arabian Seas and the Gulf of Aiden, (3) a small dwarf from (with a dorsal photophore) is found in the Red Sea and Mozambique Channel, (4) the middle-sized "typical" form (with double axes on the gladius) is found throughout the species range, and (5) the "typical" form (with single axes on the gladius) is found in the Red Sea, Gulf of Aden, and the Northern Arabian Sea.

10.1.2. Life History

Mohamed et al. (2011) provide detailed information on the life history of *S. oualaniensis* stating that the lifecycle of the dwarf form (modal sizes of 90–100 mm for mature males and 90–120 mm for mature females and a maximum length of 140–150 mm;) is estimated at 6 months, whereas the lifecycle of the middle form (modal sizes 120–150 mm for mature males and 190–250 mm for mature females) and giant (modal sizes 400–500 mm and maximum size of 650 mm) forms is one year. Females tend to be larger than males (Chen et al., 2007c). The giant forms inhabit depths 400–1100 m during the day, migrating to 50–150 m at night (Mohamed et al., 2011), whereas the middle size form is found near the surface (Mohamed et al., 2011).

Chen et al. (2007c), investigating the fisheries biology of this species in the northwest Indian Ocean, found three spawning groups with different growth rates: a summer spawning group (highest growth rate, Chen et al., 2008b), a spring spawning group and an autumn spawning group (lowest growth rate, Chen et al., 2008b).

There is some evidence indicating *S. oualaniensis* is an intermittent multiple spawner, with spawning occurring over a period of 1–3 months (Mohamed et al., 2011). Unlike loliginids, eggs are not attached to the substrate and spawning is not dependent on suitable or available substrate. Instead, eggs are released in the epipelagic zone (Mohamed et al., 2011). The tentacles of the rhynchoteuthion paralarvae are fused to form a proboscis. During growth, the proboscis gradually separates, and this separation is complete by 7.0–8.0 mm ML. Subadults and adults migrate vertically. At night, they inhabit the surface and subsurface layers from 0 to 150 m to feed, with maximum numbers between the surface and about 25 m depth. In the morning, they descend to 200–1100 m and remain there during the day. Wormuth (1976) reported that *S. oualaniensis* usually forms small schools comprising about thirty individuals of nearly the same size, most likely to avoid cannibalism. Giant forms larger than 35 mm ML have been observed swimming alone in the Arabian Sea (pers. ob.).

The diet of *S. oualaniensis* not only varies with size but also with region (Chen et al., 2007c). Generally, early juveniles are active-grazing predators (feeding on crustaceans), late juveniles and middle sized squid are predator pursuers (feeding on small fish) with large squid being attacking predators (feeding on fish and squid; Nesis, 1977; Mohamed et al., 2011). In larger squid, cannibalism accounts for 50% of the diet (Chen et al., 2007c).

10.1.3. Fisheries

A small-scale Chinese commercial jig-fishery targeting *S. oualaniensis* in the Northwest Indian Ocean commenced in 2005 (Chen et al., 2008b). This fishery has yielded more than 5,000 t in production (Chen et al., 2008b).

In India, this species is caught using hook and line by fisherman targeting tuna and sharks (Mohamed et al., 2006). Due to the lack of market demand, these squid are not currently landed, but there is potential for the development of a new fishery (Mohamed et al., 2006). There has also been an investigation of the abundance of *S. oualaniensis* in the Arabian Sea as a first step to possibly developing a fishery for *S. oualaniensis* in Indian waters (Mohamed et al., 2011).

Studies suggest fishing grounds that yield a high daily catch can be identified by the presence of zooplankton *Chaetognatha*, *Copepoda*, and *Mysidacea*, all of which have been found in the stomachs of *S. oualaniensis* (Chen et al., 2008b). This would suggest fisheries target this species on their feeding grounds. However, during the spawning period, no significant decrease in feeding rate has been observed (Mohamed et al., 2011) and it may be that spawning individuals are not vulnerable to exploitation.

10.1.4. Stock Identification

No work been done on identifying specific stocks.

10.1.5. Catch and Effort Data

Research survey catch, using Chinese squid jigger vessels, in the northwest Indian Ocean showed the catch rate to vary from 0.1–36 t/d with an average catch of 4.4 t/d (Chen et al., 2007c). A total of 1570 t of *S. oualaniensis* was caught throughout the three surveys (one in 2003 and two in 2005), the majority of which were captured on the edge of an upwelling area (Chen et al., 2007c). Since its inception in 2005, the small-scale *S. oualaniensis* fishery has yielded 5000 t in production (Chen et al., 2008b).

10.1.6. Stock Assessment Management

The biomass of *S. oualaniensis* in the Indian Ocean ranges from 50 to 75 kg.km^{-2}, with the highest concentration (4–42 ton.km^{-2}) found in the Arabian Sea (Zuev et al., 1985; Pinchukov, 1989). A more recent biomass survey (2010–2011) of the Arabian Sea (area between the Lakshadweep Islands) provided estimates of biomass in excess of 5 t.km^{-2} (Mohamed et al., 2011). Total biomass throughout this species range has been estimated to be 8 to 11 million t (Nigmatullin, 1990). An earlier estimate of total biomass in the Indian Ocean alone was approximated to be 2 million t (Zuev et al., 1985).

10.1.7. Economic Importance

S. oualaniensis is used as bait for tuna as well as for human consumption.

10.2. *Uroteuthis duvaucelii (Indian Squid)*

10.2.1. Distribution

The Indian squid *U. duvaucelii* (formally *Loligo duvaucelli*) is one of the most common species among the Indo-Pacific loliginids (Jereb and Roper, 2006). It is distributed in coastal waters within depths of 0–170 m (Bergman, 2013), from Madagascar, the Red Sea and the Arabian Sea, eastward to the Bay of Bengal (Sri Lanka) and the Andaman Sea, with Taiwan being the northern limit (Meiyappan et al., 1993; Jereb and Roper, 2006; Choi, 2007; Sukramongkol et al., 2007; Bergman, 2013). *U. duvaucelii* is the most abundant squid species in Indian waters (Meiyappan et al., 1993), the Gulf of Thailand and the Andaman Sea of Thailand (Sukramongkol et al., 2007).

10.2.2. Life History

Length frequency analysis of *U. duvaucelii* from the waters of India suggest a lifecycle of more than 12 months (Kasim, 1985 in Jereb and Roper, 2006; Mohamed, 1996; Mohamed and Rao, 1997); however, results from statolith age readings suggest that this may be an overestimate with the lifecycle not exceeding 1 year (Jereb and Roper, 2006). Similar results were found for specimens from the Gulf of Thailand, as described by Sukramongkol et al. (2007). Interestingly, statolith age determination of specimens collected from both Hong Kong waters (Choi, 2007) and the Andaman Sea (Sukramongkol et al., 2007) has suggested an even shorter lifespan of 7–8 months and 161 days, respectively. It is also possible that similar sized *U. duvaucelii* from the Andaman Sea mature at a younger age than those from Gulf of Thailand (Sukramongkol et al., 2007).

As described by Choi (2007), the maximum ML of *U. duvaucelii* varies throughout its' range with the largest specimens found in India (371 mm), while those in Thailand reach just 300 mm and those in Hong Kong 160 mm. Further investigation on the maximum dorsal length of *U. duvaucelii* from India has shown squid on the west coast to attain a greater size than those on the east coast (Meiyappan et al., 1993; Meiyappan and Mohamed, 2003). This was evident in both sexes (males west coast: 371 mm, males east coast: 260 mm and females west coast: 235 mm, females east coast: 210 mm). Size at first maturity also appears to vary between regions in the waters of India (Rao, 1988), but in general size at 50% maturity for this species is 90–130 mm ML for females and 70–150 mm ML for males (Jereb and Roper, 2006).

Spawning appears to occur throughout the year, with seasonal peaks dependent on the region (Meiyappan and Mohamed, 2003; Choi, 2007; Sukramongkol et al., 2007). For example, Meiyappan and Mohamed (2003) reported peaks in spawning in India during the postmonsoon period whereas in Hong Kong waters peak spawning appears to occur during both summer and winter (Choi, 2007). Spawning aggregations are formed close inshore and become vulnerable to exploitation during this period (Meiyappan and Mohamed, 2003).

U. duvaucelli have been found to prey on both fish and crustaceans, with fish forming an important component of the diet throughout the size range, and a preference for crustaceans declining with increasing size (Meiyappan et al., 1993). Cannibalism increases with size (>80 mm) (Meiyappan et al., 1993).

10.2.3. Fisheries

U. duvaucelii is exploited throughout its range by artisanal subsistence fishers (Roper et al., 1984). It is also one of the most important commercial cephalopod species in India (Jereb and Roper, 2006), Thailand (Chotiyaputta, 1993), the Andamen Sea (Sukramongkol et al., 2007), Hong Kong (Choi, 2007), and the Gulf of Aden (Roper et al., 1984). It further forms a large portion of the bycatch of prawn trawlers off the northeastern South African coast (Fennessy, 1993 in Bergman, 2013).

INDIA: During the 1970s, *U. duvaucelii* was generally caught as an incidental catch by Indian EEZ shore seine, trawl, boat seine, and cast net fisheries (Sarvesan, 1974). Due to the small numbers caught in shore and boat seines, it was initially thought this species was not abundant (Sarvesan, 1974). The use of mechanized vessels and the consequent ability to fish further offshore resulted in much higher yields of *U. duvaucelii* (Sarvesan, 1974). Landings of cephalopods in the 1980s were mostly as a bycatch of the shrimp trawl fisheries, with some 10,000 trawlers operating in 1982 (Silas et al., 1982). Cephalopod production increased ten-fold in the period between the 1980s and late 1990s (Mohamed and Rao, 1997), but only in the last decade have they become a targeted resource (Sasikumar and Mohamed, 2012). Trawl nets operating up to 100 m depth account for nearly 85% of the cephalopod landings in Indian marine waters (Sundaram and Deshmukh, 2011). For example, along the Karnataka coast the trawl fishery is made up of a single-day fleet and a multi-day fleet (Mohamed and Rao, 1997), with the latter undertaking fishing trips of up to seven days in depths from 25–100 m and accounting for 98% of the squid catch (Mohamed and Rao, 1997). Hand jigging is now slowly emerging as a viable method for targeting cephalopods and has been observed in a number of regions, and catches fetch a premium price (Sundaram and Deshmukh, 2011).

THAILAND: *U. duvaucelii* is exploited for both local consumption and export in the Gulf of Thailand and the Andaman Sea (Srichanngam, 2010). During the period 1977–1978, small trawlers targeting squid were replaced by purse-seiners with strong lights to attract squid (Department of Fisheries, 2006 in Srichanngam, 2010). Over time cast nets were replaced by falling nets, lift nets, and scoop nets, and the electric power of light lures has been increased from 20 to 30 Kw (Panjarat, 2008). Together with *Loligo chinensis*, *U. duvaucelii* is the most valuable commercial cephalopod in the Andaman trawl fishery (Sukramongkol et al., 2007). Age at recruitment into the fishery is within 2–4 months of hatching (Sukramongkol et al., 2007).

HONG KONG: Choi (2007) provided a brief synopsis of the Hong Kong *U. duvaucelii* fishery, recording that *U. duvaucelii* has recently become the dominant species in the Hong Kong cephalopod fishery, replacing *U. chinensis*/*edulis*. In addition, a new recreational jigging fishery targeting *U. duvaucelii* has developed. As a number of Hong Kong fisheries are in decline, the “new” recreational fishery is seen as having a number of benefits: it is a high-profit fishery with revenues 27 times higher than those generated by the commercial trawl fishery (Recreational catch: HK$ 635/kg, vs. commercial catch, HK$: 20–30/kg) and benefits the local economy; it is potentially sustainable as catch rates are low and the escape rate of squid high (due to the inexperience of fishers), as jigging is a very selective method of fishing there is little to no bycatch; and jigging does not disturb the benthic habitat.

10.2.4. Fishing Seasons

In the Karnataka state mechanized fishing operations are suspended from 1st June to 31st August, due to the southwest monsoon (Rao, 1988).

10.2.5. Stock Identification

Population genetic studies have not been carried out throughout the distributional range of *U. duvaucelii*. However, a study by Bergman (2013) has found *U. duvaucelii* from Iranian waters to be genetically distinct from specimens caught in Thai and Chinese waters. As Bergman (2013) elucidates, a phylogeographic pattern similar to this has been observed in *Sepia pharaonis*, another neritic cephalopod found throughout the Indo-Pacific.

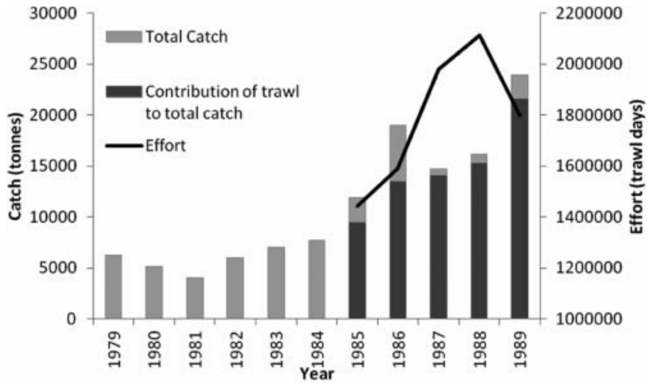

Figure 46. Production of *Uroteuthis duvaucelii* in India.

10.2.6. Catch and Effort Data

The increased production of *U. duvaucelii* from India (Figure 46) is a result of the increased demand for cephalopods (Meiyappan et al., 1993). Trawl catches account for the majority of the catch (Figure 46), with the remainder being caught by artisanal gears including boat seines, shore seines, hooks and line, fixed bag nets (*dol*) and drift nets (Meiyappan et al., 1993).

A review of the emergent jig fishery in India by Sundaram and Deshmukh (2011), reports CPUE of cephalopods (of which *U. duvaucelii* forms over 95%) varies from 30–50, 100–120, and 200–250 kg, dependent on the vessel size and power. In Thailand, total squid production increased from 63,996 t in 1985 to 76,202 t in 2006 (Srichanngam, 2010). According to Kaewnuratchadasorn et al. (2003) (in Choi, 2007), over 95% of the squid landed is *U. duvaucelii*. Srichanngam (2010) found the average size and the CPUE of *U. duvaucelii* to have decreased, possibly as a result of the improvements in fishing gear and high fishing effort. No species specific landing data exists for Hong Kong (Choi, 2007).

10.2.7. Stock Assessment and Management

Numerous stock assessments have been carried out on *U. duvaucelii* in Indian waters (Meiyappan et al., 1993; Mohamed and Rao, 1997). Meiyappan et al. (1993) found exploitation of *U. duvaucelii* to be just below the level of maximum sustainable yield (MSY) and increases in effort would only result in a marginal increase in catch. An assessment of the stock off the Karnataka coast (west coast of India) was carried out by Mohamed and Rao (1997). Using virtual population analysis (VPA) and a Thomson and Bell analysis they concluded there had been a slow but steady increase in the spawning stock biomass since 1988, possibly contributing to the increased abundance of *U. duvaucelii* stocks in the 1990s. An assessment of stocks on the east coast of India, undertaken by Abdussamad and Somayajulu (2004) revealed large size differences of squid caught in comparison to the west coast, suggesting that this was either a result of size overfishing on the east coast or two separate stocks exist on the east and west coasts of India. They concluded that the level of exploitation on the east coast, although high, would most likely not adversely affect recruitment, but suggested a cap on effort. The studies highlight the complexity of managing bycatch of a multi-species trawl fishery, particularly those targeting shrimp with small mesh sizes. As suggested by Abdussamad and Somayajulu (2004), the only feasible solution is the regulation of effort to reduce fishing pressure in coastal waters during periods of peak abundance and by limiting the operation of larger trawlers to deeper water.

In Thailand fisheries are open access, with licenses only required for some of the main fishing gears, and are not an accurate indication of fishing activity, as motorized vessels are registered separately and “illegal” or unlicensed fishing gear is often used on these vessels (Panjarat, 2008).

10.3. *Sepioteuthis lessoniana* (Bigfin Reef Squid)

10.3.1. Distribution

The bigfin reef squid *S. lessoniana* is a neritic species common throughout the coastal waters ($<$100 m) of the Indo-West Pacific (Chotiyaputta, 1993; Triantafillos and Adams, 2005). It is distributed from Japan to Australia and New Zealand, and from Hawaii to East Africa, north to the Red Sea and south to Madagascar (Jereb and Roper, 2006).

Due to different reproductive features (number of eggs in a single capsule, capsule attachment, and spawning season, Jereb and Roper, 2006) evident in *S. lessoniana* in Japanese waters, it has been suggested a species complex exists (Aoki et al., 2008). These consist of *aorika* or *shiroika* which has a white body color and is the most abundant, *akaika* which has a red body color, and *kuaika* which has a small body size at maturity in comparison to the other two. Population genetics studies have shown the genetic structure of *S. lessoniana* around Japan to differ significantly (Yokogawa and Ueta, 2000 in Aoki et al., 2008), but interestingly a study comparing *S. lessoniana* from Japan and Thailand report a single large gene pool (Izuka et al., 1996 and Pratoomchat et al., 2001 in Aoki et al., 2008). The results of a study by Aoki et al. (2008) suggest limited gene flow between Japan and East and South China Seas, resulting in isolated Japanese populations with low genetic variability.

Two genetically distinct groups of *S. lessoniana* have also been recorded in Australian waters (Bergman, 2013). This Australian form is also genetically distinct from the southeast Asian groups (Bergman, 2013). Bergman (2013) also refers to the recent finding of a third genetically distinct group from Sumatra and concludes that six or more separate species could exist.

10.3.2. Life History

Early length frequency analysis and field observations indicated a lifespan between 1 and 3 years for *S. lessoniana* (Jereb and Roper, 2006). However, rearing experiments and direct ageing techniques indicate a much shorter lifespan of ~6 months (Jackson and Moltschaniwskyj, 2002), with animals reaching sexual maturity between 110 and 140 days (Jereb and Roper, 2006). Significant variation in growth rates and maturity exist between equatorial, tropical, and subtropical Indo-Pacific populations (Jackson and Moltschaniwskyj, 2002). In the equatorial waters of the Gulf of Thailand, growth is faster and squid mature at a smaller size when compared to *S. lessoniana* inhabiting the subtropical waters of southern Australia (Jackson and Moltschaniwskyj, 2002). *S. lessoniana* in tropical waters show intermediate growth when compared to the two extremes previously mentioned (Jackson and Moltschaniwskyj, 2002). As mentioned the size at maturity differs between regions, but generally males mature at a smaller size compared to females (Mhitu et al., 2001).

S. lessoniana spawns in multiple batches throughout its adult lifespan (Jereb and Roper, 2006). In the waters of India, these squid migrate inshore after winter to begin mating and spawning (Jereb and Roper, 2006). The spawning season varies throughout its distribution as summarized by Chung (2003) and Jereb and Roper (2006). In southern India, *S. lessoniana* moves inshore to spawn from January to June, from mid-June to August in southern Japan and in Okinawa three spawning seasons have been documented, late January to late February, late April to late May and late June to mid-September.

S. lessoniana preys mainly on prawns and fish, with stomapods and crabs also contributing a small percentage to the diet (Silas et al., 1982).

10.3.3. Fisheries

S. lessoniana is one of the most commercially important squid species throughout its distributional range (Jereb and Roper, 2006). In Palk Bay and the Gulf of Mannar off India, *S. lessoniana* is caught by specialized shore seines (*ola valai*, Silas et al., 1982), by hand jigs and as trawl bycatch (Silas et al., 1985a). It is one of the most valuable fishery species in the Jaffna Lagoon in the Northern Province of Sri Lanka where it is caught by "sirahu valai," jigs and pots and also as bycatch from trawl, cast net, and beach seine fisheries (Sivashanthini et al., 2009). In Taiwan, *S. lessoniana* is caught by jigging, producing a high quality product (Chung, 2003). In Zanzibar, *S. lessoniana* is used as bait in the hook and line fishery and also for human consumption (Mhitu et al., 2001). In Japan, it is caught by a directed trawl fishery, a directed seasonal purse seine fishery around Hong Kong and by jigging (Jereb and Roper, 2006). It is also caught in the South China Sea, Indonesian waters, northern Australian waters, the Gulf of Thailand, and the Andaman Sea (Jereb and Roper, 2006).

10.3.4. Catch and Effort

In general, there is very limited information on the catch and effort for *S. lessoniana*, and where it exists, is often outdated. In Indian waters, the *S. lessoniana* fishery is mostly confined to Palk Bay, with *S. lessoniana* and *Doryteuthis* spp. contributing 300 t to the annual average squid production of 11,030 t (Alagarswami and Meiyappan, 1989). Silas et al. (1985b) reports that cephalopods around Mandapam are caught as bycatch of some ~120 (1985 records) otter trawlers, with total squid landings, recorded for 1976 and 1977, of 1,366 and 1,457 kg, respectively, 65.5–74.9% of which consisted of *S. lessoniana*. About 140 trawlers operate out of Rameswaram, with the fishing grounds of these trawlers coinciding to a large extent with those from Mandapam. Unlike landings recorded at Mandapam, however, *S. lessoniana* is not the dominant species making up the squid catch (1976: 4,685 kg and 1977: 7,138 kg) but contributes only 37.4–45.3%. This species is also caught by handlines in these two areas, operated by fisherman in canoes or standing in shallow waters. Annual landings are small, varying between 143–480 kg, and with CPUE of 0.9–12.4 kg. In the Kilakarai region *S. lessoniana* is targeted by shore seines (*Kara valai* and *Ola valai*) and handlines. From 1973–1975 *Kara valai* annual landings ranged between 3,781–4,797 kg, dropping to 329 kg in 1977.

On the east coast of India, *S. lessoniana* was recorded as contributing 7% (750 t) to total cephalopod landings in the period 1990–1994 (Meiyappan et al., 2000).

10.3.5. Stock Assessment

Stock assessment studies of *S. lessoniana* appear limited. However, a stock assessment of *U. duvaucelli*, *Doryteuthis sibogae*, *S. lessoniana*, *Sepia pharaonis*, *S. aculeata*, and *Sepiella inermis* from the Tuticorin coast reported overexploitation of four of the species viz. *U. duvaucelii*, *Doryteuthis sibogae*, *S. lessoniana*, and *Sepiella inermis* (Mohan, 2007). A reduction of 10% of effort levels was recommended to sustain the stock of squids and cuttlefishes of the area (Mohan, 2007).

An assessment of *S. lessoniana* in Sikao Bay (1987–1997) by Thapanand and Phetchsuthti (2000), indicated that the squid resource had been overfished since 1991, resulting in decreased catches in the following years. After a reduction in fishing effort however, catches increased. MSY was calculated to be 301.693 t, optimum fishing effort to be 54,000 days and the number of fishermen should be limited to 225.

10.3.6. Economic Importance

S. lessoniana is consumed by a certain class of people in the coastal areas of India (Alagarswami and Meiyappan, 1989). At Mandapam and Rameswaram this species is sold at a price almost twice that of *Sepia aculeata* and *U. duvaucelii* (Silas et al., 1985a).

11. EAST INDIAN OCEAN

Over the last two decades the annual yield of loliginid squids in Thai waters varied between 70,000 and 100,000 t, 1986–2010 (DOF, 2013), with approximately 90% of the catch from the Gulf of Thailand and 10% from the East Andaman Sea. Catches from these areas make up almost half of the total squid yield for the south-east Asian region (200,000–250,000 t). Other major countries that fish for squids are Indonesia and Malaysia, with annual yields of about 60,000 t (SEAFDEC, 2013). In Thailand, one-third of the catch is locally consumed and the remaining two-thirds processed on both a small and large scale and exported. Thailand is one of the major exporters of cephalopod products to Japan and Europe. Commercial cephalopod catches are comprised of loliginid squids (60%), cuttlefish (35%), and octopus (15%) (Kittivorachate, 1980; Supongpan, 1995). Small species are processed into fish-meal, which is the main ingredient of feed used by the aquaculture industry.

The main species captured in the East Indian Ocean are neritic, with nine species recorded in Thai waters (Nabhitabhata et al., 2009; Nabhitabhata and Nateewathana, 2010). These are *Uroteuthis chinensis* (Gray, 1849); *U. duvaucelii* (Orbigny, 1835); *U. edulis* (Hoyle, 1885); *U. singhalensis* (Ortmann, 1891); *U. sibogae* (Adam, 1954); *Loliolus affinis* Steenstrup, 1856; *Loliolus sumatrensis* (Orbigny, 1835); *L. beka* (Sasaki, 1929), and *S. lessoniana* Ferussac, 1831. However, no detailed statistics of individual species exist. All cephalopods caught are mixed and roughly categorized as (*loliginid*) squid, cuttlefish or octopus according to size at landing. Small-sized species (e.g., *Loliolus*) are mixed with juveniles of other large-sized species. The gears used by the industrial fishery are mainly trawlers (otter board trawlers, paired trawlers) purse seiners and lift-netters using lights. The artisanal fishery uses mostly traps and hand jigging under lights. The use of lift-netting emerged in about 1979 and soon became an important gear for squid fisheries. By the 1990s, more than 40% of trawlers had changed to lift-netting and purse seining (Supongpan, 1995).

11.1. Distribution and Lifecycles of Commercial Loliginids

Only the three major commercially important species are described here.

11.1.1. Uroteuthis chinensis (Mitre Squid)

Uroteuthis chinensis is the largest (350–460 mm ML) and most commonly caught species in this region. Although distributed throughout the depth range 10–100 m, squid are most abundant in the 30–50 m depth range. Males mature at 105 mm ML and females at 90 mm ML. Female fecundity is 3000–20,000 eggs. The sex ratio is 1:1.5 males to females. Spawning is thought to occur all year round with two minor peaks during March–July and August–December (Chotiyaputta, 1995a; Boonwanich et al. 1998; Suppanirun et al., 2011).

11.1.2. Uroteuthis duvaucelii

Uroteuthis duvaucelii is routinely fished in this region. Although smaller (30–300 mm ML) than *U. chinensis*, this species is more abundant in shallower waters, 10–30 m. Males also mature at a smaller size (80 mm ML) compared to *U. chinensis*. Females mature at 90 mm. Female fecundity is 1500–12,000 eggs. The sex ratio of males to females is 1:1.3. Spawning is likely to occur year round, but peak spawning is observed during January–June and August–December (Supongpan et al., 1993; Chotiyaputta, 1995a; Boonwanich et al. 1998; Suppanirun et al., 2011).

11.1.3. Sepioteuthis lessoniana

The bigfin reef squid *S. lessoniana* inhabits rocky reefs in shallow water between 5 and 45 m deep. Aggregation and school size is smaller (5–20 individuals) compared to that recorded for the genus *Uroteuthis* (Nabhitabhata, 1996). Squid trapping is the most important fishing method, and annual yields are 2000–4000 t. Catch is composed of squid across the size range 75–325 mm ML. The fecundity is estimated at 700–2300 eggs (Rattana-anant, 1978, 1979, 1980). Spawning occurs year round with peaks during November–January, March–May, and July–August in the Gulf of Thailand (Chotiyaputta, 1984, 1988; Roongratri, 1997) and June-December in the East Andaman Sea (Yakoh et al., 2013).

11.2. Stock Identification

Stock identification methods employed for each economically important species include morphometric measurements (dorsal ML and weight), and; age and growth rate (see Dawe and Natsukari (1991) and Natsukari et al. (1988) for methods) (Chotiyaputta, 1995b; Supongpan, 1996; Boonwanich et al. 1998). Length frequency analysis is based on von Bertalanffy's growth model. Bhattacharya's method is used to separate normal distribution curves from the total distribution plot. Modal progression analysis is used to estimate growth. Fecundity, sex ratio and reproductive status are used to determine reproduction seasons.

The CPUE is estimated from routine research survey catch composition. The MSY is estimated from Schaefer's surplus production models and Fox's derivatives (Vibhasiri et al. 1985; Supongpan, 1996).

Tropical neritic squids have a fast growth rate and a short lifespan of less than 1 year. Spawning can occur all year round without prominent peaks. As a result, the stocks or populations are mixed and it is possible to distinguish at least two to three annual growth cohorts.

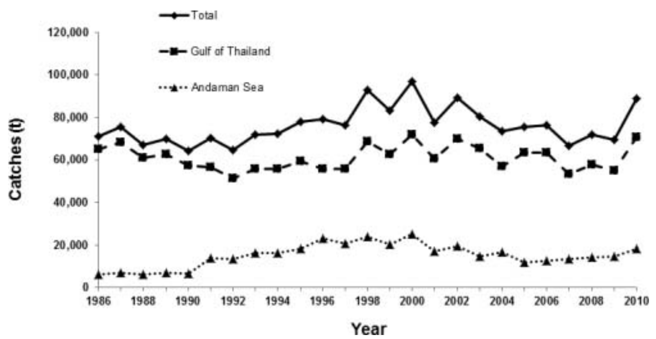

Figure 47. Total loliginid squid catches (t) in the Gulf of Thailand and the East Andaman Sea during 1986–2010 (DOF 2013).

11.3. Fisheries

Squid catches contribute about 50% to total cephalopod production in Thai waters. Annual yields range from 51,000–97,000 t (1986 to 2010, Figure 47). Catch composition is made up of 15–52% *U. chinensis*, 29–64% *U. duvaucelii* and 5–8% *S. lessoniana* (Kittivorachate, 1980; Chotiyaputta, 1995b; DOF, 2013). The potential yield of the squid stock in Thai waters has been estimated to be about 67,000 t for *U. chinensis* and 60,000 t for *U. duvaucelii*, with a corresponding optimum fishing effort of 6.29 million hours (Supongpan, 1995). Vibhasiri (1980), FAO (2010) and Supongpan (1995) estimated that the MSY of the squid stock had already been reached by 1977, and in fact *U. chinensis* had been overexploited by some 20% (Supongpan, 1995). However, it is important to note that estimations have been based on the premise that the squid resources in Thai waters belong to a homogeneous single stock.

11.4. Fishing Methods

Squid capture fisheries in south-east Asian countries can be categorized by fishing gear type. Historically, gears consisted of hook and line, gill nets, cast nets, and bamboo stake traps. More recently small-scale or artisanal fishing gears include gill nets, small push nets, hook and line, jig, cast nets, and traps (Munprasit, 1984; Bjarnason, 1992). Small scale or artisanal fishing boats are non-powered, equipped with an outboard engine (so-called "long-tail boats" in Thailand) or a small inboard engine. A larger industrial sector uses otterboard trawls, beam trawls and pair trawls, large push nets, and large-scale squid traps. All industrial vessels are powered with inboard engines that can be classified according to length as small (<14 m), medium (14–18 m), and large (>25 m) (DOF, 1997).

In Thai waters, approximately 40–55% of the annual yield is captured by trawlers (10–35% from otterboard trawlers and 10–20% from pair trawlers) (Chantawong, 1993; Supongpan, 1996).

Light luring squid nets include a stick-held lift and a giant cast net or falling net. The main catch from this kind of fishing operation is loliginid squids (approximately 90%) with the rest of the catch being made up of pelagic fish. The yield from this fishery (Squid Light luring Fishery or SLLF) accounts for 30–50% of Thailand's production (Supongpan, 1996; Songjitsawat and Sookbuntoeng 2001) (Figure 48). There are three types of nets used by the industrial sector: the lift net of 12 × 12 m with 2–3 cm mesh size, the cast net of 12 × 12 or 16 × 16 m with 2.5–3.2 cm mesh size and the box net of 14–30 × 14–30 × 20 m with 2.5–3.2 cm mesh size. The cast net is also used with small boats of less than 6 m length (Ogawara et al., 1986; DOF, 1997). The catch is comprised of 36.7–93.9% loliginid squids and 2.9–9.0% *S. lessoniana*. Among loliginids, 76.4–80.3% comprises *U. chinensis*, 14.8–22.5% *U. duvaucelii*, and 1.1–4.95% *Loliolus sumatrensis* (Songjitsawat and Sookbuntoeng, 1988).

Small scale squid fishing boats (cast netting and jigging with light luring) operate in shallow water zones of 5–15 m (Chenkitkosol, 2003). The artisanal jig fishery currently makes use of small generators and florescent lamps to attract squid (Bjarnason, 1992; Chenkitkosol, 2003). Green fluorescent light rods are used (Chenkitkosol, 2003). Hand jigging uses artificial bait with light lures during the night and trolling during the day. *S. lessoniana* makes up 100% of the catch at night, and 95% during the day with the other 5% comprising of loliginid squids (*U. duvaucelii* and *U. chinensis*). Yield is about 10–15 kg/d (Supongpan et al., 1988).

Squid traps are the only artisanal fishing gear used to target loliginid squid with *S. lessoniana* being the target species (Boongerd and Rachaniyom, 1990) (Figure 49). Squid trapping originated in Eastern Thailand in the late 1960s and by the 1980s was widespread throughout Thailand and the south-east Asian region (Munprasit, 1984). Around 2005 a collapsible squid trap was developed in eastern Thailand, allowing larger vessels to carry up to 2000 traps. *S. lessoniana* comprises 90–95% of the catch, with the remainder made up of sepiid cuttlefish. Loliginids and octopus do not enter the traps. The lifespan of the trap is 90–120 days (Boongerd and Rachaniyom, 1990; Khrueniam and Suksamrarn, 2012). The CPUE is 10.3 kg/trip for *S. lessoniana* and 1.3 kg/trip for cuttlefish (Supongpan et al., 1988). During 1986–1999, the annual yield of *S. lessoniana* caught by trapping in Thai waters exceeded 5,000 t, decreasing to 1,000 t in 2007 (DOF, 2013). A major concern is the loss of squid egg capsules that have been attached to the traps. During 1990–2003, the Thailand Department of Fisheries tackled this problem by purchasing egg capsules from the fishermen and rearing them in a hatchery before releasing them for restocking. The number of *S. lessoniana* produced and released annually now averages 1.8 million individuals (Nabhitabhata et al., 2005).

Another major threat is the conflict between squid trap fisheries and trawlers operating on the same fishing grounds (Figure 50). Traps are damaged or lost when they are in the line of a trawling operation. On the other hand, trawl nets are damaged by

Figure 48. A falling net boat participating in squid light luring fishery for loliginid squid in Thailand.

traps. Resolution has been reached in some communities through an agreement to annually assign zones (spatial partitioning) for the different fishing gears and limiting the fishing period for each fishery in each of the zones (temporal partitioning) (Supongpan, 1995; Srikum and Binraman, 2008). Rising costs of fishing, particularly fuel is threatening the long term viability of the fishery (Yamrungrueng and Chotiyaputta, 2005; Srikum and Binraman, 2008; Khrueniam and Suksamrarn, 2012).

The annual landings of loliginid squids caught in the Gulf of Thailand by squid light luring netting constitutes about 40–50% of the total cephalopod catch (Chantawong, 1993), and is therefore described here in some detail. Squid fisheries using the light luring technique emerged around1978 and rapidly became popular over the next 3 years (Munprasit, 1984). The high yield of this fishing gear allowed fishermen to transform small to medium trawlers into squid netters. The number of squid light luring nets in the Gulf of Thailand registered to Thailand Department of Fisheries has continuously increased from 230 units in 1980 to 3,160 in 2004 (Figure 51). By contrast, the number of trawl nets, (10,428 units in 1980) decreased to 5757 units in 2005. The total yield of loliginid squids in Thailand increased to more than 70,000 t after the introduction of squid light luring nets in the early 80s (Supongpan, 1996), but has since stabilized. More recently, the only area where there has been an increase in yield, estimated to be at least 20%, is in the Andaman Sea subregion (Chantawong, 1993).

Figure 49. A long tail artisanal fishing boat with squid traps targeting *Sepioteuthis lessoniana* in Thailand.

11.5. Stock Assessment and Management

The MSY from trawling and cast netting of *U. chinensis* and *U. duvaucelii* is estimated at 37,179 t when the relative fishing effort (RFE) equals 1.15 in the Gulf of Thailand (Kongprom et al., 2010) and 1,728 t at a RFE of 0.75 in the Andaman Sea (Boonsuk et al., 2010). Fishing effort is considered to be about 15% below MSY in the Gulf of Thailand, but 25% above this in the Andaman Sea. In 2010, fishing mortality (F) of *U.* (*P.*) *chinensis* was estimated at 2.48 in the Gulf of Thailand and 8.60 in the Andaman Sea. For *U. duvaucelii,* F was estimated as 4.41 and 4.83, respectively (Boonsuk et al., 2010, Kongprom et al., 2010).

The principle legal framework is the 1947 Thailand Fisheries Act, which was amended in 1981. The Act is a provision for the adoption of regulations and notifications which are issued for purposes of conservation and management of marine fisheries resources. Notification by the Ministry of Agriculture and Cooperatives issued in 1981 prohibits the use of nets with a mesh size smaller than 3.2 cm as well as any other kinds of fishing appliances using electric lights to target squid (Charuchinda, 1987, 1988). Push netting and trawling are prohibited within 3 km from the shoreline. At present, some of the local provincial governments have expanded this to 5.4 km (3 nautical miles). The above fishing gears are also banned in certain fishing grounds over spawning periods and also on the nursery grounds of economically important pelagic finfish species. It is proposed that these regulations should include SLLF (Supongpan, 1996) allowing for the spatial management of squid stocks. Zoning of Marine Protected Areas and Marine National Parks as well as other zoning initiatives under different names (with similar purposes) can also indirectly enhance squid stocks. The so-called "annual Gulf closing season" and "Andaman Sea closing season" that ban commercial fishing targeting pelagic fish from February to May in the western Gulf of Thailand and from April to June in the Andaman Sea (Petsalapsri et al., 2013) should be expanded to cover squid light luring fishing.

Supongpan (1996) also proposed that the numbers of SLLF boats should be reduced by 20% through stepwise measures in order to make the measures politically acceptable. However, the Thai government experienced strong opposition (that turned into a political issue) soon after trying to limit the

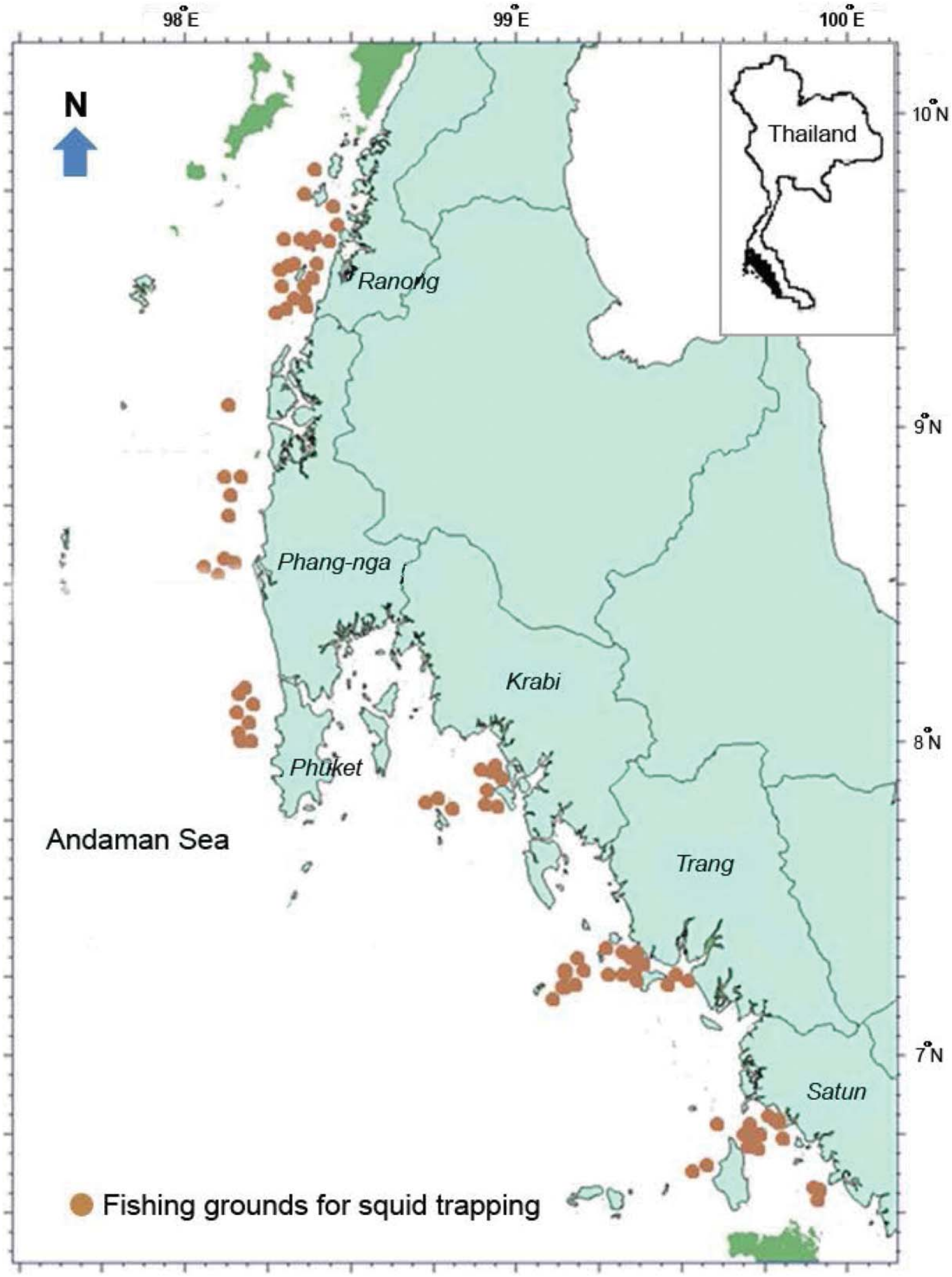

Figure 50. Fishing grounds for squid trapping in the Andaman Sea, Eastern Indian Ocean (after Suppapreuk et al. 2013).

numbers of trawlers. It may be possible to limit light intensity used in this fishery and Munprasit (1984) has suggested that 10 kW generators can produce enough light intensity for fishery operations at depths of less than 80 m in the Gulf of Thailand.

12. NORTHWEST PACIFIC

The Northwest Pacific region encompasses the Pacific Ocean waters of the southeast Kamchatka Peninsula, the Kuril Islands and Japan including the Bering Sea (western part), the Sea of Okhotsk, the Sea of Japan, the Internal Japan Sea, the Yellow Sea, the East China Sea, and the South China Sea (northern part). This region is fished by the Peoples' Republic of China, Taiwan, Japan, the Democratic People's Republic of Korea, the Republic of Korea, and the Russian Federation (Spiridonov, 2005) The Northwest Pacific has a high productivity and contributes the largest proportion of world fish and seafood (Spiridonov, 2005). In the southern regions, squids are one of the principle groups exploited. Species supporting squid fisheries in this region include *Heterololigo bleekeri*,

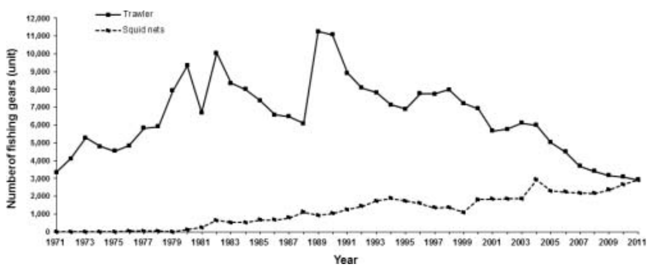

Figure 51. Numbers of trawlers and squid light luring netters registered in the Gulf of Thailand, 1971–2011 (DOF 2013).

S. lessoniana, *U. edulis*, *U. chinensis, U. duvauceli, Berryteuthis magister, T. rhombus, W. scintillans. T. pacificus, S. oualaniensis*, and *O. bartramii*. The squids are caught using a variety of methods and gears such as trawl nets, set nets, angling, jigging, trolling, bait fishing, and purse seine.

12.1. Heterololigo bleekeri (Spear Squid)

12.1.1. Distribution

The spear squid *Heterololigo bleekeri* is mainly distributed in the coastal waters of Japan from Hokkaido to Kyushu and the coast of Korea, but is occasionally found in the East China Sea and the Yellow Sea (Natsukari and Tashiro, 1991, Ti et al., 1987) (Figure 52, Tian et al., 2013). The spawning season and depth distribution depend on water temperature. In the warmer southern region, squid inhabit deeper waters compared to the colder northern region. In Tosa Bay, Kochi Prefecture, spear squid are caught in a depth range of 70–300 m and at bottom temperatures of between 11 and 15°C (Toriyama et al., 1987).

12.1.2. Population Structure and Life History

Spear squid in Japan are divided into two stocks: the Tsushima Warm Current (TWC, the Sea of Japan) stock and the Pacific stock (Tian, 2012; Nashida and Sakaji, 2012). This division is convenient for stock assessment and is based on geographical distribution, but without a strict biological definition. The spear squid is a commercially important species for coastal fisheries in Japan. The fisheries depend largely on four groups: southern and northern stocks in the TWC region of the Sea of Japan, and southern and northern stocks in the coastal Kuroshio and Oyashio Current regions of the Pacific (Figure 52). There is no difference in genetic structure of the Japanese spear squid population (Ito et al., 2006).

The main spawning seasons are in winter in the southern region and in spring in the northern region both in the Sea of Japan and in the Pacific. In the south-western Sea of Japan, spear squid spawn through winter to spring, grow quickly to about 100 mm ML within 6 months (Kinoshita, 1989; Murayama and Kitazawa, 2004), and recruit to the fishery in autumn and winter when they are caught by bottom trawls and set nets in Japanese coastal waters (Kitazawa, 1986). Spear squid move from deep offshore waters to coastal waters to spawn, but the species does not undertake large-scale migrations like that of the Japanese flying squid *T. pacificus* (Sato, 1990).

In northern Japan, spawning stocks tend to move southward from December to February with decreasing water temperature and northward from March to June with increasing water temperature (Sato, 1990). This movement is considered to allow the squid to utilize the optimum water temperature of 10–12°C for spawning (Sato, 1990), with the water temperature in the spawning season ranging from 7 to 14°C (Hamabe, 1960; Ishii and Murata, 1976). The spawning grounds occur in shallow reef areas, and egg capsules are laid beneath the undersurfaces of firm substances (Isahaya and Takahashi, 1934). Embryonic development and hatching are affected by water temperature and salinity. The optima for development of eggs are 12.2°C and 36.0 psu, and the lower limits for normal development are 8.3°C and 28.0 psu (Ito, 2007).

The estimated mean ML at 50% maturity is 193 mm for males and 171 mm for females (Ito, 2007). Large and small males have different reproductive strategies (Iwata et al., 2005).

12.1.3. Fishing Fleets, Seasons, and Catches

In Japan spear squid are fished mainly by trawls, set nets and angling (Kasahara, 2004). The extended continental shelf of the south-western Sea of Japan, from Tsushima Islands to Oki Islands, supports the southern stock in the Sea of Japan and historically has been an important fishing ground for pair trawlers (Figure 52) (Tian, 2007, 2009). The northern stock in the Sea of Japan, which ranges from north of Noto Peninsula to the west coast of Hokkaido, is one of the most important target species of the set-net fishery (Ito, 2007; Tian, 2012). From the east coast of Kyushu to the south of Bousou Peninsula in the Pacific, the southern stock is a target of set nets and trawlers, but mainly fished by pair trawlers in the waters south of Shikoku. In the north Pacific, from Bousou Peninsula to Iwate Prefecture, the northern stock is a target of trawlers, but single trawlers operating in the waters from Bousou to Kinkazan Island had the largest contribution (Nashida and Sakaji, 2012; Tian et al., 2013).

Annual landings in Japan between 1978 and 2012 ranged from 3900 to 20,000 t, showing large interannual variations (Figure 53). Total catches decreased from 20,000 t in 1979 to less than 5,000 t in recent years, showing a declining trend. In addition to the linear trend, it also showed some periodicity with peaks in 1979, 1989, 1994, and 2008 (Tian et al., 2013).

Catches of the northern stock in the Sea of Japan are made mainly by set-net fisheries in Aomori and Hokkaido Prefectures; catches from Toyama to Akita form a small part of the total (Figure 54A). The catches show large interannual variation, with high catches during the late 1970s and 1990s and lower catches during the 1980s and 2000s. CPUEs for set nets

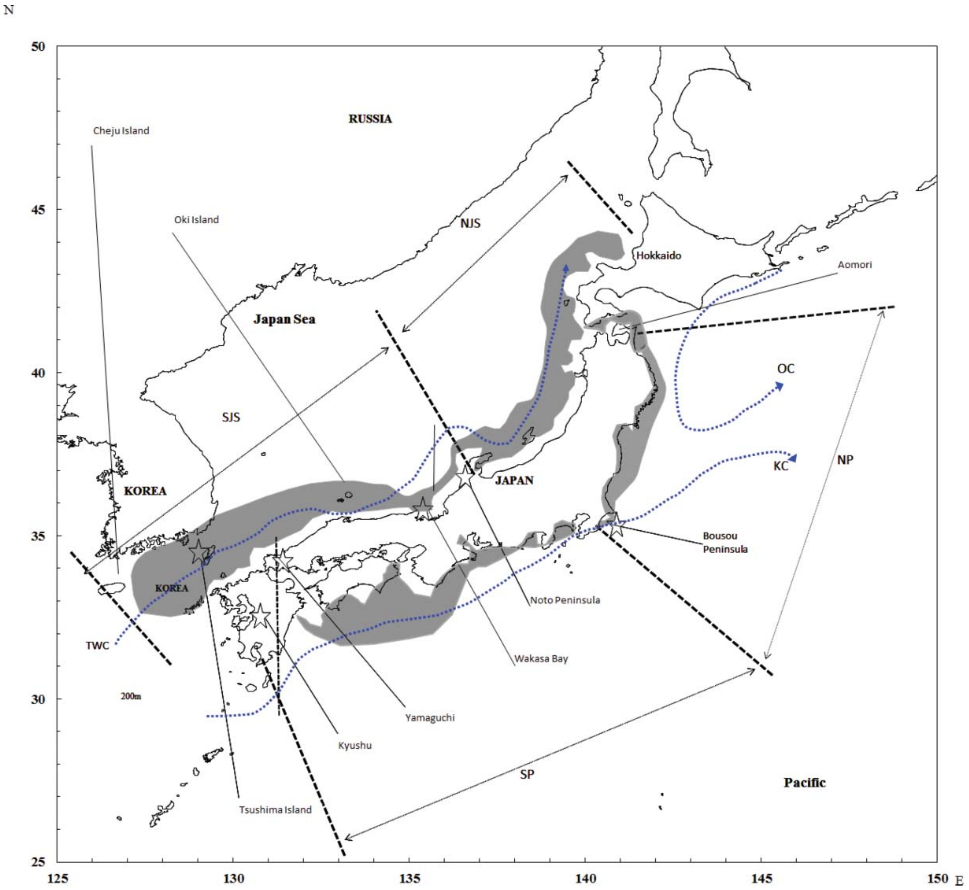

Figure 52. Distribution (shaded grey area) of spear squid and oceanographic structure around Japan (Modified from Tian et al., 2013). Four fisheries regions for southern and northern Sea of Japan (SJS, NJS) and Pacific (SP, NP) are marked by bold dashed lines and thin dotted arrows. Thick dotted bold arrows indicate the Tsushima Warm Current (TWC), Kuroshio Current (KC) and Oyashio Current (OC), respectively. Locations of some place names mentioned in the text are shown with stars.

in Aomori Prefecture show a trend similar to the catches. The catches from the southern stock in the Sea of Japan are made mainly by pair trawlers; however, the proportion of catches from Ishikawa to Hyogo Prefecture has increased since the 1990s (Figure 54B). Catches from pair trawlers decreased from a maximum of 13,700 t in 1977 to a minimum of 16 t in 2003, and maintained an extremely low level thereafter. The trend of abundance index (AI, similar to CPUE) was consistent with the catch; it was high during the 1970s and 1980s, but extremely low since the 1990s, indicating decadal-scale variation (Tian, 2009; Tian et al., 2013).

The catches from the Pacific northern stock depend largely on the catches from single trawlers operating from Bousou Peninsula to Kinkazan Island (Figure 54C), and catches from trawlers in Iwate Prefecture. Catches increased after the late 1980s, peaked in 1996, and decreased thereafter to the minimum in 2005. CPUE for the single trawlers in the Bousou-Kinkazan region showed large inter-annual variations. For the Pacific southern stock, catches from the pair trawl fishery were high in the 1980s, decreasing in the 1990s (Figure 54D). The CPUEs for the pair trawlers mirrored the catch throughout, excluding the last 5 years (Tian et al., 2013).

Trends in catch and CPUE indicate that the abundances of the southern stocks both in the Sea of Japan and Pacific Ocean

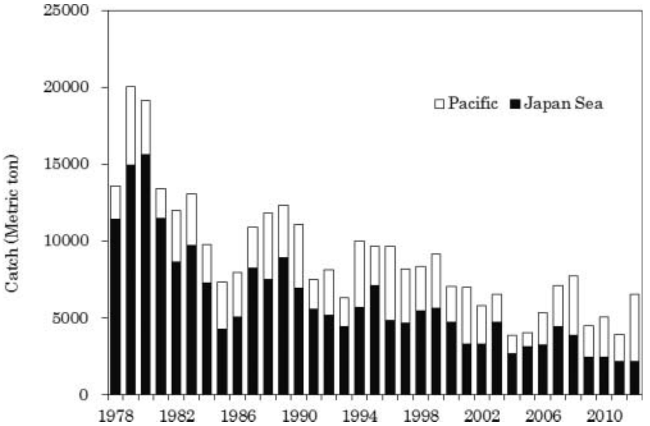

Figure 53. Annual changes in catches of spear squid from Pacific (white bars) and the Sea of Japan (black bars) for the period of 1978–2012 (Modified from Tian et al., 2013).

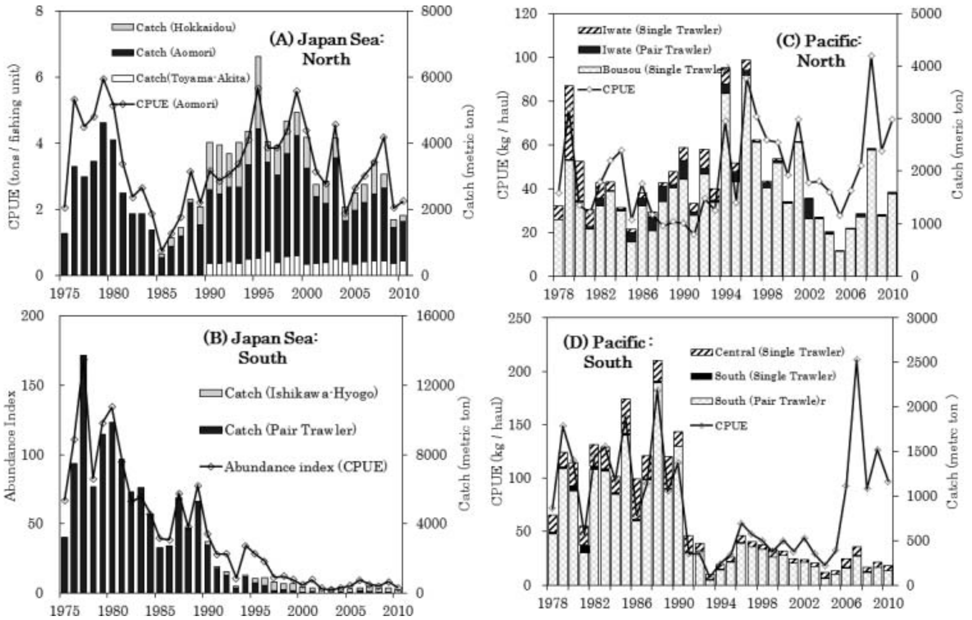

Figure 54. Annual changes in catch (vertical bars) by fishing methods and CPUE or abundance index (solid line with diamonds) for the main fishery for the four stocks of spear squid around Japan (Modified from Tian et al., 2013). (A) Northern stock in the Sea of Japan during 1975–2010 (the data for Hokkaidou and for Toyama-Akita were for 1985–2010 and 1990–2010, respectively). (B) Southern stock in the Sea of Japan during 1975–2010 (the data for Ishikawa-Hyogo was for 1990–2010). (C) Northern stock in the Pacific during 1978–2010. (D) Southern stock in Pacific during 1978–2010.

decreased abruptly around 1989/1990, whereas the abundance of northern stocks increased around 1993/1994. This strongly suggests synchronicity in abundance with step changes during the late 1980s to early 1990s in the Sea of Japan and Pacific (Tian et al., 2013). The disparate patterns between the southern and northern stocks indicate latitudinal difference in abundance.

12.1.4. *Impact of Fishing, Stock Assessment, and Implication for Management*

It is notable that the decadal variation in the abundance of spear squid corresponds closely with the water temperature; the southern stocks were high during the cool thermal regime and low during the warm thermal regime since the 1990s, whereas the northern stocks showed the opposite pattern (Tian et al., 2013). The close correspondences between CPUE and WT strongly indicates the impacts of the late 1980s regime shift, which was characterized by abrupt changes from cool to warm temperature around 1987/1988 (Tian et al., 2011). On the other hand, the impacts of fishing on spear squid are unclear. Fishing effort (including the cumulative hauls and number of licensed fishing trawlers, and number of fishing units for the set-net fishery), has been declining since the 1980s (Nashida and Sakaji, 2012; Tian, 2012). However, fishing effort of both set nets and trawl fisheries appeared to intensify during the short spawning season (Tian, 2009). A case study of the southern stock in the Sea of Japan indicated that fishing mortality estimated from the DeLury model increased substantially since the late 1980s (Tian, 2009). This example strongly suggests that fishing pressure can be intensified under unfavorable climate regimes despite a decline in total fishing effort.

Spear squid are one of the target species under the Japanese government stock assessment program. The status of the stock is assessed annually based on trends in catch and CPUE. Spear squid stocks have been lower since the 1990s, both in the Pacific and the Sea of Japan (Tian, 2012; Nashida and Sakaji, 2012). This is largely associated with the warming in water temperatures (Tian et al., 2013).

As stated above, the responses to the regime shift differed between the southern and northern stocks. It is important to identify both favorable and unfavorable climate conditions and evaluate fishing pressure in order to develop a stock-specific management strategy to ensure the recovery of southern stocks. For the northern stocks, it is notable that the positive effects of a warm winter could be compensated by the negative effects of a warm summer. Recommended management measures to allow the recovery of southern stocks include a delay of the fishing season to protect juveniles, and a ban on fishing on the spawning grounds during the autumn spawning season (Tian, 2009; Tian et al., 2013).

12.2. *Sepioteuthis lessoniana (Bigfin Reef Squid)*

12.2.1. *Stock Identification*

In Japan, the bigfin reef squid (*S. lessoniana*; also called the oval squid) occurs in nearshore to offshore waters from southern Hokkaido to the Nansei Islands (Sasaki, 1929; Okutani, 1973) and is a commercially important coastal resource

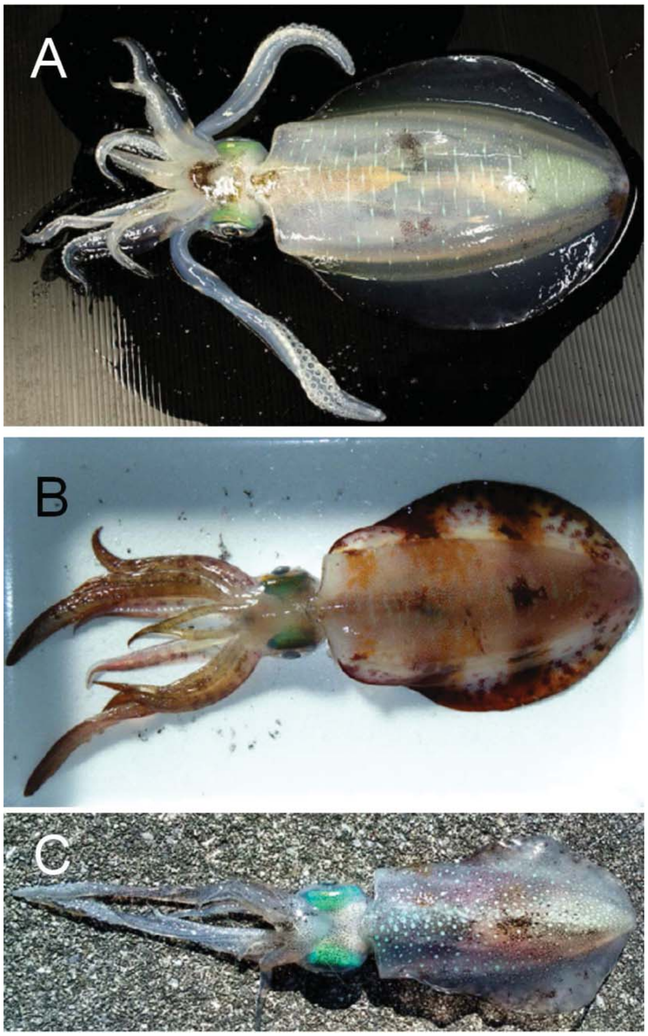

Figure 55. *Sepioteuthis lessoniana* variations in Japanese waters: *Shiro-ika* (A), *Aka-ika* (B) in Tokushima Prefecture, and *Kua-ika* (C) in Okinawa Prefecture.

(Figure 55) (Okutani, 1973; Ueta, 2000). Fishers in Okinawa Prefecture have long separated local populations into three groups based on the size, color in freshly killed condition, and fishing ground (Izuka et al., 1994; Izuka et al., 1996). In Japan, three genetically and reproductively independent forms are now recognized: "*shiro-ika*" ("white squid"), "*aka-ika*" ("red squid"), and "*kua-ika*" (Izuka et al., 1994; Izuka et al., 1996; Figure 55). The distribution and ecology of each form differ (Izuka et al., 1996).

12.2.2. Shiro-ika

12.2.2.1. Distribution and Lifecycle. *Shiro-ika* is widely distributed throughout Japan from southern Hokkaido to the Nansei Islands and Ogasawara Islands (Okutani, 1973; Izuka et al., 1996), (Figure 56), and occurs from the surface to about 100 m depth. In Japan's main islands, juveniles and young squids occur at 0–20 m depth in nearshore waters, where food is abundant and large predators are less abundant than offshore during summer to autumn (Figure 57). In winter, subadults and adults migrate southward from coastal waters <15–20°C to offshore waters >15–20°C. Schools are mainly distributed at the thermohaline front between 15 and 20°C in high density (Ueta, 2003). In spring, adults migrate to near-shore waters to spawn.

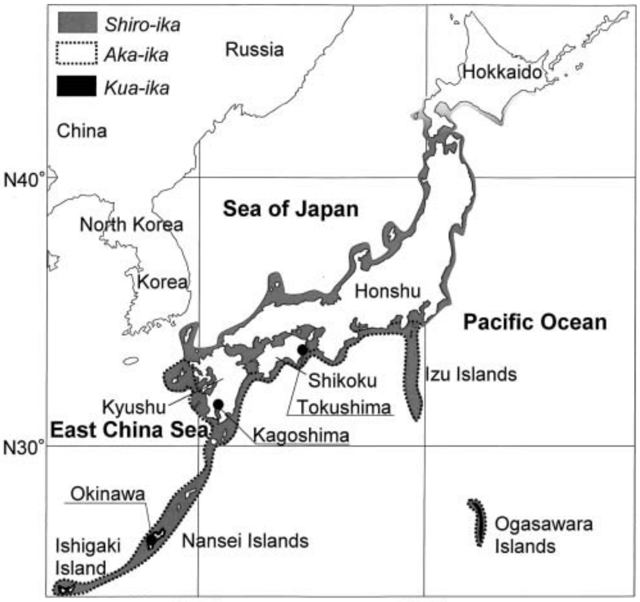

Figure 56. Geographical distributions of *Shiro-ika* (black portions), *Aka-ika* (dotted line), *Kua-ika* (black portions) (Izuka *et al*. 1996) in Japan.

Spawning occurs mainly during April to September around Japan's main islands and from January to October in Okinawa (Ueta, 2000). Captive females have been observed to make

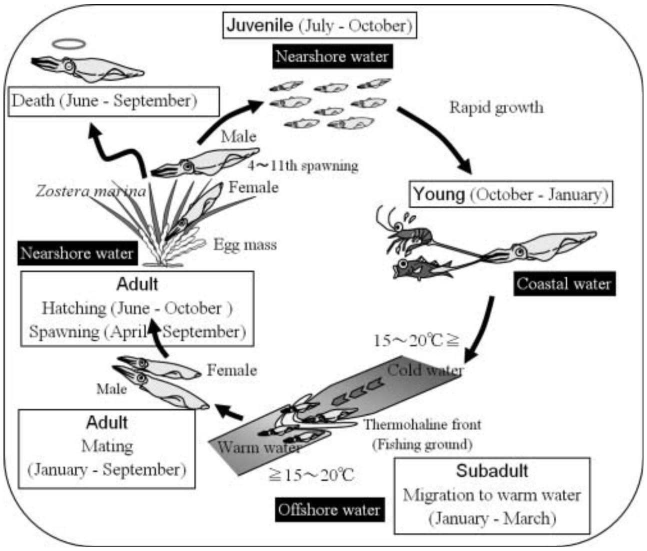

Figure 57. The lifecycle of *Shiro-ika* around Tokushima Prefecture, Japan.

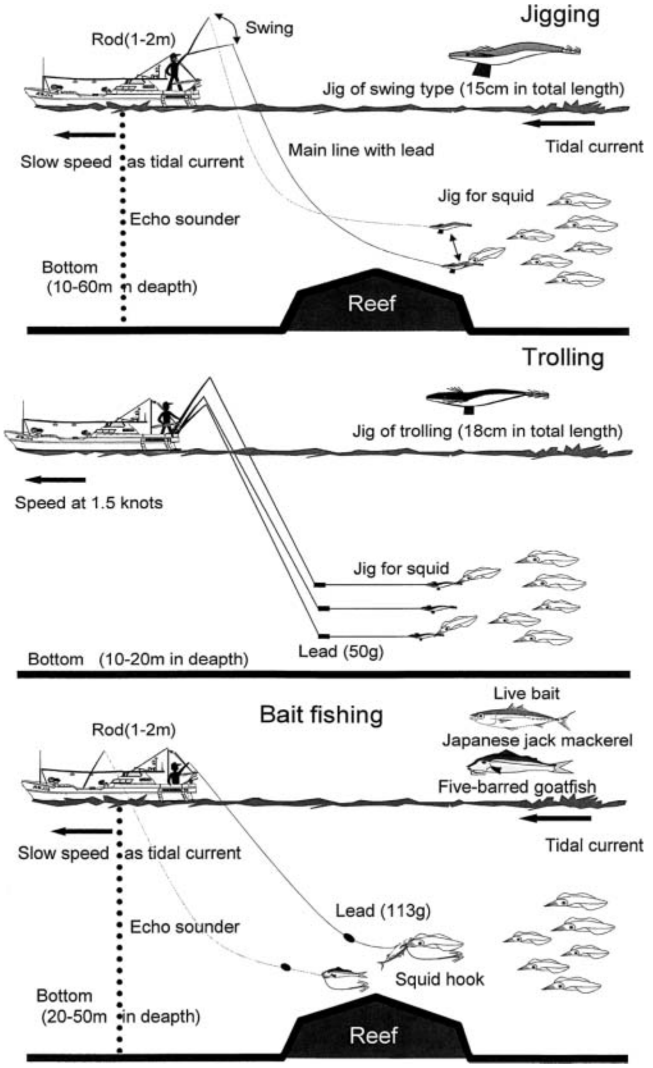

Figure 58. Schemata of squid-jigging, trolling, and bait fishing for *Shiro-ika* in Tokushima Prefecture, Japan.

multiple copulations and spawn 4–11 times during a spawning season (Wada 1993Wada and Kobayashi, 1995). Egg capsules contain 1–9 eggs (mode = 5–6) and are attached to seaweed, eelgrass, corals and manmade spawning beds near the nearshore (Ueta, 2000). It is estimated that spawned eggs hatch after 24–27 days at 25°C from laboratory experiments (Segawa, 1987).

Shiro-ika in the main islands recruits during July to October and dies after several spawnings in April to September of the following year (Ueta, 2003; Wada and Kobayashi, 1995). The lifespan in the main islands is about 1 year (Ueta, 2000). Water temperature has a marked effect to both the hatching period and growth rates. High water temperature appears to cause early hatching and higher growth rates, and high water temperature is associated with higher survival rates and successful recruitment (Ueta et al., 1999; Ueta, 2000). Individual difference of mantle length in adult is large, influenced by the long spawning season (April–September) and growth differences. Large males grow to about 2–3 kg (370–440 mm ML), and large females grow to about 1–1.5 kg (280–330 mm ML). The minimum size at maturity of females is approximately 15.5 cm ML (209 g body weight) (Ueta, 2000).

12.2.2.2. Fishing gear. In western Japan, *shiro-ika* is mainly caught year round by jigging, trolling, bait fishing, set net, and purse seine fisheries. Monthly catches peak during the recruitment period (October–January) and spawning period (April–June). *Shiro-ika* is mainly caught by jigging, trolling, bait fishing, set net in the night time, and daily catches tend to increase around the full moon, rainy days being the exception (Munekiyo and Kawagishi, 1993; Ueta, 2000). Moonlight of suitable luminous intensity seems to accelerate movement and predation behavior.

Jigging and trolling fisheries use a traditional jig shaped like a prawn called "*egi*," which was developed in Kagoshima Prefecture in the 1800s (Okada, 1978) and had been repeatedly improved (Figure 58). Catches occur mainly at dusk and at night. *Shiro-ika* caught in squid jigging and trolling fisheries are larger than those caught in the set net fishery due to the size selectivity of the jig (Tokai and Ueta, 1999). Trolling is more efficient than jigging, because trolling uses several lures at the same time and does not require that the rod be manually swung back and forth. Bait fishing is conducted during the day using live Japanese jack mackerel and amberstripe scad as bait.

In Tokushima Prefecture, *shiro-ika* is mainly caught by nearshore set nets below 15–20 m depth. Fishers use the small-sized set nets of pound net type and bag net type (Figure 59). Both net types are operated by one or several fishers using small (<1–2 GRT) boats. The scale and structure of the nets vary among regions and fishers. 20–70 m leader nets are set perpendicular to the shore, and the bag net or pound nets attached to fish court for landings are positioned at the offshore end of the leader nets (Figure 59). Squid swim along leader nets and enter the bag net (bag net type). In the pound type, squid move from the fish court to the pound net with a nonreturn device. Squid tend to enter the bag net with a large mesh size (50 mm ML) more often than nets with a small mesh size (16–21 mm ML), which is used to catch Japanese sardine and Japanese anchovy.

Fishers in Kyushu use purse seines and boat seines. These gears catch *Shiro-ika* migrating to brush woods sunk by fishers and natural seaweed beds to spawn (Figure 60). These gears are laid near a steep slope with sandy bottoms at 5–15 m depth. Fishers using a purse seine, encircle the squid and then direct the squid into the pocket net using a scaring device - tied up colored ropes.

12.2.3. Aka-ika

Aka-ika has a redder body color than the other forms due to its many red chromatophores (Figure 55). It is distributed in the Ryukyu Islands and probably occurs along the Pacific coast of Honshu (Figure 56). It occurs deeper than the two other

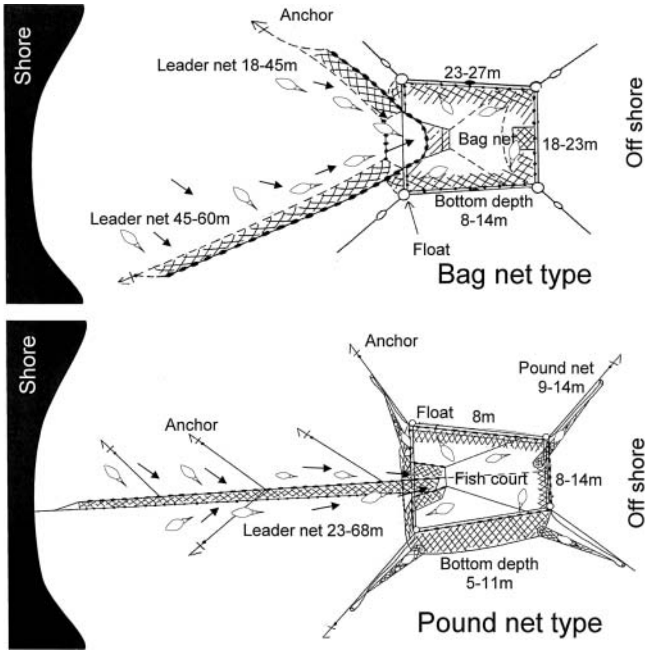

Figure 59. Schemata of two types of small-sized set net for *Shiro-ika* in Tokushima Prefecture, Japan.

forms. Females in Ishigaki Island have been observed to attach egg capsules containing 5–13 eggs (mode = 9.2) on the branches of dead staghorn corals at about 23 m depth in May (Segawa et al., 1993b). Females in the Ryukyu Islands were observed to attach egg capsules on the upper part of steel artificial fish reefs at 81–100 m depth in April and July (Ueta and Umino, 2013). The maximum body weight is about 5–7 kg, corresponding to 500–600 mm ML. It is caught at the Ryukyu Islands, Tanegashima Island and Yakushima Island, by jigging and bait fishing at 20–50 m depth. The fishing methods are the same as those used for *Shiro-ika* (Figure 58). Live five-barred goatfish, *Parupeneus multifasciatus* and striped mullet, *Mugil cephalus* are used as bait fish. *Aka-ika* is rarely caught around Japan's main islands except the Izu and Ogasawara Islands.

12.2.4. Kua-Ika

Kua-ika occurs only near the Ryukyu and Ogasawara Islands (Figure 56) (Izuka et al., 1996). At Ishigaki Island, it occurs only near coral reefs and attaches two-egg capsules to the underside of dead tabletop corals in shallow coral reefs during June to October (Segawa et al., 1993a; Izuka et al., 1996). The maximum body weight is estimated to be about 100 g, corresponding to 100–150 mm ML. The stock size of *Kua-ika* is very small, and its importance as a fishery resource is small.

12.2.5. Catch Statistics

The Statistics and Information Department at the Japanese Ministry of Agriculture, Forestry, and Fisheries does not collect catch data for *S. lessoniana* in Japan, but regional catch statistics are available from some local fisheries research stations. Based on these data, annual landings during the 1980s in Japan were estimated to be several thousand t (Adachi, 1991). Most of landings in Japan are *Shiro-ika*. The annual catch in eight major fishing markets between 1986 and 2010 was variable from year to year, ranging from 55 to 166 t.

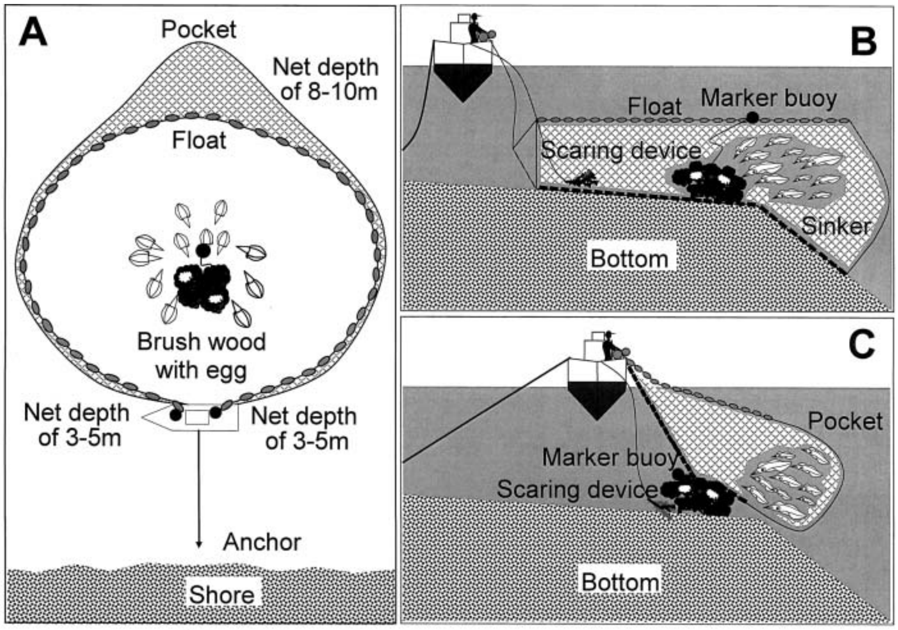

Figure 60. Schemata of purse seine for *Shiro-ika* in Kagoshima Prefecture, Japan.

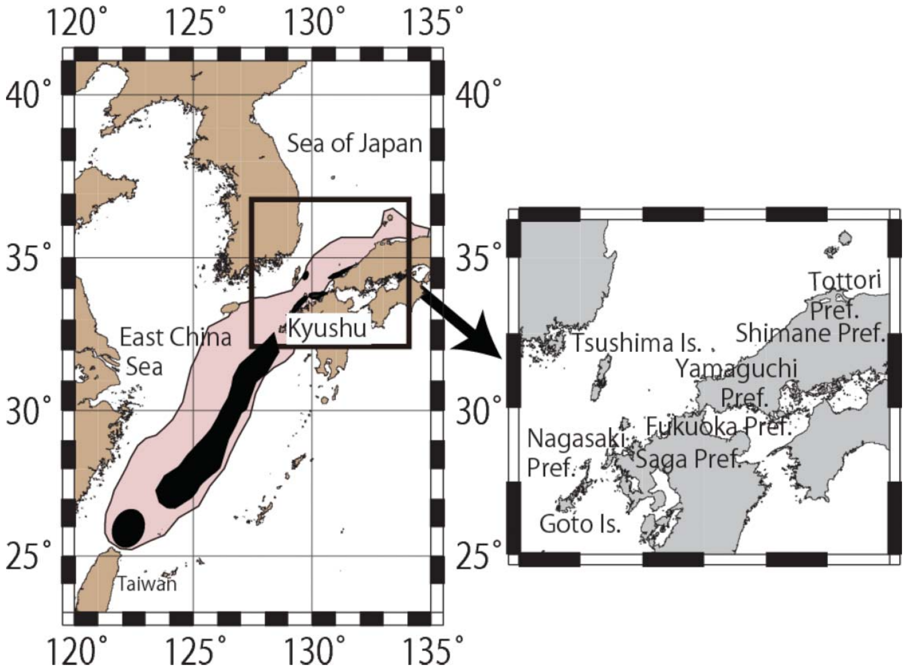

Figure 61. Main distribution area (shaded) and presumed spawning grounds (black) of *Uroteuthis edulis*.

12.2.6. *Economic Importance*

The bigfin reef squid is generally caught nearshore and landed within several hours, so it is sold fresh. In Japan, *S. lessoniana* is called the "king of squids" because of its good taste and the beautiful transparency of its meat in sashimi and sushi. Therefore, this squid is expensive; squid >1 kg are traded at >2000–3000 yen/kg (20–30 USD/kg) at the Tsukiji fish market in Tokyo and by wholesalers selling to fancy sushi restaurants and Japanese restaurants. Some of the catch is sold live to restaurants specializing in squid dishes. In western Japan, jigging using "*egi*" is very popular with recreational fisherman, and the market for fishing gear such as "*egi*," rods, reels, and lines is very large and growing.

12.3. *Uroteuthis edulis* (Swordtip Squid)

12.3.1. *Japanese Fisheries*

12.3.1.1. Stock identification. *Uroteuthis edulis* occurs in the Indo-West Pacific Ocean from central Japan to the South China Sea and northern Australia (Roper et al., 1983; Carpenter and Niem, 1998). From the southwestern Sea of Japan and the East China Sea, this species has a continuous distribution (Figure 61). Despite large differences observed in size and maturation stage among several migrating groups, allozyme analysis indicates the stock consists of an identical population (Natsukari et al., 1986).

Three seasonal migrating groups of *U. edulis* occur in the southwestern Sea of Japan (Yamada et al., 1986; Kawano et al., 1990). The spring group consists of the largest mature individuals (200–450 mm ML), which hatch from June to September, and are fished from April to June the following year. The summer group consists of medium sized mature individuals (200–300 mm ML), which supposedly hatch from November to December, and are fished from August to September the following year. The autumn group consists of immature individuals smaller than the others (100–200 mm ML), which hatch from January to March, and are fished from September to November of the same year. Another group occurs in the waters off northwestern Kyushu in autumn, which matures at 200–300 mm ML (Tashiro, 1978; Kawano et al., 1990). The minimum size of mature squid is 120 mm ML for males and 160 mm ML for females in spring, and 110 mm ML for males and 120 mm ML for females in summer (Yamada et al., 1983).

Spawning grounds in the southwestern Sea of Japan are on sandy seabed up to 80 m in depth, with spawning taking place between April and July (Figure 61; Natsukari, 1976; Furuta, 1980; Aramaki et al., 2003; Kawano, 2006; Ueda, 2009). In the East China Sea, a large spawning ground exists in the inshore waters off northern Taiwan, with spawning occurring in spring and autumn (Wang et al., 2008). The concurrent occurrence of male and female squid, and the spring and autumn presence of juveniles (20 mm ML), on the shelf edge in the northern East China Sea, suggests spawning also occurs here (Yamada and Tokimura, 1994).

12.3.1.2. Distribution and Lifecycle. Both immature and mature *U. edulis* are distributed over the continental shelf

(Natsukari and Tashiro, 1991), although seasonal migrations occur in the southwestern Sea of Japan and the waters off northwestern Kyushu (Tashiro, 1977; Kawano et al., 1990). The migration routes of the seasonal groups are hypothesized as follows (Kawano et al., 1990): the spring migrating group spawns in neritic seas whilst moving northward from waters off the southern Goto Islands, west of northern Kyushu. The summer migrating group migrates into offshore waters of northern Kyushu from offshore waters of northwestern Kyushu, and spawns after maturing while searching for food. The autumn migrating group moves southward from the southwestern Sea of Japan to waters off northwestern Kyushu from September to December. Another autumn group migrates from the waters around Goto Islands to the coastal waters off northwestern Kyushu. *U. edulis* is distributed over the East China Sea, especially in the southern area, throughout the year, with distribution expanding northeastward in summer and concentrating into the southern area in winter (Tokimura, 1992). The maximum number of statoliths growth rings (350) indicates a lifespan of c.a. one year (Natsukari et al., 1988).

12.3.1.3. Fishing Grounds and Seasons. During the 1970s and early 1980s, the small boat jigging fishery operated in the coastal areas (20–50 m depth) in the southwestern Sea of Japan and waters off northwestern Kyushu between April and May (Furuta, 1978a; Ogawa et al., 1983; Kawano, 1987). Since 1982, when "Tarunagashi" jigging (a kind of bottom drifting long line fishing, Kawano et al., 1990) was introduced; fishing occurred on natural reefs (<100 m depth) in the waters off northern Kyushu and off Yamaguchi Prefecture, in spring and winter (Takahashi and Furuta, 1988; Akimoto, 1992; Kawano and Saitoh, 2004). The main fishing ground moved gradually offshore to 70–120 m depth from summer to autumn (Furuta, 1978a; Ogawa et al., 1983; Kawano, 1987; Kawano, 2013).

During the 1970s, the jigging fishery grounds occurred at water temperatures of 18–24°C and salinities of 34.1–34.7‰ (Furuta, 1976). After the introduction of "Tarunagashi" jigging, fishing grounds were found to be at temperatures between 13 and 24°C and salinities of 33.4–34.8‰ in winter (Takahashi and Furuta, 1988). The formation of fishing grounds is related to not only sea temperatures and salinity but also the distribution of prey for the squid; and fishing grounds coincide with distributions of pelagic fish schools (Moriwaki and Ogawa, 1986). However, the distribution of spawning groups can differ from that of fish schools (Kawano et al., 1990). Small squid (100–200 mm ML) are jigged all year round. Larger squid (> 250 mm ML) are fished in waters off northwestern Kyushu between spring and autumn, and in waters off northern Kyushu and the southwestern Sea of Japan between spring and summer (Furuta, 1978b; Yamada et al., 1983). Since 1991, the medium-size boat squid jigging fishery began to fish the squid in the East China Sea and expanded the fishing grounds in the southern areas (Yoda and Fukuwaka, 2013).

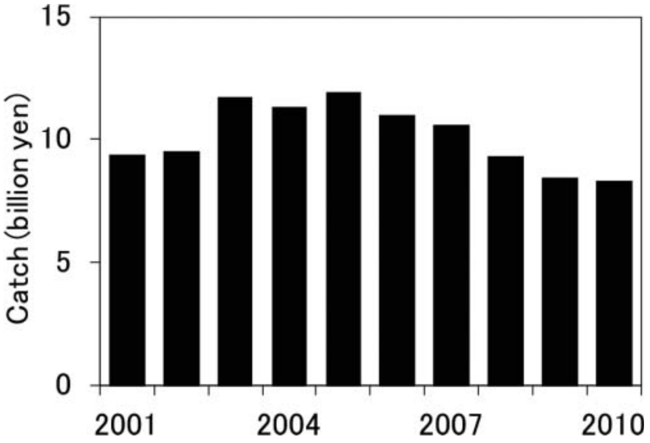

Figure 62. Value of annual catches of *Uroteuthis edulis* from six prefectures located along the southwestern Sea of Japan and northwestern Kyushu shown in Figure 53. (Data are estimated values by each prefectural fisheries research institute.)

East of 128°30'E, offshore pair trawl fishery CPUE (catch in case per haul) is high from the eastern Tsushima Straits to waters off the southern Tsushima Island, with these high CPUE areas tending to be inshore in spring and offshore in autumn (Ogawa and Yamada, 1983; Kawano, 1997). Bottom conditions in the high CPUE areas are generally 13–15°C and 34.50–34.70% in March, 10–15°C and 34.25–34.75% in May and August, and 13–19°C and 34.25–34.70% in November (Kawano, 1997). Many small squid (<200 mm ML) are caught year round by the offshore pair trawl fishery (except for the fishing-closed period during June and July) (Kawano, 1991). Smaller squid (90–150 mm ML) account for a large portion of the catches between August and October, and the size of squid increases gradually from November to March, with the majority having a ML of 70–200 mm (Kawano, 1991).

The Japanese western pair trawl fishery in the East China Sea, west of 128°30'E, begins its fishing in the southern East China Sea over the continental shelf in May. Its fishing grounds expand toward Kyushu in summer and begin to shrink from the northern area in autumn (Yamada and Tokimura, 1994). Apart from *U. edulis*, the fishery changes its targets in October. MLs of *U. edulis* caught by trawl nets are generally small in autumn and winter and large in summer (Furuta, 1978b).

12.3.1.4. Economic importance. The value of annual catches from six prefectures located along the southwestern Sea of Japan and northwestern Kyushu were 8.2–11.9 billion yen from 2001 to 2010 (Figure 62). *U. edulis* is highly important in the local fishing industry as the catch value is one of the highest of marine products in each of the prefectures, and many fishermen are involved in fishing for squid.

12.3.1.5. Composition and numbers of Japanese fishing fleet. Most of squid jigging boats targeting *U. edulis* are less

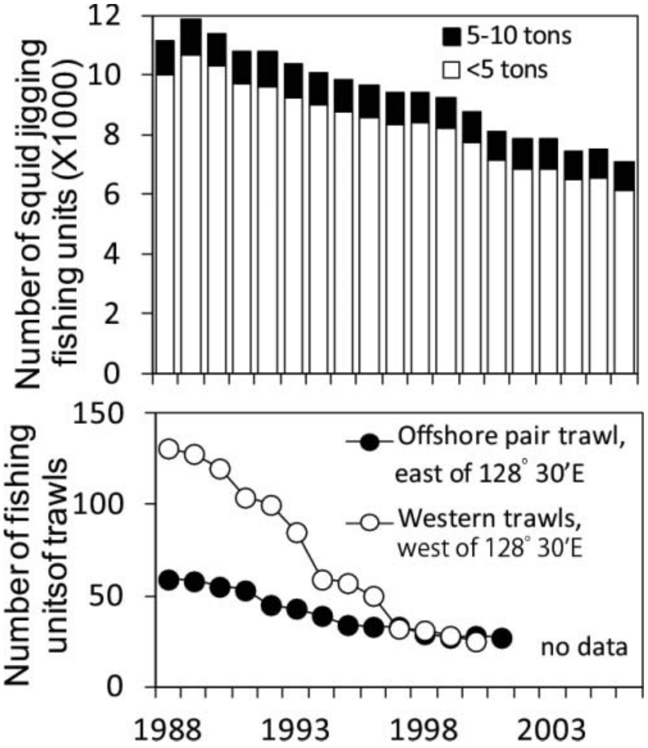

Figure 63. Annual number of fishing units of small-size boat jigging fishery in the six prefectures located along the southwestern Sea of Japan and northwestern Kyushu shown in Figure 53 and trawl fisheries operating in the southwestern Sea of Japan and the East China Sea. (Annual Report of Catch statistics of Fishery and Aquaculture, Ministry of Agriculture, Forestry and Fisheries, 1988–2006.)

than 10 t, with the majority being less than 5 t (Kawano et al., 1990). The number of fishing vessels in the six prefectures located along the southwestern Sea of Japan and northwestern Kyushu decreased from 11,851 boats in 1989 to 7082 boats in 2006 (Figure 63). Fishermen operate two to four rigs consisting of several jigs tied to a nylon line (Natsukari and Tashiro, 1991). Operating "Tarunagashi" jigging in spring and winter, fishermen float 10–20 buoys with the rigs. The catches of the squid by fishing boats (>5 GRT) equipped with automatic squid-jigging machines have dramatically increased in the southwestern Sea of Japan since the end of the 1990s (Kawano, 2013). The number of medium-size squid jigging boats (≥30 GRT) operating in the East China Sea decreased from 18 in 2001 to 3 in 2011 (Yoda and Fukuwaka, 2013).

The number of fishing vessels in the offshore pair trawl fishery operating in the southwestern Sea of Japan, and western trawl fisheries operating in the East China Sea, decreased from 59 and 131 in 1988 to 28 and 25 in 2000, respectively (Figure 63).

12.3.1.6. Duration of fishing period by fishing region. Squid jigging begins in March or April in waters off northwestern Kyushu, around Goto Islands, with the arrival of the spring migrating group. The fishing grounds expand along the coastal areas between May and August, and from September to December, the autumn migrating group is fished in waters off northern Kyushu (Furuta, 1978c). In the southwestern Sea of Japan, the fishing season is also from April to December, with catches increasing around May and peaking in early summer or autumn, before decreasing in December (Figure 64; Ogawa et al., 1982). "*Tarunagashi*" jigging catches more squid in the waters off northern Kyushu in spring and winter compared to other jigging fisheries (Kawano, 1997). Catches peak in spring and summer in waters off northwestern Kyushu and in autumn in the southwestern Sea of Japan (Figure 64; Kawano, 1997). However, the peak in catch varies concurrently with long-term alternations of dominant

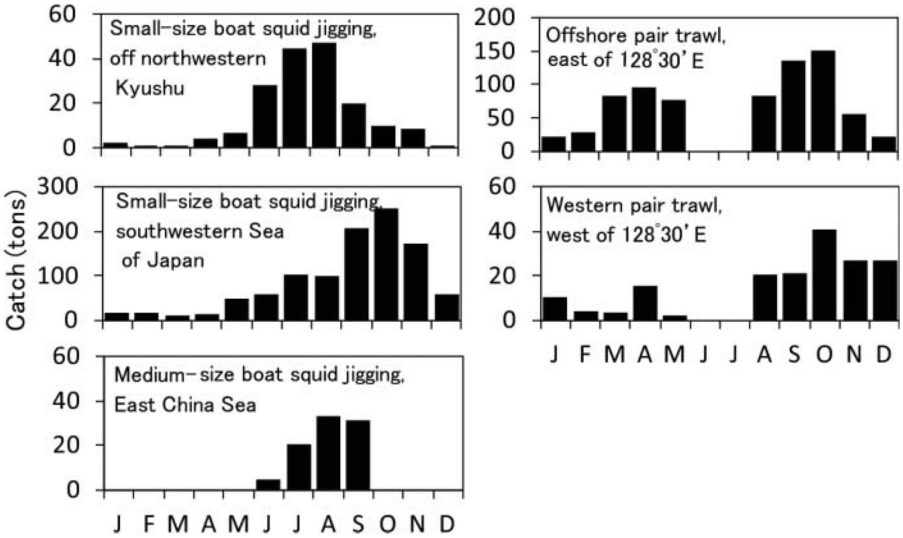

Figure 64. Monthly catches of *Uroteuthis edulis* by fisheries operating in the southwestern Sea of Japan and the East China Sea in 2011. (Data were compiled from Yoda and Fukuwaka, 2013.) Catches by small-size boat jigging fisheries are from the catches at representative fishing ports.

species in pelagic fishes in the southwestern Sea of Japan (Ogawa, 1982; Moriwaki and Ogawa, 1986). The fishing season of the medium-size boat squid jigging fishery in the southern East China Sea is from June to October (Figure 64; Yoda and Fukuwaka, 2013).

The offshore pair trawl fishery in the southwestern Sea of Japan catches *U. edulis* throughout the year (except for during the June-July closed season) with a major peak in catch in autumn and a minor peak in spring (Figure 64; Moriwaki, 1986). Catches of *U. edulis* by western trawl fisheries in the East China Sea operating all year round were high in summer and autumn, especially in August, in the 1960s (Furuta, 1978c). However, the fisheries have been closed in summer since 2004 (Figure 64; Yoda and Fukuwaka, 2013).

12.3.1.7. Catch and effort data of Japanese fisheries. Total squid catches from the southwestern Sea of Japan to the East China Sea decreased from 35,000 t in 1988 to 11,000 t in 2011 (Figure 65; Yoda and Fukuwaka, 2013). In the southwestern Sea of Japan and in waters off northwestern Kyushu, the catches decreased from about 24,000 t in 1988 to 11,000 t in 2011. In the southern East China Sea, catches significantly dropped from 11,000 t in 1988 to about 170 t in 2011 (Yoda and Fukuwaka, 2013).

Fishing effort targeting squid has decreased continuously since the late 1980s: The number of fishing days of small-size squid jigging boats (<10 GRT) in the six prefectures located along the southwestern Sea of Japan and northwestern Kyushu gradually decreased from 725,000 days in 1988 to 356,000 days in 2006 (Figure 66). That of medium-size squid jigging boats in the southern East China Sea also decreased (Figure 66; Yoda and Fukuwaka, 2013), and the total number of hauls by trawlers in the southwestern Sea of Japan and the East China Sea decreased markedly from 1988 to 2011 (Figure 66; Yoda and Fukuwaka, 2013).

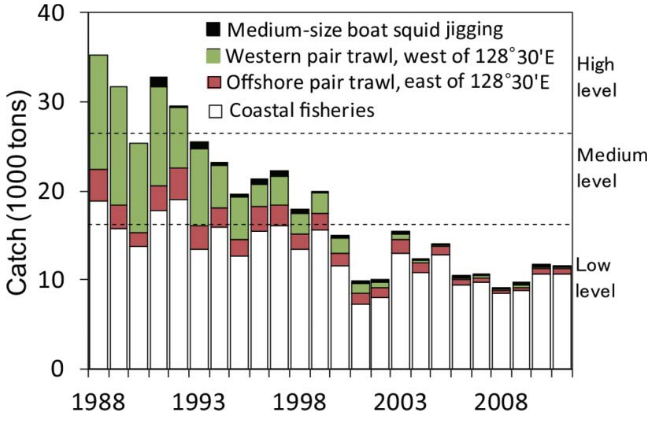

Figure 65. Annual catches of *Uroteuthis edulis* by fisheries operating in the southwestern Sea of Japan and the East China Sea (after Yoda and Fukuwaka, 2013).

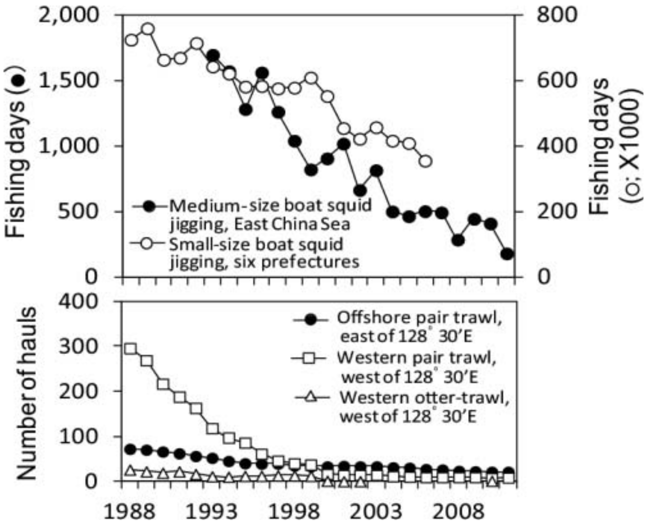

Figure 66. Annual fishing days by squid jigging fisheries and number of hauls by trawl fisheries operating in the southwestern Sea of Japan and the East China Sea. (Data were compiled from Yoda and Fukuwaka, 2013 except for the fishing days by small-size boat jigging fishery which were from Annual Report of Catch statistics of Fishery and Aquaculture, Ministry of Agriculture, Forestry and Fisheries, 1988–2006.)

12.3.1.8. Stock assessment and management. The exploitation rate was generally under 10% and the resource was not being overfished in the southwestern Sea of Japan in the 1980s (Kawano et al., 1986); therefore, fishing impact on the resource of *U. edulis* was small and management measures were not planned at that time.

Hamada (1998) estimated%SPR (percentage of spawning-biomass per recruitment) of the spring/summer-hatched group and the winter-hatched group as 50% and 55%, respectively, based on a cohort analysis of *U. edulis* in waters off northern Kyushu during the 1990s, and recommended one day of fishing closure per week to improve%SPR for both groups. Hamada and Uchida (1998) proposed: (1) conservation of the eggs (protected areas and periods in the spawning grounds), (2) reduction of fishing effort (one closed day per week), and (3) restriction of squid size and spawning stages in the catch.

Recently, stock assessment of *U. edulis* in the Sea of Japan and the East China Sea has been conducted by the Japanese government based on trends of catches by trawls and squid jigging fisheries, and an immigration abundance index of *U. edulis* estimated following Kitahara and Hara (1990). The assessment showed that the stock of *U. edulis* constantly remains at a low level (Yoda and Fukuwaka, 2013). The assessment suggested that the catch should be managed so as to be lower than the ABC (allowable biological catch) and that management effort should be required not only by Japan but also by countries which harvest the stock in the East China Sea, in order for the stock to recover (Yoda and Fukuwaka, 2013).

12.3.2. *Chinese Fisheries*

12.3.2.1. Stock identification. Spring and autumn spawning groups are separated based on spawning seasons (Wang et al., 2008, 2010).

12.3.2.2. Distribution and lifecycle. The swordtip squid is a large-sized loliginid squid widely distributed in the continental shelf waters from northern South China to northern China (Roper et al., 1984). The squid spawn all year round (Wang, 2002; Wang et al., 2008), and the longevity is no more than one year (Natsukari et al., 1988). Females mature at about 5 months, which is about 2 months later than males (Wang et al., 2010). The size at first maturity of mature males was about 120 mm in spring and 170 mm in autumn groups, while that of mature females was about 165 mm in spring and 185 mm in autumn groups (Wang et al., 2010).

12.3.2.3. Fishing grounds. The suitable temperature for fishing ranges from 15 to 28°C and salinity from 29.0 to 34.5. The fisheries have developed in three main areas in the East China Sea, viz., the southern, central and northern parts, and two main regions in the South China Sea viz. the southern part of Hainan Island, and the central-southern part of Beibu Gulf (Chen et al., 2013b). Liao et al. (2006) suggested that the fishing grounds were generally located in the area between 25 and 29°N, 121 and 126°E, where the water depths range from 100 to 200 m.

12.3.2.4. Economic importance. The annual economic value of the swordtip squid has been more than $20 million for the past 10 years in Taiwan, while separate statistics were not reported for the Chinese mainland (Wang et al., 2008).

12.3.2.5. Duration of fishing period by fishing region. In the southern part of the East China Sea, the fishing season is from May to October with a peak from June to August. In the central regions of the East China Sea, the fishing season is from July to October with a peak from July to August. For the southern part of Hainan Island, fishing occurs year round with peaks in spring and summer. In the central-southern Beibu Gulf, fishing also occurs year round but with peaks in spring, summer, and autumn.

12.3.2.6. Catch and effort data. The swordtip squid is the most important coastal fishery species, being fished mainly by the torch-light fishery in Taiwan and by the trawl fishery on the southeast coast of China, and with annual landings of more than 20,000 t (Chyn et al., 1998; Song et al., 2008; Chen et al., 2013b). In the Beibu Gulf, previous survey data showed that the average CPUEs were 0.36, 3.55, and 2.80 kg/hr in 1997–1999, 2000–2002, and 2007, respectively (Sun et al., 2011). From 2000 to 2002, the highest CPUEs were up to 9.64, 15.50, and 15.15 kg/h in the northern South China Sea, Beibu Gulf and southern Hainan Island, and the eastern Hainan Island, respectively (Li et al., 2010). In the area west of 25°30'N and 33°30'N, 128°00'E of the East China Sea, the average CPUEs were 8.2 and 4.2 kg/h in 1994–1996 and 2004–2006, respectively (Song et al., 2008). In China, the catch of swordtip squid were generally recorded together with Mitre squid and the total catch fluctuated between 100,000 and 200,000 tones since 1996.

12.3.2.7. Stock assessment and management. Fishing is forbidden in the spawning grounds during the breeding period. There is a need to explore light-lure fishing instead of the traditional trawl fishery.

12.4. *Uroteuthis chinensis (Mitre Squid)*

12.4.1 *Stock Identification*

Spring and autumn spawning groups are separated based on spawning seasons (Chen et al., 2013b).

12.4.2. *Distribution and Lifecycle*

The Mitre squid is widely distributed in the South and East China Seas from Japan, Gulf of Thailand, Arafura, and Timor Seas to northern Australia in the western Pacific Ocean (Roper et al., 1984). Spawning occurs throughout the year (Roper et al., 1984). The Mitre squid has a longevity of no more than 7 months (Jackson and Choat, 1992; Sukramongkol et al., 2007). The size range of the mature females is smaller than that of mature males. In the Andaman Sea of Thailand, the age of mature squid ranges from 87 to 125 days (121–286 mm ML) for males and 75–151 days (104–235 mm ML) for females (Sukramongkol et al., 2007).

12.4.3. *Fishing Grounds*

The suitable temperature for fishing is from 21 to 29°C and suitable salinity is from 32.0 to 34.5%. The fisheries have developed in three main areas in the South China Sea: the waters around the southern part of the Hainan Island, the southwest part of Beibu Gulf, and the Taiwan shoal (Chen et al., 2013b).

12.4.4. *Economic Importance*

The fishery accounts for up to 90% of the Chinese loliginid catch (Chen et al., 2013b).

12.4.5. *Duration of Fishing Period by Fishing Region*

Around the southern part of the Hainan Island, the fishing season is from April to September with a peak from July to September. In the southwest part of Beibu Gulf, the fishing season is from April to January with a peak from July to September. In the Taiwan shoal, fishing occurs from April to September with a peak from July to September.

12.4.6. *Catch and Effort Data*

The Mitre squid is the most targeted species in the Chinese loliginid fishery with a maximum catch of 100,000 t (Chen et al.,

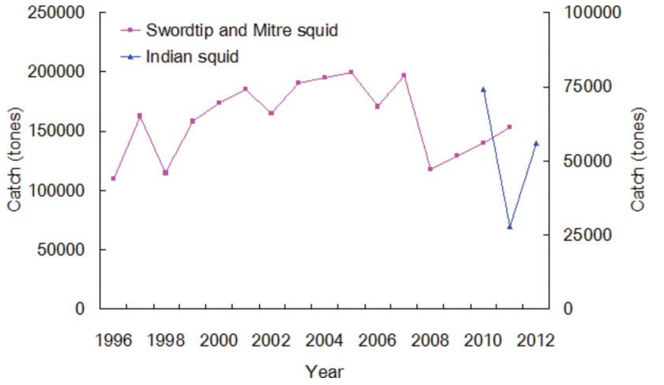

Figure 67. Total annual catches of swordtip, mitre, and Indian squid in China in 1996–2012.

2013b) (Figure 67). In the Taiwan shoal fishing grounds, annual landings were 20,000–25,000 t (Zhang et al., 2008). In the Beibu Gulf, the CPUE ranged from 0.07 to 1.91 kg/h, 1.07 to 5.51 kg/h, and 2.08 to 3.49 kg/h in 1997–1999, 2000–2002, and 2006–2007, respectively (Li and Sun, 2011).

12.4.7. Stock Assessment and Management

Fishing is banned in the spawning grounds during the breeding period.

12.5. Uroteuthis duvaucelii (Indian Squid)

12.5.1. Stock Identification

Spring, summer, and autumn spawning groups are separated based on spawning seasons (Chen et al., 2013b).

12.5.2. Distribution and Lifecycle

The Indian squid is widely distributed in the Indian Ocean periphery including the Red Sea and Arabian Sea, extending eastward from Mozambique to the South China Sea and Philippines Sea, northward to Taiwan (Roper et al., 1984). Spawning of the squid occurs throughout the year, but usually peaks when water temperature increases (Roper et al., 1984). The squid longevity is no more than 1 year (Supongpan and Natsukari, 1996; Sukramongkol et al., 2007). The size range of mature females is smaller than that of mature males.

12.5.3. Fishing Grounds

The fisheries have developed in two main areas of China, namely, the northern South China Sea and the waters off Zhejiang province (Chen et al., 2013b).

12.5.4. Duration of Fishing Period by Fishing Region

In the northern South China Sea, fishing occurs throughout the year with peaks in autumn. Off the Zhejiang province, fishing occurs throughout the year with peaks in summer.

12.5.5. Catch and Effort Data

During 2006–2007, in the waters off southern Zhejiang province, the CPUE was from 0.65 to 7.05 kg/h (Chen et al., 2013b). In recent years, the average catch was around 50,000 t (Figure 67).

12.6. Taiwanese Loliginids

12.6.1. Species

There are at least nine species of loliginid squids that have been identified around Taiwan: four species in the genus *Lilolus*, one species in the genus *Sepioteuthis* and four species in the genus *Uroteuthis*. *S. lessoniana* is targeted by the recreational fishery (angling) in the coastal waters of North Taiwan from August to March, and occasionally found in the harvest of commercial fisheries (trawlers).

12.6.2. Distribution and Lifecycle

Uroteuthis edulis are predominant in the south East China Sea, while *U. chinensis* and *U. duvaucelii* are predominant in Taiwan Strait.

12.6.3. Population Structure

Based on maturation and growth parameters, the spawning grounds of *U. edulis* are thought to be around three isles off north Taiwan (Wang et al., 2008). Based on statolith microstructure analysis, hatching may occur year round, peaking in spring (March–April) and autumn (October–November) (Wang et al., 2010). The lifespan of *U. edulis* was estimated to be at least 9 months.

12.6.4. Fisheries Status

The annual production of neritic squid (loliginid squid) from Taiwan ranged from 1900 t (in 1968) to 20,000 t (in 1998) between 1959 and 2011. The average annual production was 9400 t, which accounted for 78.4% of the domestic cephalopod fisheries in Taiwan for the last two decades (Figure 68). The annual production of neritic squid reached a historic high (20,000 t) in 1998 and then declined thereafter. Loliginid squids are harvested by a torch-light net fishery (accounting for 62.1% of domestic neritic squid production), and secondly by a trawl fishery (accounting for 32.9%). The contribution to total catch of the torch-light net fishery showed a decrease in recent years (Figure 69).

12.6.5. Fishing Grounds and Seasons

The fishing grounds are located on the shelf of the East China Sea with isopleths at 100–200 m and range from 25° to 28°N and 121° to 126°E. Seasonal movement of the fishing vessels was applied to infer the migration of the squid in this region (Liao et al., 2006). The fishing season of the torch-light net fishery is between April and November, and particularly between July and September.

12.6.6. *Conservation Management Measures*

Although the fishing vessels need a legal license to operate in the waters around Taiwan, no conservation management measures are currently adopted for the squid fishery. However, at least two scientific projects were carried out since 2010 to examine the species and stock status of loliginids off North Taiwan and in the northern Taiwan Strait. The reference points for management will be determined in the near future based on the results from these studies.

12.7. *Berryteuthis magister (Schoolmaster Gonate Squid)*

Berryteuthis magister (Berry, 1913) is also known as schoolmaster gonate squid, magistrate armhook squid, commander squid, or red squid. *B. magister* belongs to the family Gonatidae (Nesis, 1982). This is the only species of the gonate squids in the North Pacific which is fished commercially both as a target species and as a bycatch by demersal and bottom trawl fisheries (Osako and Murata, 1983; Fedorets, 2006; Ormseth, 2012). This squid species is widely distributed in the boreal North Pacific Ocean and its marginal seas (Naito et al., 1977; Nesis, 1998).

12.7.1. *Stock Identification*

Various stock identification approaches have been applied to reveal stock composition of *B. magister* across the species range. Extensive population structure studies of *B. magister* using biochemical genetic techniques have revealed geographically related patterns within the species gene pool (Katugin, 1999, 2002). Similar geographic patterns were revealed using morphometric analysis of *B. magister* gladius (Katugin et al., 2004). These studies along with the analyses of size-at-maturity data and distribution of different ontogenetic stages in *B. magister* suggested that there presumably exist geographical superpopulations associated with major basins in the North Pacific: the Japan, Okhotsk and Bering Seas, and Gulf of Alaska. The Japan Sea squid differ most strikingly from the others and constitute a separate subspecies; conspecific populations inhabiting other areas are much closer to each other than to their counterparts from the Japan Sea in genetic composition, biology and morphology. A multi-disciplinary approach has revealed that squid populations from the Okhotsk Sea show certain differentiation from the northwestern Bering Sea squid; however, these squid have much in common in lifecycle patterns and differ from the Northeast Pacific stocks at least in size-at-maturity profiles (Katugin et al., 2013). A number of studies suggested a rather complicated stock structure for *B. magister* inhabiting the Northwest Pacific. The existence of two major successive spawning groupings, or cohorts (spring-summer and autumn-winter) were proposed to comprise *B. magister* aggregations off the Kuril Islands and in the western Bering Sea based mainly upon long-term observations on monthly changes in size-and-maturity composition of the squid catches (Fedorets et al., 1997a, b; Fedorets, 2006). More detailed analysis using data on length-frequency, maturation, and age structure (based upon microstructure of gladii and statoliths) has revealed the existence of several seasonal groups in *B. magister* aggregations inhabiting the northwestern Bering Sea slope (Arkhipkin et al., 1996). In the southeastern Bering Sea, along the Aleutian Islands and in the Gulf of Alaska, aggregations of *B. magister* also exhibit a rather complex structure with successive seasonal cohorts, judging from size structure of the squid in trawl catches (Ormseth, 2012; Katugin et al., 2013).

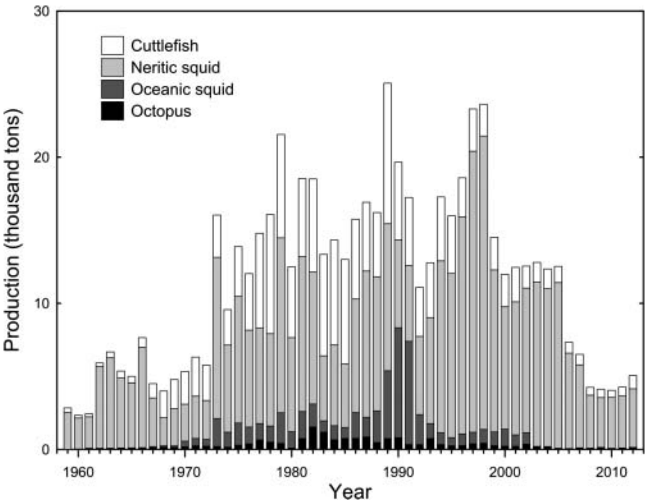

Figure 68. Production of total domestic cephalopod fishery, neritic squids, cuttlefishes, octopus, and oceanic squids of Taiwan from 1959 to 2011.

12.7.2. *Distribution and Lifecycle*

The distribution range of *B. magister* extends along the continental slope of the North Pacific Rim: in the Japan, Okhotsk,

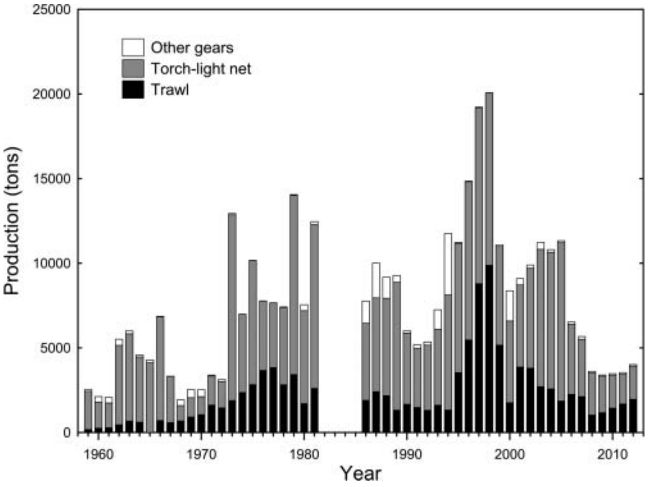

Figure 69. Production of total domestic neritic squid fishery, as separated by torch-light net fishery and trawl fishery, of Taiwan from 1959 to 2011.

and Bering seas, including underwater rises (Jamato, Kitajamato, and Oki in the Japan Sea; Shirshov and Bowers ridges in the Bering Sea), in the North Pacific Ocean off the northeast coast of Honshu and east Hokkaido, along the Kuril Islands and east Kamchatka, along the Commander-Aleutian chain of islands, in the Gulf of Alaska and further southeast to waters off California (Nesis, 1998). This is a boreal demersal species living within a wide depth range from the lower sublittoral zone down to the bathyal (mostly upper-bathyal) zone (Nesis, 1985), and is considered quasibenthic in its life mode, which means that its lifecycle is associated with the bottom (Okutani, 1988). Bathymetric distribution of *B. magister* is very characteristic: the densest concentrations of adult individuals are found on the slope predominantly within 300–500 m depth in most areas of the squid occurrence (Nesis, 1998). Squid frequently occur within the core of the warm intermediate layer where water temperature is about 3.5–3.9°C in the northwestern Pacific Ocean, Okhotsk, and Bering Seas (Fedorets, 1983, 2006; Arkhipkin et al., 1996), and live in generally much colder conditions at about 0–1.5°C in the Japan Sea (Railko, 1979).

There is no shortage of information on distribution and biology of *B. magister* micronektonic juveniles through spawning adults. However, reports on *B. magister* egg-masses are still to be verified, and data on the earliest ontogenetic stages are scanty, which strongly hampers the understanding of the species lifecycle. Some authors suggest that squid paralarvae live in the epipelagic plankton community for several months and are therefore susceptible to wide dispersal over vast geographic areas (Kubodera, 1982; Fedorets, 2006). However, in spite of high abundance of juveniles and adults, paralarvae of *B. magister* occur extremely rarely, and the most reliable information suggests that they occur primarily in deep water (e.g., Okutani, 1988). It was proposed that functional structure of the species range can be associated with the large-scale gyres in the North Pacific, which serve as major external factors influencing the observed population structure and life history patterns (Katugin, 1998; Alexeev, 2012). A modified version of the species lifecycle, based on critically analyzed data on distribution and occurrence of different ontogenetic stages, suggests that passive dispersal of newly hatched squid is rather limited, and squid are demersal during the greater part of their life, foraging in the pelagic zone mainly as juveniles and living primarily near the bottom as adults (Katugin et al., 2013).

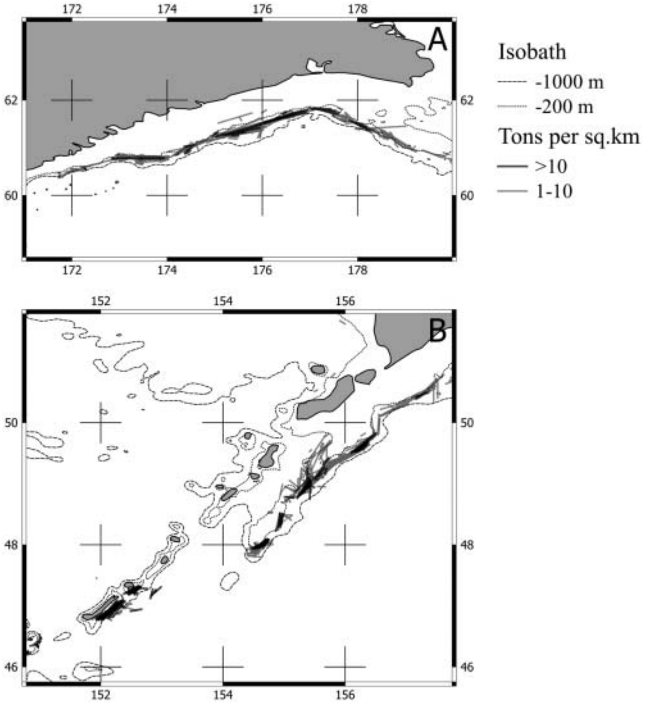

Figure 70. Distribution density (tons per square km) of *Berryteuthis magister* in areas where commercial fishery takes place: (A) northwestern Bering Sea and (B) Pacific Ocean off the Kuril Islands.

12.7.3. *Fishing Grounds and Seasons*

Fisheries for *B. magister* takes into consideration the existing knowledge on the species distribution and lifecycle, and in different areas, is based upon aggregations of large adult individuals at different stages of maturity. Areas where *B. magister* has been historically harvested by commercial trawlers are scattered all over the extended geographic range of the species, and include underwater rises in the central and continental slope in the northwestern Japan Sea, Pacific Ocean along the Kuril Chain and east Kamchatka, western and southeastern Bering Sea, continental slope around the Commander and Aleutian islands, and the Gulf of Alaska. However, today major fishing areas for this species are located within the Russian EEZ in the northwestern Pacific Ocean off the Kuril Islands and southeast Kamchatka, and in the northwestern Bering Sea (Figure 70). Maximum distribution density of *B. magister* calculated from bottom trawl catches appeared the highest on the underwater plateau off the north Kuril Islands, of about 1,300 t per square km. Off the Simushir and Urup islands maximum distribution density peaked at 810–855, on the bank between Bering and Mednyi islands at 690, and in the western Bering Sea at about 560 t per square km.

Size and maturity features of *B. magister* in the harvested commercial aggregations vary in different fishery areas. In the western Bering Sea, where there is no direct fishery for *B. magister* and squid are taken mostly as a bycatch during fishing for groundfish and walleye pollock, aggregations are usually comprised primarily of large maturing, fully mature, and prespawning individuals. In that region, about 60% of captured females ranged from 240 to 270 mm ML, and 70% of males had ML of 200–230 mm, and up to 70% of all animals were at advanced maturity stages (IV and V). On the banks close to the Commander Islands, where trawlers intentionally fished for *B. magister* close to the spawning grounds, about 70% of captured females had ML ranging from 230–270 mm, and up to 90% of males had ML of 200–270 mm; over half of harvested females and about 80% of males were at advanced

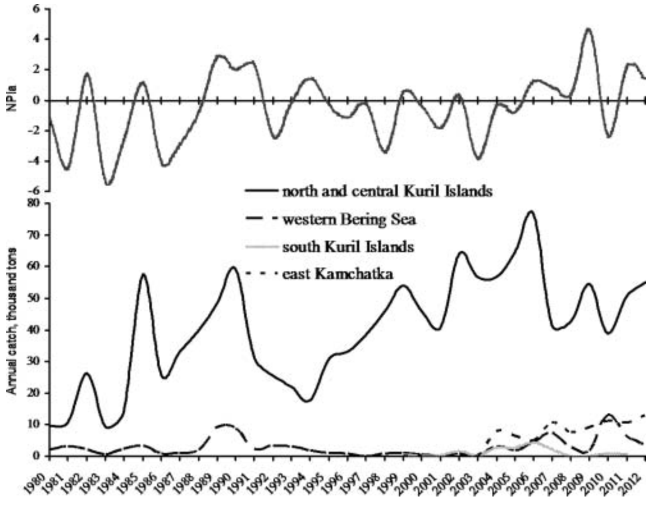

Figure 71. Annual catch for *Berryteuthis magister* in the northwestern Pacific Ocean fishing grounds, and oscillations of the Aleutian Low index (NPIa).

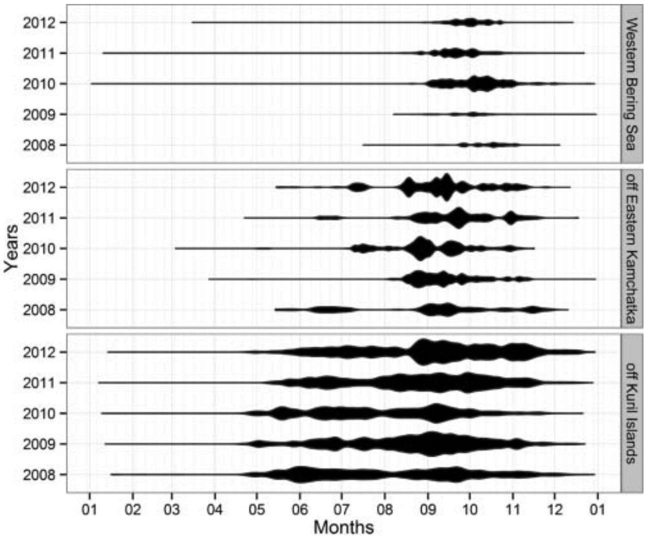

Figure 72. Seasonal variability in catch for *Berryteuthis magister* in different fishing areas (shaded area correspond to the total annual catch in each fishing region).

maturity stages. Occasionally up to 100% of harvested squid were prespawning (stage IV) and spawning (stage V), and spent individuals (stage VI) sometimes comprised 20–30% of commercial catches (Fedorets et al., 1997b). In the Pacific Ocean off the Kuril Islands, where *B. magister* is a target species, commercial aggregations of the squid consist mainly of foraging adult squid, mostly females being at the onset of maturation and males at more advanced stages. In fishing areas off the north Kuril Islands (Paramushir and Onekotan islands), about 60% of captured females had ML ranging from 210–250 mm, and 70% of males had ML of 190–220 mm; about 70% of all females were virtually immature (stage II), while almost half of all males were maturing and ready to mate (stages III and higher). Off the central Kuril Islands (Simushir and Ketoy islands), 60% of captured females ranged from 220–250 mm ML, and 80% of males had ML of 200–240 mm; about 60% of females were at stage II, and 70% of males were at stage III and higher. Therefore, commercial harvest for *B. magister* within the Russian EEZ is based upon aggregations of adult animals; however, mostly mature and ready to spawn individuals are captured in the western Bering Sea and near the Commander Islands, and mostly immature individuals comprise the bulk of the catch off the Kuril Islands.

12.7.4. Catch and Effort Data and Fishing Fleet

In Russia, targeted or specialized fishery for *B. magister* dates back to 1977, and during the last three decades, total annual catch of this squid fluctuated from 9,200 to 90,200 t with an evident drop in the mid-1990s, followed by a positive trend and a peak in 2006 (Figure 71). In these years, targeted fishing for *B. magister* took place mainly off the north and central Kuril Islands, where total annual catch ranged from 8,600 to 76,630 t, and accounted for 60–99% of the total catch for this squid in the Russian EEZ. In the ocean off the south Kuril Islands and east Kamchatka, and in the western Bering Sea (on the slope along the Koryak coast and in the Olutorskyi Bay), the species was harvested as a bycatch in walleye pollock and bottom-fish fisheries during 1999–2003. However, the beginning of a targeted fishery in these areas in 2004 resulted in a sharp increase of the annual catch, up to about 13,000 t in the western Bering Sea in 2010 and off east Kamchatka in 2012. High-density near-bottom aggregations of *B. magister* at spawning grounds on the slope of the banks ocean-ward off the Commander Islands were harvested in the late 1960s–early 1970s, and occasionally through the early 1990s until closure was imposed on any fishing operations within the 30-miles prohibition zone around the islands, which were declared a state nature reserve. Annual landings of *B. magister* around the Commander Islands did not exceed 3000 t.

CPUE for *B. magister* has been traditionally estimated and reported by captains of fishing vessels as the catch in t per day per vessel (CPDV). Large commercial trawlers with gross capacity exceeding 2500 t account for the greater portion of *B. magister* total catch off the Kuril Islands and east Kamchatka and in the western Bering Sea. For example, from 74% to 89% (on average, 81.8 ± 2.7%) of the total squid catch off the Kuril Islands came from large fishing trawlers in 2009–2013. For large gross capacity vessels, CPUE varied within a wide range, and peaked usually at about 20–30 t CPDV during "high season" in major fishing areas, rising occasionally up to 45–46 t CPDV (e.g., off the north Kuril Islands in the late summer–early autumn in 1998 and 1999).

Distribution of daily catch for *B. magister* in different fishing areas shows that, in the western Bering Sea and off eastern Kamchatka, squid are harvested mainly during fall, while off the Kuril Islands, there are two seasons of high catches: early (usually in the late spring and early summer) and late (usually in autumn) (Figure 72).

A number of studies provided explanations for the variability in catch during fishery operations for *B. magister*. On the one hand, the observed seasonal changes in the squid catch (and abundance) are related to such factors as the species life-cycle features and stock structure, in particular, to the existence of successive cohorts. On the other hand, external factors may also have direct or indirect impacts on the squid abundance. At the fishing grounds off the Kuril Islands in the Pacific Ocean, high-density concentrations of the squid were frequently associated with quasi-stationary mesoscale eddies, which originated as a result of interaction between large-scale (geostrophic) currents and local tidal activity coupled with specific geomorphological structures of the bottom (Railko, 1983; Malyshev and Railko, 1986). Monthly fluctuations in the character and intensity of daily tidal currents along the Kuril Chain supposedly influence both density and distribution depth of the squid commercial aggregations: the densest concentrations are frequently associated with the depth of warm intermediate layer, and squid usually aggregate at shallower depths during the highest tides (when daily tidal fluctuations are up to 1.2 m) and are found notably deeper when tidal amplitude is low (of about 0.3–0.6 m) (Fedorets et al., 1997a). Regional changes in atmospheric pressure may also presumably influence the squid distribution by changing the sea level height and associated intensity of water exchange between the sea and the ocean through the Kuril passes: low pressure over the south Okhotsk Sea and high pressure over the oceanic area off the islands may provide favorable conditions for squid migrations from the sea through the passes to fishing grounds in the ocean (Alexeev, 2012). On the decadal scale (1997–2010), the squid distribution and abundance along the Kuril Islands were evidently impacted by changes in hydrology associated with the variability in the atmospheric pressure system over the North Pacific, in particular, with the position and structure of the Aleutian Low: in warm years, when due to the position of the Aleutian Low the winter monsoon was relatively weak, the squid catches tended to be higher (Katugin et al., 2013).

To efficiently identify important variables influencing catch fluctuations, we used maximum information coefficient (MIC) (Reshef et al., 2011; Speed, 2011). It appeared that, among an array of climate indices (AOIa, NPIa, PDOw, PDOs, PDOa, SAI, SI, AI, WPw, and WPsp with and without time lag) commonly available (http://www.beringclimate.noaa.gov), only the Aleutian Low index, or NPIa (Kalnay et al., 1996) showed relatively strong association with annual *B. magister* catch off the north Kuril Islands (MIC = 0.53). However, although during 1980–2012, increased catches were observed mainly in years with positive NPIa, and vice versa (Figure 71), only less than 10% of changes in annual catches were due to oscillations of NPIa, and most of the observed variability in catch was explained by temporal autocorrelation between catches in successive years (Katugin et al., 2013, 2014).

12.7.5. Stock-Assessment Methods

Direct survey-based assessment of *B. magister* biomass in the major fishery area along the Kuril Islands is impossible because high-density squid aggregations are located on the narrow sharp slope and near rough ground in that area. The method of the so-called “trawl tracks” (Railko, 2005), which takes into account distribution patterns and behavior of the species, has been suggested to estimate the squid biomass in fishing areas off the Kuril Islands. It has been noticed that, during the fishing season, squid density decreased by the end of each fishing day, and the more vessels trawling for squid, the quicker the fall of catch per hour trawling. However, by the new day, when the fishing is resumed after a break for the night, squid again became numerous on the fishing grounds. Therefore, to calculate squid biomass, it has been assumed that, within a given depth range, all squid are taken out during a day of fishing and new squid migrate from adjacent areas and totally replenish the harvested aggregation. During 1987–2012, biomass of *B. magister* assessed using the “trawl tracks” approach off the central and northern Kuril Islands, fluctuated from 77,000 to 284,100 t. However, along the Kuril slope, tracks for relatively safe bottom trawling are located within a narrow depth range on the slope, generally between 270 and 450 m, which automatically leads to underestimation of the real squid biomass in the region. The total area occupied by trawl paths or tracks, suitable for trawling, account for only 7–10% of the slope area off the islands, where the squid occur in large quantities. Therefore, we may assume that biomass assessments for *B. magister* off the Kuril Islands are in fact underestimated. Contrary to that, in the northwestern Bering Sea, where the continental slope is less rugged (e.g., along the Koryak coast, Olutorskyi-Navarin region between capes Olutorskyi and Navarin), stock assessments for *B. magister*, based on bottom trawl surveys, which almost totally cover the depth range of squid occurrence, seem to be more realistic. For example, within a wide area from the Olutorskyi to Anadyr bays, the squid biomass has been assessed at about 190,000 t in the autumn of 1998 based on bottom trawl survey (Lapko et al., 1999).

Seasonal changes in the squid distribution density in the western Bering Sea have been thoroughly studied during a experimental fishery by Japanese research bottom trawlers (Bizikov, 1996). It was shown that in May-June, mean density distribution of the squid is low, about 200–300 kg/km^2; by August, average density grows to 500 kg/km^2 and in aggregations even higher, up to about 2,000 kg/km^2. The squid density grows toward early October, and then decreases. The instantaneous harvested stock of *B. magister* was estimated to vary from about 4,500 t in June to about 30,000–60,000 t in October in different years within the Olutorskyi-Navarin region. Retrospective data for the western Bering Sea (*B. magister* stock abundance estimated from research trawl surveys) suggested that, in the Olutorskyi-Navarin region, autumn biomass was the highest ever recorded during 1976–1979, about

350,000–390,000 t (Fedorets and Kozlova, 1986), and decreased down to about 200,000 t in the 1990s (Fedorets et al., 1997).

Assessments of *B. magister* biomass have been used to set limits for TAC of this species in major fishing areas. Conventionally, TAC is set at about 45–55% of the total assessed biomass within each major fishing area (waters off the Kuril Islands, waters off East Kamchatka, and western Bering Sea). Such a proportion of TAC from the total assessed biomass has been historically applied for *B. magister* taking into consideration similar values usually applied for short-lived iteroparous animals such as pelagic squid, for example, *T. pacificus* (Osako and Murata, 1983), and other squid species (Au, 1975). Usually, the TAC limit for *B. magister* has not been attained in any of the statistical fishing regions. Annual catch usually accounted for about 75% of the TAC off the north and central Kuril Islands and 50% of the TAC off east Kamchatka only rarely hitting the limit (e.g., in 2006 off the Kuril Islands), and has been considerably lower, accounting for only 10–12% of the TAC in the western Bering Sea though showing a positive trend in recent years (Dudarev et al., 2012). Such a discrepancy between areas in the use of TAC stems from the fact that, in the western Bering Sea, *B. magister* was harvested as a bycatch up to 2003 and mainly in autumn, and off the Kuril Islands, squid are fished almost all the year round.

The fact that *B. magister* is harvested at a relatively low level (below TAC) does not allow us to apply the concept of MSY for the management of this species. However, the use of a production model fairly satisfactorily predicted biomass values, and given that, during the last decade, MSY showed a slight positive trend, as well as the percent of TAC taken annually, the TAC must be higher than 70,000 t even under a precautionary approach with bias-corrected approximate confidence limits of 80%.

12.7.6. Economic Importance

The economic importance of *B. magister* can be estimated from the amount of and wholesale price for food products that are prepared annually from squid by different companies fishing for this species in Russia. Time series of production output and interpolated price for different *B. magister* frozen products which are delivered to the wholesale market (e.g., mantle without fins, skinned mantle without fins, arms, etc.) suggest that general production increases by the end of the year, which is associated with high squid catches during the autumn season; and though production output showed a similar intra-annual pattern every year, the price for products from squid varied among seasons and years (Figure 73). Beginning from 2009, the highest profit from selling the squid products on the market within Russia was made in 2011, reaching almost 4.5 billion rubles, which roughly equaled 150 million US dollars.

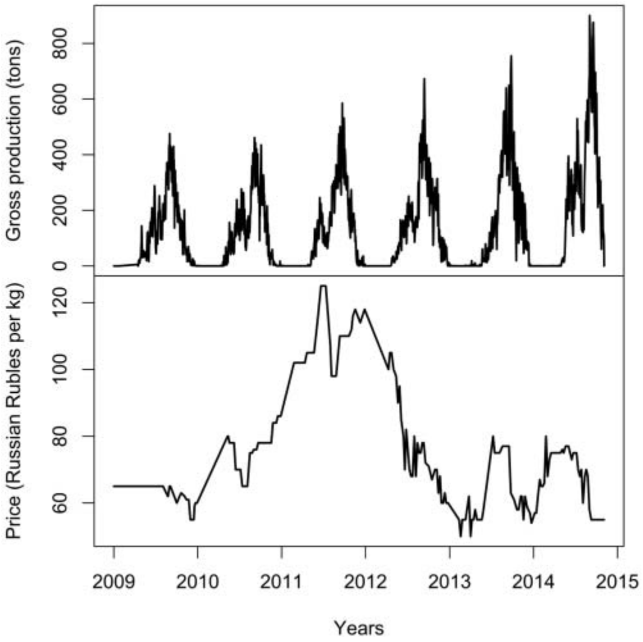

Figure 73. Time series for food production (tons) from *Berryteuthis magister* delivered to the Russian whole-sale market and associated income from sales per unit of production weight (Russian Rubles per kg).

12.8. *Thysanoteuthis rhombus* (Diamond Squid, Diamondback Squid)

12.8.1. Stock Identification

Mitochondrial DNA analyses of individuals collected around Japan (Okinawa, the Sea of Japan, and the Ogasawara (Bonin) Islands) and from the eastern Pacific near the Galapagos Islands have found no evidence of stock structure either around Japan or across the Pacific (Kitaura et al., 1998).

12.8.2. Distribution and Lifecycle

Thysanoteuthis rhombus is a cosmopolitan species distributed worldwide in tropical and subtropical waters. In Japan, it occurs around central and southern Japan at higher latitudes than in other regions in the world due to its association with the Tsushima Current, which transports young stages northeastward from southern spawning grounds into the Sea of Japan (Nishimura, 1966). Catch data and stranding records suggest it is more abundant along the Sea of Japan coast than along the Pacific coast.

Spawning in southern Japan appears to occur almost year round, and more than one microcohort is observed annually in the Sea of Japan (Miyahara et al., 2006c). Back-calculations from growth-increment counts in statoliths and catch dates indicate that individuals in the Sea of Japan hatch from January to September, with a peak in February–March. Spawning also occurs during summer-autumn in the Sea of Japan (Miyahara et al., 2006a), but individuals that hatch during this period will encounter reduced temperatures as they grow, which will slow growth and presumably reduce survival.

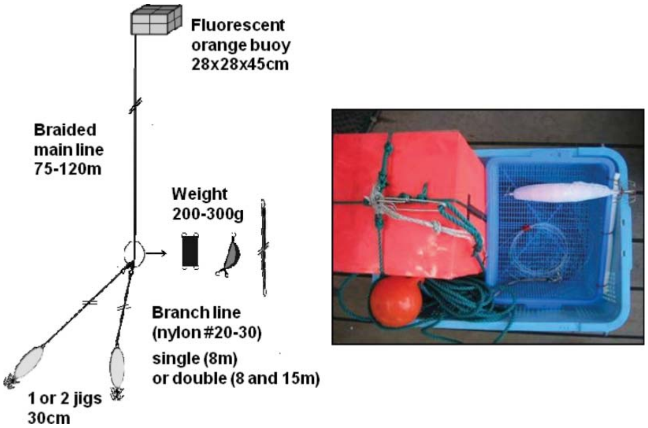

Figure 74. Scheme and picture of typical gear used in the *taru-nagashi* fishery of *Thysanoteuthis rhombus* in the Sea of Japan. The gear used in the *hata-nagashi* in Okinawa Prefecture is very similar, but has a longer main line (350–700 m) and more jigs. Also a flag is attached to the floating buoy so that fishers can find the gear easily in the wide ocean.

The early life stages have characteristics similar to those of other oceanic squid whose young are passively dispersed (Miyahara et al., 2006b). Growth rates do not differ significantly between sexes, but the microcohorts in the Sea of Japan grow at different speeds depending on the time of hatching; earlier-hatched squid grow faster than later-hatched ones (Miyahara et al., 2006c). In the Sea of Japan, males mature from about 470–520 mm ML, and females mature from about 590–610 mm ML (Nazumi, 1975; Takeda and Tanda, 1997, 1998). Analyses of statolith growth increments and catch length–frequency data suggest its lifespan is about one year (Miyahara et al., 2006c).

12.8.3. Fishing Grounds

The only country with a major fishery for *T. rhombus* is Japan. The main fishing grounds are the Sea of Japan, Okinawa Prefecture, and Kagoshima Prefecture, with most catches occurring in the Sea of Japan and Okinawa. Fishing trials have also been promising in the Pacific near the Ogasawara (Bonin) Islands and Izu Islands (Okutani, 1995b; 1998).

The fishery in the Sea of Japan began in the early 1960s using baited hooks, and in 1967 vertical long line gear called "*taru-nagashi*" with an attached free-floating buoy was developed in Hyogo Prefecture. The gear is now used widely in the Sea of Japan. It comprises a weighted vertical main line (75–120 m) attached to one or two jigs (artificial lures) approximately 300 mm in length with two to three rows of stainless steel hooks (Figure 74 and 75). The other end of the line is attached to a rectangular, fluorescent-orange buoy (float) that rests on its side at the surface until an attached jig is grabbed by a squid, which causes the buoy to stand up and signals to the fisher that a squid is on the line. The squid is then pulled either by hand or using a winch to the surface, where it is gaffed or netted, and brought on board. Since this gear is operated visually, it is primarily a daytime fishery (Figure 76).

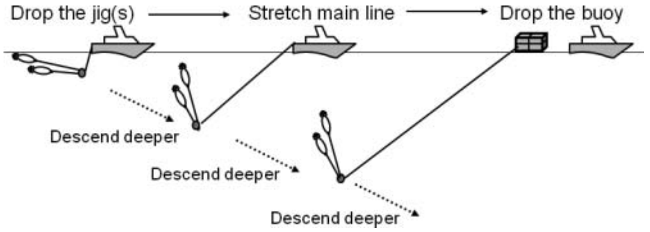

Figure 75. Sequential diagram showing the descent of the *taru-nagashi* fishing gear. One fisher uses 30–80 sets of gear a day (daytime fishery), which are set along a north-south line approximately 100 m apart. A standing buoy signals that a squid has been hooked.

The fishing grounds in the Sea of Japan are located in coastal areas and extend from Shimane to Niigata Prefectures. Good catches occur where seawater temperatures during late summer to early winter are >19°C at 50 m and >14–15°C at 100 m (Miyahara et al., 2007a). Most squid in the catches are 300–800 mm ML and weigh 1–20 kg.

In 1989, fishing gear used in the Sea of Japan was introduced in Okinawa Prefecture to target *T. rhombus*, which was previously collected as a bycatch in a fishery for purpleback flying squid (*S. oualaniensis*) (Kawasaki and Kakuma, 1998). The gear was adapted to suit oceanographic conditions there. This improved gear is named "*hata-nagashi*" (*hata* means "flag"). It comprises several jigs attached to a longer main line (300–750 m) than those used in the Sea of Japan, and the line is attached to several buoys and a flag at the surface. After it was introduced, catches increased, and the fishery spread throughout the prefecture and to Amami Oshima Island (Kagoshima Prefecture).

MLs of squid caught around Okinawa and Kagoshima Prefectures range from 300 to 900 mm, and most measure 600–800 mm (Kawasaki and Kakuma, 1998; Ando et al., 2004); this size is larger than those caught in the Sea of Japan. This difference is due to the different fishing seasons, growth rates, and migration routes (Figure 77).

Interest in *T. rhombus* is growing outside Japan. There is a small-scale, artisanal fishery in the Dominican Republic (Herrera et al., 2011), and there is interest in developing fisheries in other areas of the Caribbean (JICA, 2010), the Philippines (Dickson et al., 2000), New Caledonia (Blanc and Ducrocq, 2012), the Cook Islands (Sokimi, 2013), and Fiji (SPC Coastal Fisheries Programme, 2014).

12.8.4. Economic Importance

Together with *T. pacificus* and *U. edulis*, *T. rhombus* is one of the most important species for small-scale coastal squid fishers in the Sea of Japan, especially in southern areas. The annual fishery production value of *T. rhombus* in Hyogo Prefecture in 1998 reached 480 million yen (about US$4.7 million). About 40% of the catch from the Sea of Japan is landed in Hyogo, thus the overall production in the Sea of Japan was roughly 1.2 billion yen (about US$11.7 million).

In Okinawa Prefecture, the estimated annual production during 2001–2010 was in the range of 1–2 billion yen (about

Figure 76. Photos showing how *Thysanoteuthis rhombus* is typically fished in Hyogo Prefecture (Sea of Japan). (A) A typical boat used in the fishery. Most boats are operated by one fisher. (B) A bouy (float) resting on its side, indicating that no squid has grabbed a jig attached to the line. If a squid grabs a jig, the buoy will stand up. (C) When a fisher spots a standing buoy, the gear is retrieved using a winch and by hand. (D) Buoys on deck. (E) When the squid reaches the surface, it is gaffed or netted, and brought onboard (F).

US$9.75–19.5 million). *T. rhombus* has become a core target species, and catch amounts there are now second only to that of tuna.

12.8.5. *Composition and Numbers of the Fishing Fleet*

In the Sea of Japan, fishers use boats smaller than five GRT. These squid are caught mainly using vertical long lines set by one to two fishers (usually one) on board privately owned boats. Licenses are not needed for angling, and the numbers of fishing boats vary depending on the annual biomass (immigration level) of *T. rhombus* and other squids, such as *T. pacificus* and *U. edulis*. Fishers also catch *T. rhombus* in inshore set nets.

Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Sea of Japan		▨	Peak months			▨	▨	Off-season				
Okinawa	Closed season*				░	▨	Peak months					▨

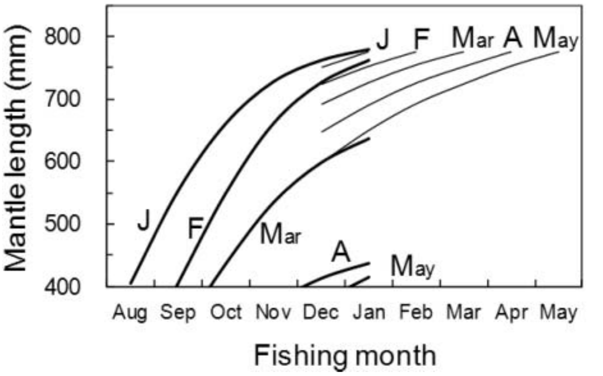

Figure 77. Fishing seasons and estimated growths of *Thysanoteuthis rhombus* in the Sea of Japan and around Okinawa Prefecture. The fishing season in Okinawa (*) is based on annual instructions from the Okinawa Sea-area Fishery Adjustment Commission. Growths were estimated by substituting hatching dates of January 1 (J), February 1 (F), March 1 (Mar), April 1 (A), and May 1 (May). Thick curves: growth curves for *T. rhombus* in the Sea of Japan (Miyahara et al., 2006c). Thin curves: growth curves for those in tropical-subtropical waters calculated using the logistic formula from Nigmatullin et al. (1995).

In Okinawa Prefecture, most fishers use boats of 5–10 t. In 2011, there were 300–400 boats in the drop-line fishery and 1 boat in the long-line fishery.

12.8.6. *Duration of Fishing Period by Fishing Region*

In the Sea of Japan, the fishery usually runs from early August to February, with highest catches occurring in September–November. Squid are transported by the Tsushima Current from upstream spawning grounds, which are thought to extend from the southwest Pacific to the East China Sea (Miyahara et al., 2006c). Immigration into the Sea of Japan through the Tsushima Strait starts in late spring and continues through early fall. The fishing period is subject to the amount and timing of this migration. The migrants are mainly postlarvae and juveniles, which are fished as they grow (Figure 77).

In Okinawa and Kagoshima Prefectures, the fishing season is regulated. It runs mainly from November to June, with highest catches occurring during February–April.

12.8.7. *Catch and Effort Data*

The Japanese national government does not publish official catch data for *T. rhombus,* but Bower and Miyahara (2005) reported that the total national catch peaked in 2001 at about 5900 t. Annual catches fluctuate widely in both the Sea of

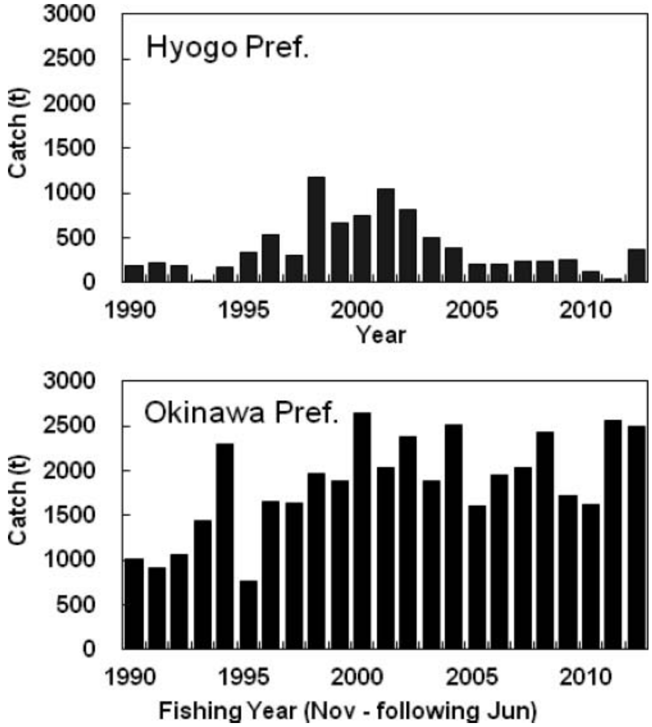

Figure 78. Annual catches of *Thysanoteuthis rhombus* in two major fishing regions in Japan. The Japanese national government publishes no official catch data for *T. rhombus*, and the catch amounts are estimated by local research institutes. Top: Hyogo Prefecture, which generally has the highest catches among prefectures in the Sea of Japan. Bottom: Okinawa Prefecture, which composes over approximately half of the national catch.

Japan and Okinawa, but the variance is larger in the Sea of Japan.

In the Sea of Japan, the annual abundance is strongly related to environmental indices (e.g., water temperature) near the Tsushima Strait, when the stock passes through the strait. Changes in catch amounts show similar trends among prefectures facing the Sea of Japan. Annual catches during 1990–2012 in Hyogo Prefecture, which generally has the highest catches among prefectures in the Sea of Japan, ranged from 10 to 1179 t (Figure 78). The highest annual production in the Sea of Japan was about 3700 t in 1998.

Catches in Okinawa compose over half of the national catch, and annual catches during 1990–2012 (caught from November to the following June) were about 800–2600 t (Figure 78).

12.8.8. *Stock Assessment Management*

Miyahara et al. (2007b) assessed the stock of Hyogo Prefecture using the DeLury method (both the standard method and a modified one taking account of the natural mortality coefficient (M) as in Rosenberg et al., 1990) and VPA. The initial stock abundance in Hyogo Prefecture on August 1 ranged from 100,000 to 700,000 individuals, and the estimated overall abundance in the Sea of Japan in 1999–2004, when M was 0.05–0.1, was roughly 200,000–2,000,000 individuals. The exploitation rates in 1999–2004 were 0.3–0.7, suggesting that the fishing pressure can be very high. However, the result of the VPA suggested that fishing pressure was not concentrated in the early fishing season, and growth overfishing was not observed.

Recruitment into the fishery in the western Sea of Japan during the peak fishing season (September–November) has been shown to be positively related to seawater temperatures 600 km upstream in the Tsushima Strait in June, and several models incorporating environmental indices near the strait have been shown to accurately predict the annual CPUE in the fishery (Miyahara et al., 2005). The distribution and abundance of catches are also related to seawater temperatures on the fishing ground (Miyahara et al., 2007a).

In Okinawa and Kagoshima Prefectures, the stock has not been assessed, but it is closely managed by administrative commissions and local governments. Annual official instructions of the Sea-area Fishery Adjustment Commissions regulate the fishing season, number of drop-line gear, number of jigs (artificial lures) on a long-line, fishing areas, etc.

Nigmatullin and Arkhipkin (1998) estimated the worldwide biomass of *T. rhombus* to be at least 1.5–2.5 million t, but the worldwide standing stock is not known (NOAA et al., 2005).

12.8.9. *Conservation Measures and Biological Reference Points*

In the Sea of Japan, the stock structure is strongly affected by environmental conditions when the squid migrate into the Sea of Japan. Environmental indices and CPUE have been found to closely correspond, so numerical models based on oceanographic conditions have been proposed to forecast future fishing conditions (Onitsuka et al., 2010). Strict in-season management can help prevent growth overfishing of the young, and simulation studies suggest that closing the fishery during the first 10–20 days, when the body size of recruited squid is small, will have little effect on total catch amounts due to its fast growth. In 2001, a community-based program to release small recruits was implemented and resulted in a more stable market price.

On the other hand, there are no known measures that can effectively stabilize the catches during the following year. Extensive tagging studies have found no evidence of a return spawning migration to the East China Sea (Miyahara et al., 2008), and spawners in the Sea of Japan have few chances to produce future recruits under the present oceanographic conditions (null dispersion), so fishing pressure in the Sea of Japan probably does not affect the future stock size.

In Okinawa Prefecture, more detailed fishery biological information about, for example, the migration during the off-season and the stock-recruit relationship, is needed to assess and evaluate the stock. But many management measures have resulted in efficient utilization of recruits and secure spawners. Continuous monitoring of exploitation strength in more tropical regions is also needed to consider future management of the fisheries around Japan.

12.9. Watasenia scintillans (Firefly Squid)

12.9.1. Stock Identification

In the Sea of Japan, there is thought to be one stock based on the extent of the spawning grounds (Nihonkai Hotaruika Shigen Kenkyu Team, 1991).

12.9.2. Distribution and Lifecycle

The firefly squid is distributed in the western North Pacific. Individuals about 70 mm ML are distributed mainly in the Sea of Japan, Sea of Okhotsk and along the Pacific coast of Japan (Okutani, 2005). Adults occur near the seafloor at depths of 200 m or more during the day and migrate upward to depths of 50–100 m at night (Nihonkai Hotaruika Shigen Kenkyu Team, 1991; Hayashi, 1995b). The lifespan is 12–13 months for females and 11–12 months for males (Yuuki, 1985; Hayashi, 1995b). Spawning in the Sea of Japan occurs mainly from April to June when the females aggregate around the 200 m isobath (shelf break) at the spawning grounds in the eastern Tsushima Channel, off Oki Island, in Wakasa Bay, and in Toyama Bay, but eggs are collected throughout the year (Yuuki, 1985; Nihonkai Hotaruika Shigen Kenkyu Team, 1991; Hayashi, 1995b; Kawano, 2007). In the southwestern Japan, the main spawning ground forms in Tsushima Current waters deeper than 130 m depth with salinity 34.2–34.6‰ (Kawano, 2007). Mating occurs mainly from January to March, after which the males die (Yuuki, 1985; Hayashi, 1995b).

12.9.3. Fishing Grounds

In the Sea of Japan, there are two main fishing grounds, which correspond with the spawning grounds: Toyama Bay (Toyama Prefecture) and the southwestern Sea of Japan. In Toyama Bay, *W. scintillans* is caught in fixed nets set around and near the shelf break in the innermost part of the bay (Figure 79), where the shelf is narrow and the break runs near the coast. The catches comprise mostly mature females, which migrate to spawn. Uchiyama et al. (2005) suggested that the potential and optimum sea temperatures for squid fishing in Toyama Bay are 9–15°C and 11–13°C, respectively. The results of multiple regression analyses suggest that potential indices for forecasting the catch of squid entering the bay from spring include water temperature, salinity and predation pressure (Nishida et al., 1998).

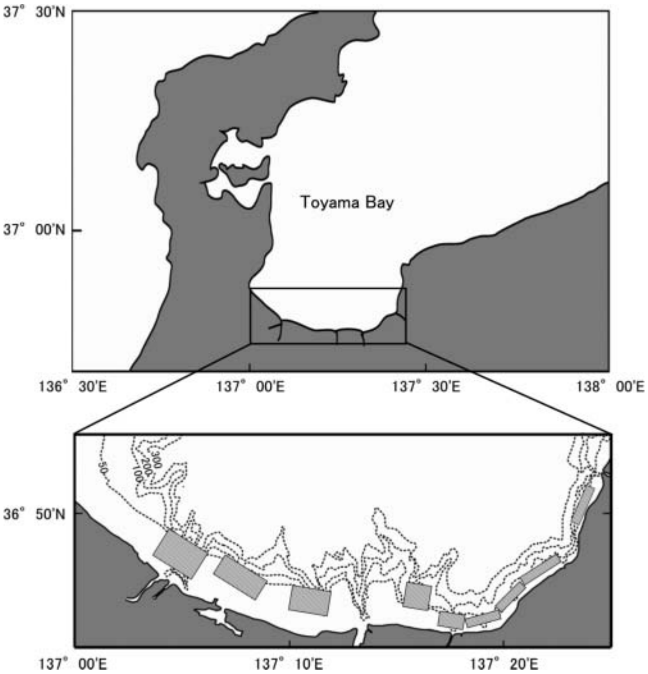

Figure 79. Locations of fixed nets used to fish *Watasenia scintillans* (shaded areas) in the innermost part of Toyama Bay, Japan.

In the southwestern Sea of Japan, *W. scintillans* is caught in bottom trawls towed at 200–230 m bottom depth, and good catches occur where the 200 m isobath runs close to Japan (mainland and/or islands) such as off Mishima Island (Yamaguchi Prefecture), off Hamada (Shimane Prefecture), east of Oki Island (Shimane Prefecture), off Tajima (Hyogo and Tottori Prefecture), and off Wakasa Bay (Kyoto and Fukui Prefectures, Figure 80). Fishing grounds form due to factors such as bathymetric features, the upwelling of bottom cold water related to Japan Sea Intermediate Water (Senjyu, 1999) and/or Japan Sea Proper Water (Uda, 1934), and vertical diffusion of warm surface waters derived from the Tsushima Current. Catches early in the fishing season (through February) comprise mostly males, but during the peak fishing season (March–May), the catches comprise mostly mature females of 50–60 mm ML, which migrate nearshore to copulate and spawn. MLs of squid caught in the southwestern Sea of Japan are slightly smaller than those caught in Toyama Bay in the same period (Nihonkai Hotaruika Shigen Kenkyu Team, 1991).

12.9.4. Economic Importance

In Toyama Prefecture, *W. scintillans* is marketed fresh or live, and served mainly either raw (mantle and arms) or boiled

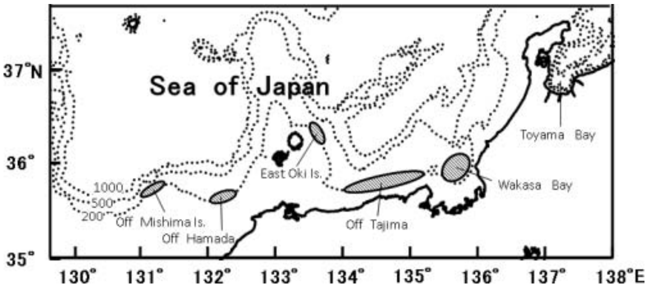

Figure 80. Main *Watasenia scintillans* fishing grounds by bottom trawl fisheries in the southwestern Sea of Japan.

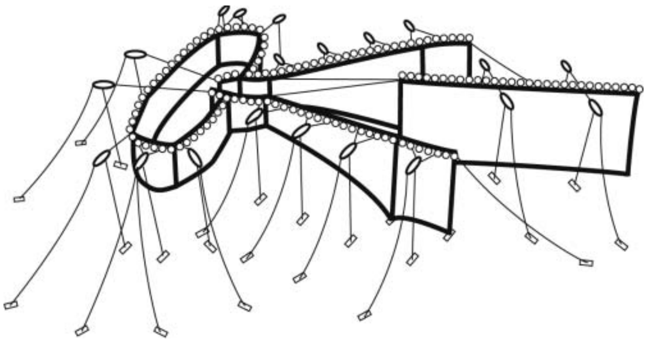

Figure 81. Design of a typical fixed net used to fish *Watasenia scintillans* in Toyama Bay.

(whole). The annual catch value of *W. scintillans* in Toyama Prefecture during 1985–1990 was 0.5–1.6 billion yen (about US$ 4.9–15.8 million at May 2013 exchange rate), which was 4–11% of the total annual value of the fishery in Toyama Prefecture (Hayashi, 1995b). In recent years, the annual catch value in Toyama Prefecture has been about 1 billion yen (about US$ 9.9 million at May 2013 exchange rate) (Uchiyama et al., 2005).

The firefly squid is also an important tourist attraction. Many people enjoy watching the bioluminescent flashing of squid caught by fixed nets in the early morning and of squid that wash ashore. Part of Toyama Bay has been designated by the Japanese government as a special natural monument called "*Hotaru-ika Gunyu Kaimen*," meaning "sea surface" where *W. scintillans* schools.

In the southwestern Sea of Japan, *W. scintillans* is now one of the most important target species for bottom trawlers. Recent annual catch values of *W. scintillans* have been about 1.1 billion yen (about US$ 10.8 million at May 2013 exchange rate), which accounts for about 6% of annual total catch value from bottom trawls (mean in 2010–2012, from Tottori to Ishikawa Prefecture). In the peak fishing season (March–May), *W. scintillans* composes 21% of the total catch value from the bottom trawls. In Hyogo Prefecture, where most of the catch in the southern Sea of Japan is landed, 96% of bottom trawlers target *W. scintillans* in April. During this month, *W. scintillans* composes 57% of the total catch amount and 54% of the total catch value.

12.9.5. Composition and Numbers of the Fishing Fleet

Probably, fishing for *W. scintillans* began as early as 1585 using primitive fixed nets (Inamura 1994), and now it is one of the most important fisheries in Toyama Prefecture. Recently 46 fixed nets have been used to catch *W. scintillans* in Toyama (Nanjo unpubl. data); in the late 1980s, 52–54 fixed nets were used (Nihonkai Hotaruika Shigen Kenkyu Team, 1991).

Fixed nets used for fishing *W. scintillans* have a large trap with a chamber, which has side walls reaching to the surface, and is closed at the bottom by netting to catch *W. scintillans* guided from a funnel-shaped entrance by a long leader net (Figure 81). The leader net is placed toward the shore to guide the females returning offshore after spawning inshore (Hayashi, 1995a). Squids that enter the net at night are landed before daybreak and transported to markets in the morning.

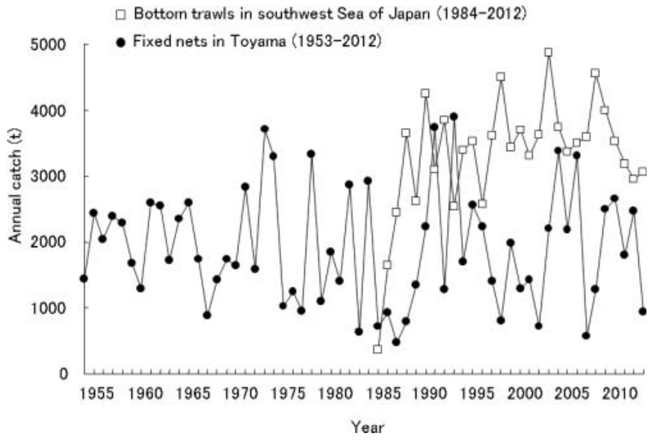

Figure 82. Annual catches of *Watasenia scintillans* fished by the fixed nets in Toyama Bay (Toyama Prefecture) in 1953−2012 and by the bottom trawls in the southwestern Sea of Japan in 1984−2012.

Trawl fisheries for firefly squid in the southwestern Sea of Japan operate using single seine trawlers of <10–125 t. The bottom trawls are operated only in daytime when adult squids are distributed near the seafloor. During 2010–2012, about 40% of bottom trawlers from Tottori to Ishikawa Prefecture targeted *W. scintillans*. The trawlers use special trawling gear to catch *W. scintillans* effectively and avoid bycatch such as brittle stars (*Ophiura sarsisarsi* et al.) and snow crabs (*Chionoecetes opilio*). The gears consist of large-sized nets with small meshes (cod-end meshes = around 13 mm) and light-weight ground ropes. The nets are suspended from the ground rope using vertical ropes or major meshes.

12.9.6. Duration of Fishing Period by Fishing Region

In Toyama Bay, the fishing period for fixed nets lasts from March to July. Peak catches have usually occurred from late April to early May (Uchiyama et al., 2005), but in recent years, catches have occurred earlier (from late February to early June with a peak in April) (Nanjo unpubl. data).

In the southwestern Sea of Japan, the fishing season for bottom trawls occurs during January-May, with a peak in March–May.

12.9.7. Catch and Effort Data

The annual landings by fixed nets in Toyama Bay during 1953–2012 fluctuated considerably between about 500 and 3900 t, with a mean of about 1900 t (Figure 82).

In the southwestern Sea of Japan, the stock was first exploited as bycatch in 1984, after which bottom trawlers began to target the stock (Figure 82). In 1985, the catch amount in the southwestern Sea of Japan exceeded that of Toyama Bay. Since 1986, catches have reached 2500–4500 t. About 130 fishing boats target the squid in this area (mean in 2010–2012).

12.9.8. Stock Assessment and Management

The stock in the Sea of Japan has been assessed using the DeLury method, scientific echo sounders, and the egg production method (Nihonkai Hotaruika Shigen Kenkyu Team, 1991). The most accurate method, the egg production method, which is based on data from the broadest sea areas in the Sea of Japan, indicated that overall exploitation rates in the Sea of Japan during 1986–1989 were 0.03–0.05. This suggests that the fishing pressure was low enough to prevent recruitment overfishing (Nihonkai Hotaruika Shigen Kenkyu Team, 1991).

Fishing with fixed nets in Toyama Bay also seems to prevent recruitment overfishing, because females can spawn before being caught. The exploitation rates using fixed nets in the bay between 1986 and 1990 was estimated to be 0.142–0.222 (Hayashi, 1995b), and the number of fixed nets has remained stable at around 50 during the last 30 years.

In the southwestern Sea of Japan, fishers in Hyogo Prefecture have used community-based management to limit maximum landing of each boat to 300–400 boxes (2.4–3.2 t) during the peak fishing season. During June–August, the season is regulated by a ministerial ordinance.

12.9.9. Conservation Measures and Biological Reference Points

The firefly squid is an important micronektonic species in the Sea of Japan (Okiyama, 1978). It is an important prey in the Sea of Japan ecosystem (e.g., as a prey for flathead flounder *Hippoglossoides dubius* (Uchino et al., 1994)), and management of the stock of this species should consider its niche in the Sea of Japan ecosystem and potential trophic cascades that could result following its removal from the ecosystem (Yamasaki et al., 1981).

12.10. Todarodes pacificus (Japanese Flying Squid)

12.10.1. Distribution and Lifecycle

The Japanese flying squid, *T. pacificus*, is an ommastrephid squid with a 1-year lifecycle distributed in the northwest Pacific including the Sea of Japan (Soeda, 1950; Hamabe and Shimizu, 1966; Araya, 1967; Okutani, 1977, 1983). *T. pacificus* spawns year round with a peak during autumn and winter (Hamabe and Shimizu, 1966; Araya, 1967; Okutani, 1977, 1983; Kasahara, 1978). The distribution range shifts seasonally with changes in water temperature (Soeda, 1950; Araya, 1967; Okutani, 1977, 1983); the northern limit of its range reaches about 50°N in September and about 40°N in April.

12.10.2. Stock Identification

The Japanese flying squid is divided into three or four cohorts based on spawning season, of which the autumn and winter cohorts are the largest in terms of biomass (Araya, 1967; Okutani, 1977, 1983; Osako and Murata, 1983; Kidokoro et al., 2003; Kidokoro, 2009). The autumn cohort spawns mainly from October to December, and is distributed and landed primarily in the Sea of Japan (Figure 83). The winter cohort spawns mainly from January to March, migrates counterclockwise around the Japanese Islands, and is caught primarily in the Pacific Ocean (Figure 83). The catch statistics of each stock are divided based on differences found in the fishing grounds throughout the seasons using monthly catch statistics (Kidokoro et al., 2003).

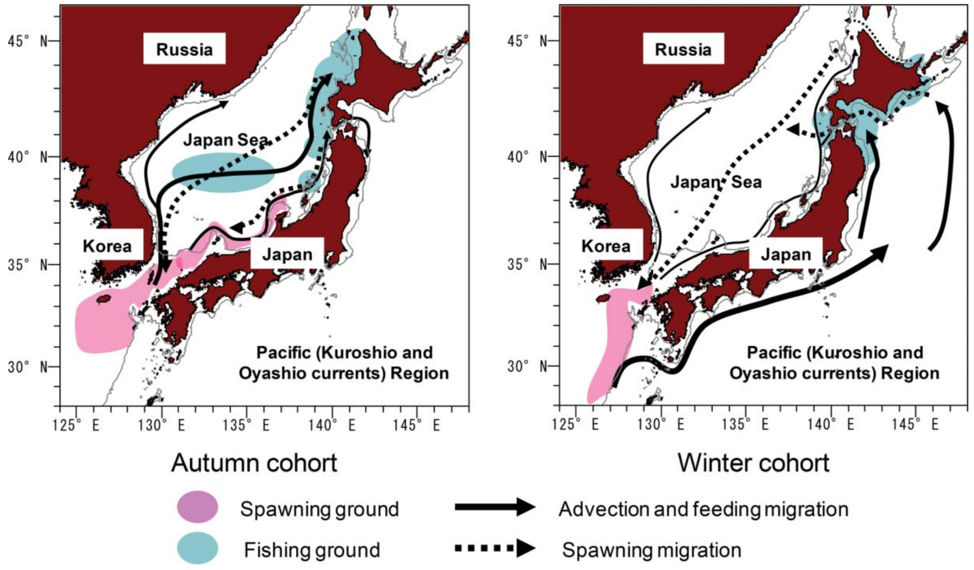

Figure 83. Diagrams of the migration routes of *Todarodes pacificus* autumn cohort and winter cohort (modified from Kidokoro et al. 2010).

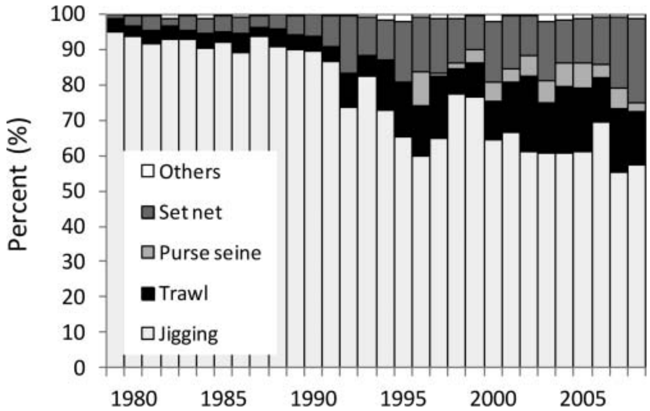

Figure 84. Catch composition of *Todarodes pacificus* by fishing methods in Japanese fisheries.

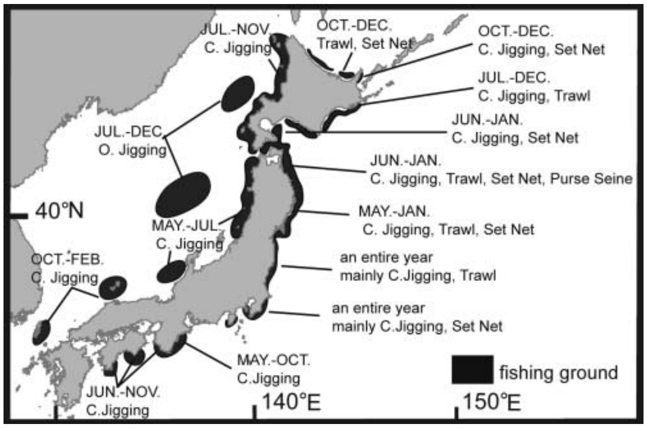

Figure 85. Main fishing grounds and fishing season for *Todarodes pacificus* around Japanese waters. In this figure, main fishing methods are also shown in each fishing ground (modified from Yamashita and Mori. 2009).

12.10.3. Fishing Grounds

The fishing grounds shift seasonally as *T. pacificus* migrates. By June, individuals of the autumn cohort measure approximately 200 mm ML and begin to be caught by commercial fisheries in the Sea of Japan. In July, the winter cohort is targeted by commercial fisheries in the Pacific Ocean. The autumn cohort is fished in the Sea of Japan during June–December. The winter cohort is fished during July–December in the Pacific and during January–March in the Sea of Japan.

12.10.4. Composition of Fishing Fleets

The Japanese flying squid is fished using several fishing methods, but the main method is jigging. There are two categories of jigging vessels: coastal jiggers and offshore jiggers. Coastal jiggers in Japan are restricted in size to less than 30 t, and offshore jiggers are restricted to between 30 and 200 t (to 100 t in the 1980s).

The Japanese flying squid is also fished by offshore trawlers, large and medium-scale purse seiners and set nets, and the catches by these fisheries has increased since the 1990s (Yamashita and Kaga, 2013). Jiggers caught approximately 90% of the total catch during the 1980s (Figure 84), but this percentage declined in the early 1990s to approximately 60% since 2000. Ratios of the other methods have increased, in particular, offshore trawlers, and set nets have reached approximately 10–20% since the 1990s (Figure 84).

The main fishing methods used differ among regions (Kidokoro et al., 2013; Yamashita and Kaga, 2013). In the Sea of Japan, *T. pacificus* is fished mostly by coastal and offshore jiggers (Figure 85). They operate on fishing grounds that are divided into various geographical regions. Coastal jiggers fish coastal areas in the Sea of Japan, and offshore jiggers fish the central part of the Sea of Japan (Figure 85). Catches in coastal areas are landed fresh, and offshore catches are frozen on board.

In the Pacific, *T. pacificus* is taken largely by coastal jiggers, but more than half of the total catch is taken by other fisheries, that is, offshore trawlers, large- and medium-scale purse seiners, and set nets. In the Sea of Okhotsk and Nemuro Strait, the northeastern most fishing ground in Japan (Figure 85), most of the catches are taken by set nets and coastal jiggers, but annual catches have been changing dramatically.

12.10.5. Economic Importance

The Japanese flying squid is commercially the most important cephalopod species in Japan. Annual landings have totaled approximately 500 million dollars in value since the mid-1970s. They are used not only as fresh foods but also processed foods.

There are many factories that process squid in cities near the fishing grounds (e.g., Hakodate and Hachinohe). The annual sales of processed squids are very important for these cities (e.g., in recent years, annual sales of processed squid in Hakodate have been approximately 500 million dollars). In these cities, industries associated with the fishery are important for generating employment. Therefore, stock size fluctuations of *T. pacificus* have greatly affected local communities and economies in these cities.

12.10.6. Catch Statistics

Trends in catch statistics for the Japanese common squid are closely related with the development of the fishery as well as changes in stock size. Before the 1930s, squid were fished in coastal areas with hand lines and jigs from small boats. In the 1940s and 1950s, the fishing boats were motorized, and the fishing grounds expanded offshore. In the 1960s, the number of fishing vessels with large freezers increased, and in the 1970s, most vessels were equipped with squid jigging machines.

Squid fishing has been conducted in Japan for several hundred years, but reliable catch statistics are available for only the past 100 years (Figure 86). Total annual landings of Japanese common squid in Japan were less than 200,000 t before the 1930s and increased in the 1940s with the development of commercial fisheries. Annual landings were usually 400,000–

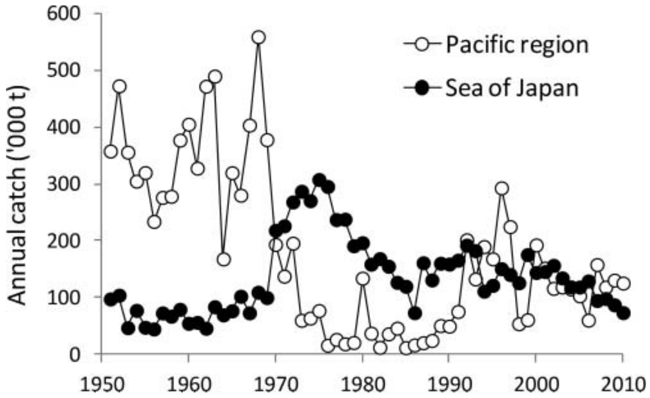

Figure 86. Annual changes in the catches of *Todarodes pacificus* by Japanese fisheries, which are shown by region (Pacific region, Sea of Japan).

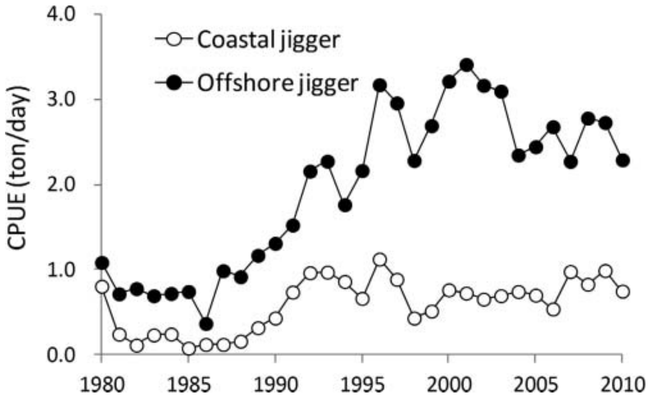

Figure 87. Annual changes in the CPUEs of coastal jigger and offshore jigger target for *Todarodes pacificus*. CPUE of coastal jigger is based on the data of operated in the Pacific region. CPUE of offshore jigger is based on the data of operated in the Sea of Japan (modified from Kidokoro et al. 2013; Yamashita and Kaga. 2013).

500,000 t during the 1950s and 1960s, but decreased during the 1970s, and dropped to 100,000 t in the mid-1980s. In the 1990s, landings increased and have rebounded to about 300,000–400,000 t. However, annual landings have decreased gradually since 2000 (Figure 86).

Annual catches in the Sea of Japan were less than 100,000 t during the 1950s and 1960s (Figure 86). They rose to 200,000–250,000 t in the early 1970s due to the development of offshore fisheries (Kasahara, 1978), but declined to 150,000 t during the mid-1970s and the 1980s with the decline of the stock size of the autumn cohort. Annual catches in the Sea of Japan increased again in the early 1990s with the rebuilding of the stock size of the autumn cohort, but have decreased gradually since 2000 and have been approximately 100,000 t in recent years.

Annual catches in the Pacific were approximately 300,000–400,000 t during the 1950s and 1960s (Figure 86). They declined drastically in the early 1970s, and were approximately 10,000–30,000 t during the 1970s and 1980s. This decline is considered to have been caused by a drastic decline in the stock size of the winter cohort in the beginning of the 1970s (Murata, 1989). However, annual catches in the Pacific region increased in the 1990s, and have been approximately 100,000–200,000 t in recent years (Figure 86).

The decline in the stock size of Japanese common squid during the 1970s and 1980s was considered to have been caused by excessive fishing effort at that time (Okutani, 1977; Doi and Kawakami, 1979; Murata, 1989). However, it is now clear that changing environmental conditions also affects the stock size (Sakurai et al., 2000; Kidokoro et al., 2003). For example, expansion of the spawning grounds with the 1989 regime shift (Goto, 2002), which is thought to have been caused by changing environmental conditions (Sakurai et al., 2000; Kidokoro 2009), was a cause of the increased stock size.

12.10.7. *Changes in CPUE and Fishing Efforts*

Changes in the CPUE and fishing efforts for *T. pacificus* in Japanese fisheries are shown in the assessment reports on the fisheries stocks around Japan (Kidokoro et al., 2013; Yamashita and Kaga, 2013). In the Sea of Japan, CPUE (t/vessel/d) of offshore jiggers was usually below 1.0 t/vessel/d in the 1980s (Figure 87). This has increased since 1989, and has remained high (2.0–3.0 t/vessel/d) for the past two decades (Figure 87). In the Pacific, the CPUE of coastal jiggers was approximately 0.1 ton/vessel/d, until the latter half of the 1980s, but increased to over approximately 1.0 ton/vessel/d since the 1990s, and has been around 0.7–1.0 t/vessel/d in recent years (Figure 87).

The stock size of the autumn cohort has been rather large for two decades (Kidokoro et al., 2013), but annual catches have been decreasing in the Sea of Japan since the beginning of the 2000s. This decrease has been due to decreasing fishing effort. The number of offshore jigger vessels has been decreasing for 30 years (Figure 88). The annual number of operation days by offshore jiggers in the Sea of Japan was more than 100,000 days during the mid-1980s, but this decreased during

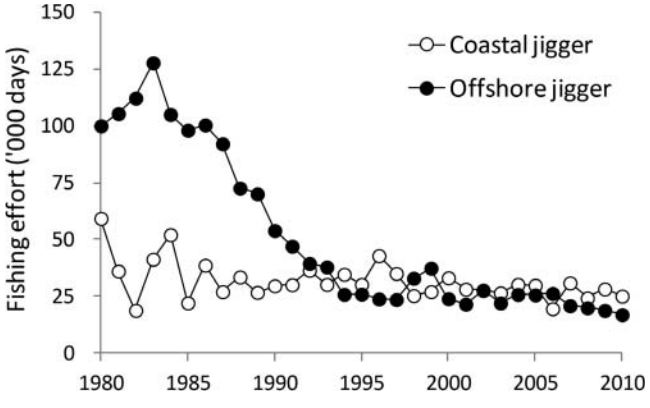

Figure 88. Annual change in the fishing efforts of coastal jigger and offshore jigger targeted for *Todarodes pacificus*. Fishing effort of coastal jigger is shown by the days operated in the Pacific region. Fishing effort of offshore jigger is shown by the days operated in the Sea of Japan (modified from Kidokoro et al. 2013; Yamashita and Kaga. 2013).

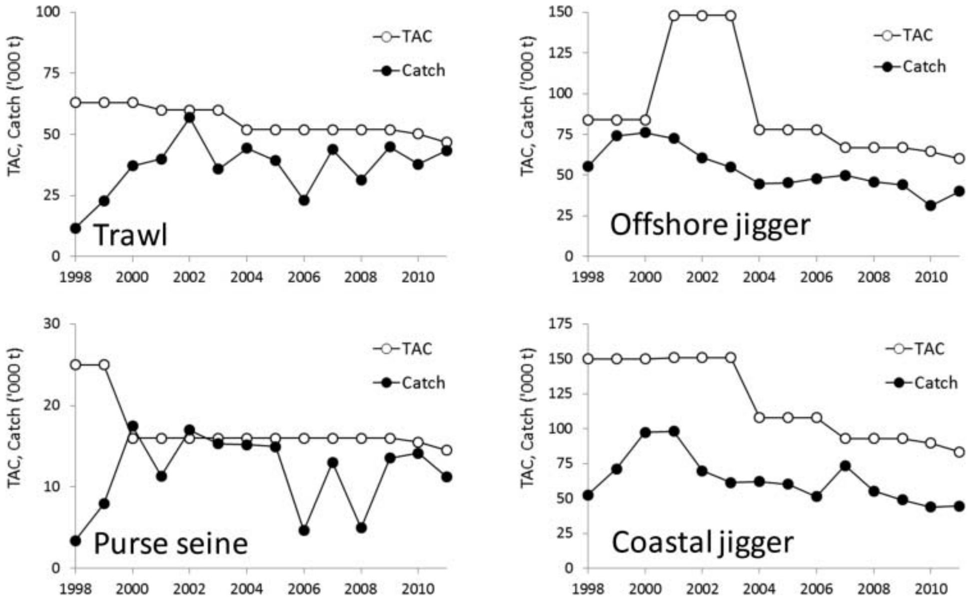

Figure 89. Annual changes in the quota on Japanese *Todarodes pacificus* fisheries. TAC is shared into major fisheries in the Japanese management system. In these figures, annual catches by each fishery are also shown.

the next two decades to approximately 15,000–20,000 days in the late 2000s (Figure 88).

On the other hand, fishing effort in the Pacific coast appears to have not decreased. The annual number of operation days by coastal jiggers that landed catches at major ports in the Pacific, have been stable at 30,000 days since 1990 (Figure 89). These differences in fishing effort by region are considered to have led to the differences in catch trends by region observed in the 2000s.

12.10.8. Stock Assessment Methods and Management

Although some Japanese fisheries have been regulated through licensing systems, practical management has been left up to the fishermen themselves. The Japanese Fisheries Agency has managed seven major fisheries stocks since 1997 using the TAC method. *T. pacificus* was added to the TAC management plan in 1998. The annual TAC is set by the government through a process that weighs a combination of socioeconomic factors and the ABC recommended by researchers at the national fisheries research institute. *T. pacificus* is assessed as two stocks (autumn cohort and winter cohort), and an ABC is recommended for each stock, but TAC is set for the total annual catch using the sum of the two recommended ABCs. The TAC is shared among the major fisheries (coastal jiggers, offshore jiggers, offshore trawlers, large and medium scale purse seiners, and set nets) and regulated separately by the fisheries, although the ratios of actual landings to TAC differ among fisheries (Figure 89).

The calculations of the Japanese ABCs are modeled after those used in the United States (Restrepo et al., 1998). ABC (ABC_{limit}) is calculated from the fishing mortality (F_{limit}) and forecasted stock abundance in the target year. The F_{limit} usually uses BRPs (e.g., F_{msy}, F_{med}, $F_{0.1}$: see Caddy and Mahon, 1995) or current fishing mortality when the current stock size is above a threshold stock size (B_{limit}). If the current stock size is below the B_{limit}, then the F_{limit} should be set below the BRP to rebuild the stock to an acceptable level within an appropriate time frame (Restrepo et al., 1998). The BRP used as the F_{limit} is revised every year using data from recent surveys.

Change in the annual stock size of *T. pacificus* has been monitored by surveys conducted by scientific research vessels with jigging machines at the beginning of the fishing season since the 1970s (Kidokoro et al., 2013; Yamashita and Kaga, 2013). The density of *T. pacificus* at each station is estimated based on the CPUE (the number of individuals caught/squid-jigging machine/hr (ind./hr)) of the research vessels, and the average CPUE is used to calculate the annual stock index (Kidokoro et al., 2013; Yamashita and Kaga, 2013).

Stock abundance is quantified based on the stock index, which is assumed to be related to stock abundance. Spawning stock abundance (the number of survivors) is calculated as survivors after fishing season based on the stock abundance, annual catch and natural mortality, which is assumed to be 0.6 (Kidokoro et al., 2013; Yamashita and Kaga, 2013). BRPs are estimated based on the estimated spawner-recruit relationship. Currently ABC is calculated based on F_{med} (Caddy and Mahon, 1995) and the forecasted stock abundance, which are both estimated from the spawner-recruit relationship (Figure 90). ABC_{limit} is calculated from F_{limit} and the forecasted stock abundance, which is also estimated based on the spawner-recruit relationship. In this way, the spawner-recruit relationship plays an important role in the present assessment and management method for *T. pacificus* in Japan (Kidokoro et al., 2013; Yamashita and Kaga, 2013).

In most cephalopod stocks, there is usually no clear relationship between spawning stock abundance and subsequent recruitment (Pierce and Guerra, 1994; Basson et al., 1996; Uozumi, 1998). However, it is well known that spawning stock abundance of *T. pacificus* as determined from the paralarval density shows a clear positive relationship with stock abundance in the following year (Okutani and Watanabe, 1983; Murata, 1989; Sakurai et al., 2000). This indicates that the spawner-recruit relationship can be used to estimate the BRP and to forecast recruitment (Kidokoro et al., 2013; Yamashita and Kaga, 2013).

For ommastrephid squids, annual variability in oceanographic conditions causes annual variation in recruitment strength (Dawe et al., 2000; Waluda et al., 2001). Moreover, decadal or inter-decadal variations or regime shifts also influence the stock status (Sakurai et al., 2000). The stock size and landings of ommastrephid squids fluctuate widely on decadal and inter-decadal scales.

The spawner-recruit relationship of *T. pacificus* is assumed to change with changing environmental conditions; in particular, decadal or inter-decadal changes are assumed to influence the stock status and spawner-recruit relationship (Kidokoro et al., 2013; Yamashita and Kaga, 2013). Therefore, the parameters used in our spawner-recruit relationship were estimated from data collected since 1990 following an apparent regime shift (Figure 90), but when the current regime changes, these parameters should be revised accordingly. However, it is unclear how changing environmental conditions influence the stock size of *T. pacificus,* and it is difficult to predict when the regime shift might occur.

On the other hand, the results of investigations show that the spawning grounds (Goto, 2002), migration routes (Nakata, 1993; Kidokoro et al., 2010), and body size (Takayanagi, 1993) all show changes that coincide with changing stock size. These changes are assumed to be closely connected with changing environmental conditions (regime shifts) and/or stock abundance. In particular, the shift in the spawning grounds may affect the survival rate of paralarvae accounting for the changing stock size. We need to better understand these ecological changes and how they affect stock size to allow us to better forecast future trends in stock abundance.

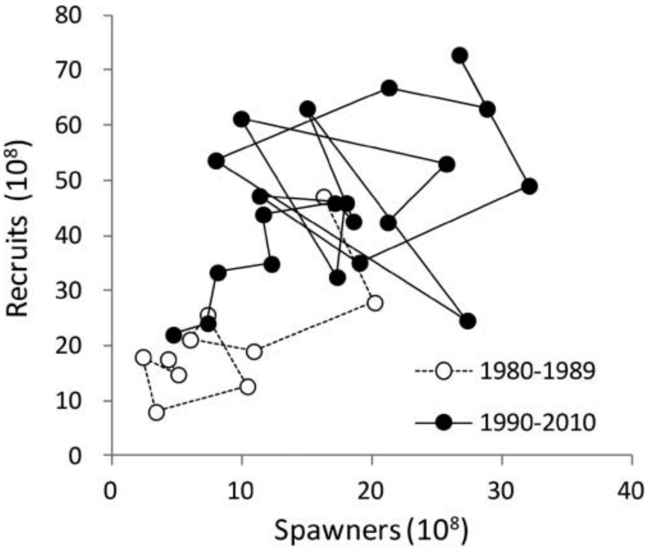

Figure 90. Spawner–recruit relationship in the autumn cohort. There is a significant positive relationship between the number of spawners and recruits in the following year (modified from Kidokoro et al. 2013).

12.11. *Sthenoteuthis oualaniensis (Purpleback Flying Squid)*

12.11.1. Stock Identification

The purpleback flying squid has a complex population structure comprising three major and two minor forms (see Section 11.1). Data from the northwest Indian Ocean on ML composition and maturity stages suggest several other groups of different sizes may exist in addition to the above forms (Chen et al., 2007). There is partial overlap in the geographic ranges of these forms. Three seasonal subpopulations with differing size-maturity relationships have been reported from Taiwanese waters (Tung, 1976). Roper et al. (2010) suggested that the species is in the process of intensive adaptive radiation and all five forms are species in the nascent state.

12.11.2. Distribution and Lifecycle

The purpleback flying squid is widely distributed in tropical and subtropical oceanic waters of the Pacific and Indian Oceans, generally where the bottom depth exceeds 200–400 m and where the surface temperature ranges from 16° to 32°C (Roper et al., 2010). The distribution is patchy and concentrated in areas of high productivity between 40°N and 40°S (Snyder, 1998). High-latitude areas are used by migrant squid as foraging zones, mainly by females (Roper et al., 2010). The species is abundant ($\sim$5 t km^{-2}) in the northwest Indian Ocean and South China Sea.

12.11.3. Fishing Grounds

Currently, no large-scale fisheries target this species. The development of commercial fisheries is impeded for three reasons: (1) its scattered and patchy distribution in the open ocean; (2) the lack of an effective fishing method; and (3) the relatively poor quality of the meat compared to other species. Despite these shortcomings, there are small-scale fisheries in the South China Sea, near Okinawa and in the Arabian Sea (Figure 91) using automatic squid jigging, light-attraction falling nets (LAFN) and hand jigging (Chen et al., 2007; Peng et al., 2010). The fisheries target mainly adults larger than 25 mm ML. The species is also collected as bycatch.

12.11.4. Economic Importance

The purpleback flying squid has increased in importance as a fishery resource during the last decade as several countries have been trying to develop fisheries. China recently developed a small-scale fishery in the South China Sea and Arabian

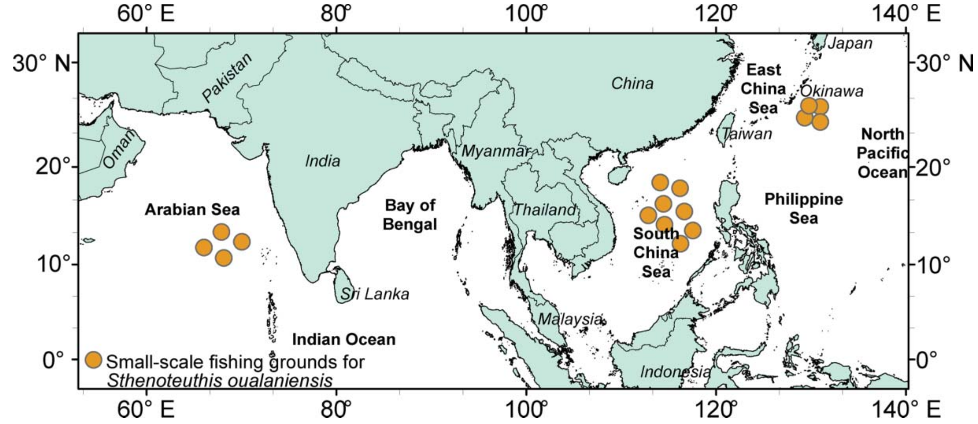

Figure 91. Locations of small-scale fisheries for *Sthenoteuthis oualaniensis* in the South China Sea, near Okinawa and in the Arabian Sea using automatic squid jigging, light-attraction falling nets and hand jigging.

Sea. In 2008, the estimated value of the catch in the South China Sea was US$ 4 million (Peng et al., 2010). Between 2006 and 2009, mean monthly catches decreased from 197.1 t to 56.7 t, whereafter many fishing vessels switched to other fisheries in the South China Sea (Peng et al., 2010). In Hawaii, the species is used mainly as bait in the tuna handline fishery.

Globally, little research has been conducted with the aim to develop commercial fisheries for *S. oualaniensis;* however countries bordering the Arabian Sea and South China Sea have recently shown an interest in developing fisheries. To explore the feasibility of a commercial jigging fishery on oceanic squid in the South China Sea and western Philippines, the Southeast Asian Fisheries Development Center (SEAFDEC) (2000) conducted a survey in the region in 1998 under the SEAFDEC Collaborative Research Program. Countries that participated in the survey included Thailand, Vietnam, Malaysia, the Philippines, and Japan. The survey estimated biomasses of 283 metric t in the western Philippines and 1.132 million metric t in the South China Sea (Siriraksophon, 2009). To date, no commercial fishery has been developed in the region.

Due to decreasing coastal resources, India has recently begun exploring offshore waters. Research cruises have been conducted to explore potential fishing areas for *S. oualaniensis* in the central Arabian Sea. Both gillnets and automatic jigging machines were used, and gillnets were found to be effective for the adult species (Mohamed et al., 2011). Dense aggregations (~130,000 ind./km^2) of juveniles ranging from 3 to 30 mm ML were observed and collected from surface waters using scoop nets. The stock abundance of adult squids was estimated to be 5 t/km^2.

The purpleback flying squid was studied in the Bay of Bengal and Andaman Sea under the "Ecosystem-Based Fishery Management in the Bay of Bengal," a collaborative survey project carried out from October to December 2007 by Bangladesh, India, Myanmar, Sri Lanka, Nepal, and Thailand. The objective was to assess potential fishery resources, including *S. oualaniensis*. Catches were slightly higher in the Andaman Sea ($n = 30$) than in the Bay of Bengal ($n = 9$), but were too low for fishers to develop a commercial fishery (Sukramongkol et al., 2008). CPUE using automatic jigging machines was 0.03 kg/line/hr. In 1997, jigging trials conducted in northern Australian waters yielded small catch amounts (Dunning et al., 2000).

The Fishery Agency of Japan conducted two survey cruises during 1975–1976 in the Arabian Sea to examine pelagic fish abundance as part of FAO's project on the Indian Ocean. These cruises identified dense aggregations of *S. oualaniensis* in the mesopelagic layer (100–300 m) during daytime and epipelagic layer at night (Fishery Agency of Japan, 1976). In 1995, the Fishery Agency of Japan conducted another survey cruise in the Arabian Sea and Indian Ocean to study the abundance and biology of *S. oualaniensis*. This survey recorded all three major forms of *S. oualaniensis* with higher CPUEs for middle-sized and giant forms. Ommastrephid paralarvae were also collected, with *S. oualaniensis* paralarvae dominating the catch (~33%) in the northern Arabian Sea (Yatsu, 1997; Yatsu et al., 1998a).

High amounts of cadmium, urea, and ammonium chloride in *S. oualaniensis* makes it less palatable than other squid on the market (Nakaya et al., 1998; Narasimha Murthy et al., 2008; Roper et al., 2010). Additional food processing is required to make it competitive against other squid products.

12.11.5. Composition and Numbers of the Fishing Fleet

In 2008, 50 boats in the South China Sea caught a total of 5000 t. In 2009, the market price decreased, and only 10 boats remained in the fishery, with a total landing of 500 t (Peng et al., 2010). Artisanal fisheries using dipnets and hand jigs are conducted near Okinawa (Japan), Taiwan, and Hawaii (USA) (Roper et al., 2010). Other countries where *S. oualaniensis* is caught either in small-scale fisheries or as bycatch include Vietnam, Iran, Thailand, Philippines, Indonesia and India. In India, it is collected as bycatch by shrimp trawlers (Mohamed et al., 2011) and as incidental catch by fishers targeting tunas and sharks using small hook and lines (Mohamed et al., 2006). In the Persian Gulf and Oman Sea, it is collected as bycatch in the Iranian fishery for the skinnycheek lantern fish (*Benthosema pterotum*) (Valinassab et al., 2007).

12.11.6. Duration of Fishing Period by Fishing Region

In the South China Sea, the main fishing season lasts from March to April with an average catch of 2 t/d (Peng et al., 2010). The main fishing gear includes automatic jigging machines and LAFNs. The fishery in Okinawa runs from June to November, and the fishery in Taiwan runs from March to November, with peak catches occurring during May–August.

12.11.7. Stock Assessment and Management

The total biomass has been estimated to be near 8–11.2 million t, including 3–4.2 million t in the Indian Ocean and 5–7 million t in the Pacific Ocean (Roper et al., 2010). Biomass has been estimated based on visual observations (e.g., Zuev et al., 1985) and on CPUE (e.g., Chesalin and Zuev, 2002).

12.12. Ommastrephes bartramii (Neon Flying Squid)

12.12.1. Stock Identification, Distribution, and Lifecycle

The neon flying squid (*O. bartramii*) is a large, oceanic species widely distributed from subtropical to subarctic waters in the Atlantic, Indian and Pacific Oceans (Bower and Ichii, 2005; Roper et al*.,* 2010). Three major populations (subspecies) inhabit the North Pacific, North Atlantic, and circumglobal Southern Hemisphere (Roper et al*.,* 2010). Significant genetic differences have been found between the populations in the North Pacific and Indian Ocean (Kurosaka et al., 2012) and between those in the North Pacific and South Atlantic (Wakabayashi et al., 2012).

The North Pacific population is widely distributed across the Pacific mainly between 20° and 50°N. It comprises two cohorts: an autumn-spawning cohort that hatches from September to February and a winter–spring cohort that hatches mainly from January to May, but extending to August. The population can be further separated into four stocks based on the mantle-length composition (Yatsu et al., 1998b), distribution of paralarvae (Mori, 1997), and rates of infection by helminth parasites (Nagasawa et al., 1998): (1) central stock of the autumn cohort, (2) east stock of the autumn cohort, (3) west stock of the winter–spring cohort, and (4) central-east stock of the winter–spring cohort. The autumn cohort is fished in the central and the northwest Pacific from late May to late July, and the winter–spring cohort is fished in the northwest Pacific and off northeast Japan from early July to February.

The neon flying squid makes an annual round-trip migration between its subtropical spawning grounds and its northern feeding grounds near the Subarctic Boundary. The feeding ground of the winter–spring cohort extends from off eastern Japan to off western Canada, whereas that of the autumn cohort occurs mainly east of the Emperor Seamounts, that is, 170°E (Ichii et al., 2006). The neon flying squid matures at 7–10 months of age and has an estimated 1-year lifespan (Yatsu et al*.,* 1997).

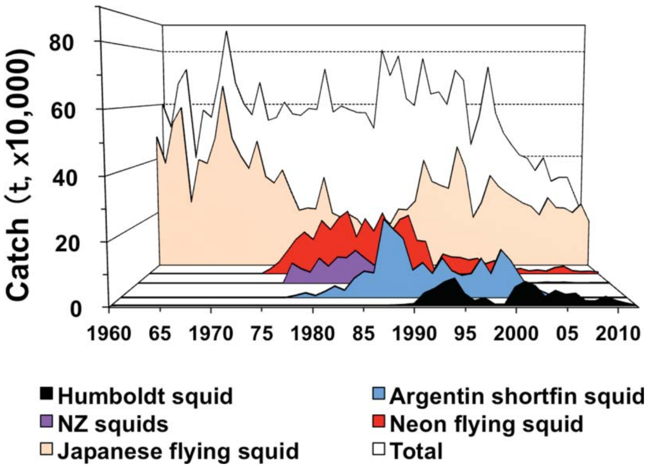

Figure 92. Squid landings in Japan.

Katugin (2002) reported a small but significant shift in genetic composition between western and eastern populations in the North Pacific, as evidenced by allele frequency distribution, and a slight difference in the total level of genetic variability. But Kurosaka et al. (2012) found no clear genetic differences among sampling locations in the North Pacific.

12.12.2. Fishing Grounds

The neon flying squid is widely distributed in several oceans, but fished commercially only in the Pacific Ocean. It is fished mainly in summer and autumn between 36° and 46°N latitude near its northern feeding grounds.

Experimental jigging surveys for *O. bartramii* conducted during 1968–1974 off the Sanriku and Hokkaido coasts of Japan found large densities during summer and autumn (Murata et al., 1976). The squid ranged in size from 200 to 400 mm ML (Akabane et al., 1979), and the species was found to be acceptable for processing (Araya, 1987). When landings of Japanese flying squid (*T. pacificus*) began to decrease in the early 1970s (Figure 92), some Japanese fishers switched to jigging for *O. bartramii* in the northwest Pacific. During 1974–77, landings increased rapidly from 17,000 to 124,037 t. In 1978, a driftnet fishery began in the same region, and the fishing ground expanded eastward off northeast Japan to near 165°E (Araya, 1987; Murata, 1990) (Figure 2).

As the driftnet fishery grew, conflicts developed between Japanese jigging and driftnet fisheries over the exploited stock and fishing grounds. To resolve these problems and conserve the stock, in 1979 and 1981, the Japanese government established a licensing system, delineated the fishing grounds (west of 170°E for the jigging fishery, and between 170°E and 145°W for the driftnet fishery) and limited the fishing season (Yatsu et al., 1994).

In the early 1980s, South Korean and Taiwanese driftnet fisheries also developed (Araya, 1987). The South Korean fishery operated from coastal waters off northwest Japan to 150°W (Gong et al., 1993a). In the autumn and early winter, the South Korean fishery was concentrated from 142°E to 160°E where the Japanese jigging fleet was operating. The fishing grounds of Taiwanese squid fishing vessels are located around 30° to 47°N, particularly between 35° and 45°N. The ranges have been as far as 150°W during the period of drift-net operation (1981 to 1992). However, the fishing grounds have been located between 150° and 170°E for the past two decades.

Due to the large impact the driftnets had on nontarget species (Northridge, 1991), the General Assembly of the United Nations imposed a global moratorium at the end of 1992 on the use of large-scale high seas driftnets (Bower and Ichii, 2005). Japanese medium-scale jigging vessels continued exploiting nearshore waters off northeast Japan after the moratorium. In 1996, there were about 100 Japanese jigging vessels operating on the former driftnet fishing grounds east of 170°E (Ichii, 2002).

The first survey on this squid by the Chinese squid jigging boats was made in the North Pacific in 1993. Chen et al. (2012) used the catch per fishing day (CPUE, t/d) of *O. bartramii* from the Chinese mainland squid jigging fleets on the feeding ground (150°–165°E and 38°-4-6°N) during August to October from 1998 to 2007 to calculate the monthly latitudinal gravity center of CPUE (LATG), and analyzed the relationship between the Kuroshio and the spatial distribution. Regression modeling of LATG versus Kuroshio transport also revealed a significant ($p < 0.05$) influence of Kuroshio strength on north-south movement of *O. bartramii*. Sea surface temperature was the environmental variable most significantly correlated with LATG ($p < 0.01$), indicating that the distribution of *O. bartramii* is controlled by optimal thermal habitat.

12.12.3. Economic Importance

Demand for *O. bartramii* increased as catches of Japanese flying squid decreased in the early 1970s. In 1978, Russia prevented access of the Japanese salmon driftnet fishery to its EEZ (Araya, 1987), so *O. bartramii* offered an alternative for the displaced salmon fishers. The species was acceptable for processing, so it became an important resource for the Japanese squid market supplying various food products, especially deep-fried squid, soft squid jerky, and semi-dried and seasoned squid (called “saki-ika” in Japanese). In the late 1970s, annual landings by mid- and large-sized jigging vessels were valued at approximately 1.6 billion US$ (based on 1978 yen-dollar exchange rate) (Miki, 2003; Ishida, 2008). Recently, its economic importance has increased in other Asian countries. The price of the frozen *O. bartramii* now costs about 2–4 US$ (200–400 yen) more per kg than Japanese flying squid The price varies depending on catch amount and the availability of other species (e.g., jumbo flying squid (*D. gigas*)) (Ueno and Sakai, 2010; Sakai et al., 2010).

12.12.4. Composition and Numbers of the Fishing Fleet

In 1973, Japanese jigging vessels fishing for *O. bartramii* ranged in size from 50 to 138 GT and numbered 2006 (Miki, 2003). The number decreased to 812 vessels in 1983. Driftnet fishing vessels in Japan numbered 534 in 1981 and 457 in 1990 (Yatsu et al., 1994). In 1980, South Korean and Taiwanese driftnet vessels numbered 14 and 12, respectively, and by 1990 the number of boats in both countries had increased to 142 and 138, respectively (Gong et al., 1993a, b; Yeh and Tung, 1993).

Since the closure of the driftnet fishery, catches by Chinese vessels have increased dramatically (Hu, 2003). The number of Chinese vessels in the fishery has fluctuated, but Koganezaki (2002) reported more than 500 jigging vessels were operating in the central and northwest Pacific, including within the Japanese EEZ.

Little information is available on the Taiwanese fishing fleet. Recently, Taiwan fishers have developed fishing vessels that operate both squid jigging gear and light trapping nets for Pacific saury (*Cololabis saira*). The gear can be used alternatively but not simultaneously. These vessels target two species, making it difficult to estimate the size of the jigging fleet.

12.12.5. Duration of Fishing Period by Fishing Region

In the late 1970s, the Japanese squid jigging fishery operated off northeast Japan from July to December (Akabane et al., 1979). Several years later, driftnet and jigging vessels operating in the same area came into conflict (Araya, 1987), whereupon in 1981, the Japanese government began regulating the fisheries. The driftnet fishery was allowed to operate from June to December in the central North Pacific (20–46°N, 170°E–145°W). The South Korean driftnet fishery operated from off northeast Japan to 160°W during early summer and autumn, and in the northwest Pacific during autumn to early winter (Gong et al., 1993b). The Taiwanese squid fishery (mainly driftnet vessels) operated from April to November between 150°E and 145°W (Yeh and Tung, 1993).

Since the driftnet moratorium, the Japanese jigging fishery has operated in the central North Pacific from early summer to autumn and off the coast of northeast Japan in winter (Bower and Ichii, 2005).The Chinese fleet reportedly fishes mainly at 40°–46°N, 150°–165°E during August–November (Chen et al., 2008).

12.12.6. Catch and Effort Data

Catch data were first collected in the North Pacific by Japan and Taiwan in 1974 (Table 4). Annual catches during 1985–1990 by Japan, South Korea, and Taiwan ranged from 248,000–378,000 t (Murata and Nakamura, 1998; Figure 93).

Table 4. Catch and effort of *O. bartramii* in the North Pacific by Japan, China, South Korea, and Taiwan.

	Japan			China		South Korea		Taiwan		
Year	Jig catch	Driftnet catch (t)	Driftnet effort (panels)	Jigging catch (t)	No. jigging boats	Driftnet catch (t)	Driftnet effort (panels)	Driftnet catch (t)	Driftnet boat no.	No. jigging boat
1974	17,000							28		1
1975	41,164							540		5
1976	81,739							792		11
1977	124,037							880		6
1978	105,000	45,000	NA					2,505		14
1979	76,000	48,000	NA					3,385		23
1980	70,450	121,585	NA					5,732	12	27
1981	56,803	103,163	NA					15,405	44	28
1982	57,575	158,760	21,928,768					24,749	73	25
1983	45,043	215,778	25,224,746			37,732	5,634,961	23,469	101	34
1984	29,061	123,719	29,251,829			49,441	12,506,039	27,600	146	
1985	51,010	197,795	34,023,355			70,762	13,943,441	21,800	124	
1986	22,900	152,226	36,367,294			59,024	17,587,232	13,887	110	
1987	21,034	208,319	32,017,130			84,470	19,781,364	18,578	94	
1988	15,610	157,773	36,055,567			100,898	24,594,370	10,478	179	
1989	15,888	171,014	34,385,032			134,120	24,780,316	29,696	167	
1990	34,376	187,660	22,769,857			123,786	24,590,505	13,573	138	
1991	13,434	101,638	23,636,744			NA		NA		
1992	2,272	99,800	19,568,627	2,000	NA	NA		NA		
1993	15,279			15,000	NA					
1994	77,744			23,000	94					
1995	86,270			73,000	191					
1996	81,528			83,770	374					
1997	83,384			102,918	340					
1998	116,494			117,278	304					
1999	69,168			132,836	398					
2000	35,002			125,655	450					
2001	30,812			81,377	426					
2002	17,880			84,967	365					
2003	26,400			83,770	205					
2004	28,874			106,508	212					
2005	16,690			99,327	227					
2006	29,882									
2007	9,268									
2008	42,126									
2009	21,844									
2010	7,566									
2011	8,586									

Following the driftnet moratorium, the winter-spring cohort became the target of an international jigging fishery (Koganezaki, 2002; Chen and Chiu, 2003), with annual catches reaching 100,000–200,000 t (Chen et al., 2007). The Japanese jigging fleet has operated from near the coast of northeast Japan to the central North Pacific, but effort data have not been published.

A large-scale jigging fishery by Chinese vessels started in 1994, and a total of 23,000 t catch was landed with an average of 234.6 t per fishing vessel. In 1995, the catch was expanded to 73,000 t as a result of an increase in the number of fishing vessels. The maximum Chinese catch in 1999 reached 132,000 t (Figure 93). During 2000–2008, the annual catch ranged from 80,000 to 124,000 t. But a sharp fall in catch after 2009 showed the annual catch to have reached only 34,000–56,000 t (Figure 93).

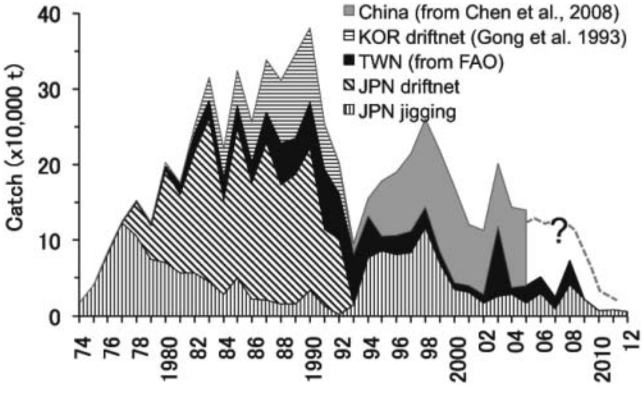

Figure 93. Annual catches of *Ommastrephes bartramii* by Japan (JPN), Taiwan (TWN), South Korea (KOR), and China (CHN) during 1974–2011. Chinese catches after 2006 are estimates.

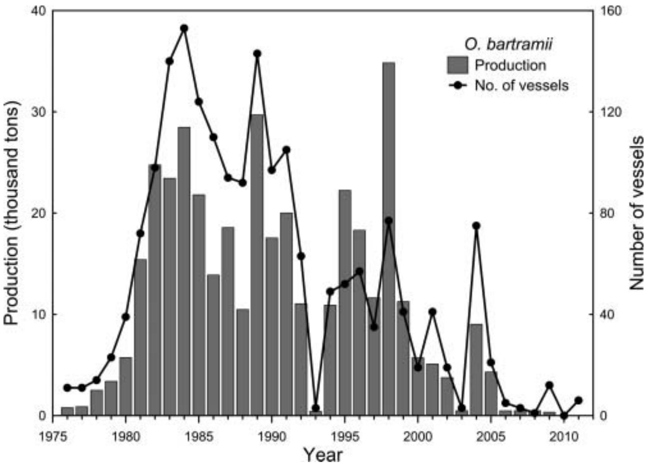

Figure 94. Production of *Ommastrephes bartramii* and number of vessels for Taiwanese distant-water squid fishery in the Northwest Pacific between 1976 and 2011.

Taiwanese squid fishing vessels began harvesting *O. bartramii* in 1977. The squid were initially harvested by the Taiwanese fleets using jigging, but in 1980, the Taiwanese fleets shifted to harvesting with large Japanese-imported driftnets. The annual production varied from 5,000 (1980) to 29,000 t (1989) between 1980 and 1992, with an annual average production of about 18,000 t (Figure 94). The annual number of vessels ranged from 39 to 183 during the same period.

After a moratorium on driftnet fishing implemented at the end of 1992, *O. bartramii* were again harvested by Taiwanese jigging from 1993. The annual production of *O. bartramii* by Taiwanese jiggers varied from 23 (2011) to 34,000 t (1998) between 1993 and 2011, with an annual average production of about 7,000 t (Figure 94). The number of vessels ranged from 1 to 77 during 1993–2011, with almost no Taiwanese vessel jigging squids in the Northwest Pacific after 2007.

Chen (2010) found that stocks in the northwest Pacific and northeast Pacific exhibited opposing trends in abundance suggesting that large-scale environmental factors are more critical than regional factors in influencing its abundance. But in a smaller scale study in the Northwest Pacific, Tian et al. (2009) suggested that spatio-temporal factors may be more important than environmental variables in influencing the CPUE. Roper et al. (2010) reported a total instantaneous biomass in the North Pacific of about 3–3.5 million t.

12.12.7. *Stock Assessment and Management*

To assess how the former driftnet fishery affected the stock size of the autumn cohort, Ichii et al. (2006) conducted a stock assessment using three methods: the swept area method, the DeLury method, and the production method. The first method estimates stock size by expanding the mean density of a target species over its distribution area. The second estimates an initial stock size assuming a closed stock (i.e., with no immigrants or emigrants) that declines as a consequence of fishing mortality. The third is a simple biomass dynamic model based on catch and relative abundance data, with parameter estimates that do not assume equilibrium. The stock size estimates using the three different methods were very similar (330,000–380,000 t), and they reported that the swept area estimate was likely the most reliable. They also suggested that the driftnet fishery may have decreased the stock to around half of its unexploited size.

For the winter/spring cohort in waters west of 170°E, Osako and Murata (1983) estimated the annual sustainable catch to be 80,000–100,000 t. Chen et al. (2008) concurred with this estimate. They fitted a modified depletion model to the Chinese jigging fisheries data to estimate the squid stock abundance during 2000–2005. Effects of using different natural mortality rates (M) and three different error assumptions were evaluated in fitting the depletion model. The assessment results indicated that the initial (prefishing season) annual population sizes ranged from 199 to 704 million squid with the M value of 0.03–0.10 during 2000–2005. The proportional escapement ($M = 0.03$–0.10) for different fishing seasons over the time period of 2000–2005 ranged from 15.3% (in 2000) to 69.9% (in 2001), with an average of 37.18%, which was close to the management target of 40%. From 2000 to 2005, the annual catch from the Chinese jigging fishery ranged from 64,000 t (in 2002) to 104,000 t (in 2000); the other fishing fleets, Japan and Taiwan, had annual catches of less than 10,000 t and 300–8500 t, respectively, during this period (Chen et al., 2008).

There are currently no governance/management measures for *O. bartramii* fisheries on the high seas of the North Pacific. The North Pacific Fisheries Commission, a regional fisheries management organization now forming with the objective of long-term conservation and sustainable use of the fisheries resources in the North Pacific, is expected to include *O. bartramii* in its list of managed species.

12.12.8. *Conservation Measures and Biological Reference Points*

There are no specific conservation measures in the North Pacific other than the driftnet moratorium. Ichii et al. (2006) suggested that a relative fishing mortality F/F_{MSY} of 0.8–1.2 and a figure of 40% of the proportional escapement (number of squid alive at the end of the fishing season as a proportion of those which would have been alive had there been no fishing), which were derived from Japanese driftnet fishery data collected during 1982–1992, be used as management targets for the autumn cohort, however these targets have not been evaluated for the jigging fishery since the driftnet fishery closed.

For the winter/spring cohort, Chen et al. (2008) consider that fishing mortality in the jigging fishery is at a sustainable level, but also note that the decrease in proportional escapement and escapement biomass from 2001 to 2005 suggest the stock might have been overexploited.

13. *SOUTHWEST PACIFIC*

The Southwest Pacific encompasses the ocean territories of the eastern side of Australia, all of New Zealand, and several Pacific Island states and territories including New Caledonia and Vanuatu. The broader Southwest Pacific region is generally characterized by deep waters with many seamounts about which mesopelagic fish resources are exploited. To the southeast of New Zealand there is an extensive raised area, the Campbell Plateau, of around 200 m depth. Another more shallow area extends from the centre of New Zealand in a northwesterly direction, the Lord Howe Rise, continuing to the eponymous mid-Tasman Sea islands. The types of habitats that are exploited in this area are varied and support varied types of fisheries, including small-scale or artisanal fisheries, coastal continental fisheries and deepwater seamount fisheries. Squids, cuttlefishes and octopuses account for approximately 10% of the catch for much of the area (the region corresponding to FAO area 81). The key squid fisheries in the Southwest Pacific are for *N. gouldi* and *N. sloanii*, with *N. gouldi* the focus in Australia and a combination of both species targeted in New Zealand. The New Zealand fishery is a low-value, high-volume fishery targeted by foreign vessels (Korean and Ukrainian predominantly), with both trawl and jig fisheries operating in different subregions. *Sepioteuthis australis*, in the southern half of Australia and north of New Zealand, and *S. lessoniana* in the northern half of Australia and north island of New Zealand are smaller volume fisheries but achieve a much price higher per kilo and are considered a superior product. Minor catches of several *Uroteuthis* spp. also occur throughout the Southwest Pacific.

13.1. **Sepioteuthis australis** *(Southern Reef Squid)*

13.1.1. Stock Identification

Sepioteuthis australis has diamond-shaped fins that extend the length of the body with varied color patterns ranging from orange-brown to white with black bands to almost transparent (Norman and Reid, 2000). The species has maximum size up to 550 mm ML and can weigh up to 4 kg (Pecl, 2001, Lyle et al., 2012). A recent study used polymorphic microsatellite markers to assess the connectivity and population structure of *S. australis* across its southern Australian range. Little genetic differentiation was detected in samples collected from Western Australia to south-eastern Tasmania, indicating a panmictic population (Smith et al., in press).

Currently there is little genetic evidence that the NZ *Sepioteuthis bilineatus* is a different species from *S. australis* (Triantafillos and Adams, 2001).

Spawning occurs throughout the year, as evidenced from collections of reproductively mature *S. australis* in most months (Moltschaniwskyj et al., 2003), and back calculation of hatch date from statoliths (Pecl and Moltschaniwskyj, 2006). So while the generations of *S. australis* overlap, there is no evidence of population structure around season of spawning (Moltschaniwskyj and Pecl, 2003). However, in Tasmania, a single location on the east coast, Great Oyster Bay, contributes at least 55% and up to 84% of the fished *S. australis* caught from along the east and southeast Tasmanian coast, and this is also the only region in that larger area with any evidence of self-recruitment (Pecl et al., 2011).

13.1.2. Distribution and Lifecycle

Sepioteuthis australis is endemic to southern Australia and northern New Zealand waters ranging from Dampier, Western Australia, along the southern coast and up to Moreton Bay, Queensland, including Tasmania (Norman and Reid, 2000). This inshore species inhabits coastal waters and bays usually in depths <70 m (Winstanley et al. 1983). The distribution and abundance of the species in South Australia's Gulf St Vincent has a strong seasonal pattern, with spawning adults moving anticlockwise around the Gulf from the south-eastern corner in spring to the western boundary in winter (Triantafillos, 2001). This is related to the seasonal wind patterns affecting water clarity, as water clarity is important for their highly visual reproductive behavior (Jantzen and Havenhand, 2003). *Sepioteuthis australis* populations are spatially segregated, with juveniles and subadults predominantly in offshore waters, while reproductively mature adults use the inshore areas.

Sepioteuthis australis has a relatively simple lifecycle. Adults typically form discrete spawning aggregations in association with shallow seagrass meadows, where courting, mating and egg deposition occur (Jantzen and Havenhand, 2003). Courtship is behaviorally complex, and females will mate with more than one male (Van Camp et al., 2003), before attaching their fertilized eggs to seagrass, macroalgae holdfast, or low relief reef. Up to 10 eggs are deposited within digitate eggs strands, with each strand attached to a common point (i.e., seagrass holdfast) to form an egg mass of >200 egg strands (Moltschaniwskyj and Pecl, 2003). More than one female can contribute to an egg mass resulting in considerable genetic diversity within a discrete egg mass (van Camp et al., 2004). Juveniles undergo direct embryonic development within the egg mass and hatch out after 6–8 weeks (Steer et al., 2002). Once hatched, juveniles are structurally and functionally adept and adopt a pelagic lifestyle, moving offshore to feed and grow prior to returning inshore to reproduce (Steer et al., 2007). Acoustic tracking of mature adults around the spawning grounds has revealed that males and females move on and off the spawning ground for at least 2–3 months, possibly spawning intermittently over this time (Pecl et al., 2006). While spawning occurs year round, the peak typically occurs during spring and early summer (Moltschaniwskyj and Steer, 2004). *Sepioteuthis australis* are short-lived (<12 months) (Pecl, 2001) and, consequently, display strong interannual variability in species abundance and recruitment (Moltschaniwskyj et al., 2003). Growth rates are rapid, individuals can increase their body weight by as much as 8% per day, and the growth pattern is nonasymptotic, with rates differing between the sexes as males generally grow faster and attain larger sizes (Pecl, 2004, Pecl et al., 2004a). Females are reproductively mature as early as 117 days, 0.12 kg and 147 mm ML while males mature at 92 days, 0.06 kg and 104 mm ML (Pecl, 2001).

13.1.3. Fishing Grounds

Sepioteuthis australis contribute to multi-species marine fisheries in all southern Australian states, particularly South Australia and Tasmania (Lyle et al., 2012). They are fished in shallow coastal bays with the peak catch obtained during spring and summer coinciding with the peak in spawning activity when they form large spawning aggregations (Moltschaniwskyj et al., 2003). Fishing methods primarily include hand jigs and haul nets (Lyle et al., 2012) and fishing does not appear to be sex-selective (Hibberd and Pecl, 2007). Trawlers targeting prawns and demersal fish, in South Australia and New South Wales (NSW), respectively, incidentally catch *S. australis* and sell it as by-product (Lyle et al., 2012).

13.1.4. Economic Importance

Sepioteuthis australis is currently sold on local and national markets and there has been little international export interest (ABARES, 2011). In comparison with most other cephalopod products, *S. australis* generally achieves a high wholesale price. For example, between 1979 and 1999 the wholesale price ranged from $3–7/kg AUD; however, the price is now upward of $12/kg with the increased price thought to be behind localized increases in fishing effort (Green et al., 2012). Throughout Australia, *S. australis* is not regarded as an economically important species, although it is of key importance for individual fishers targeting the species. It is also an important recreational fishery in many parts of southern Australia.

13.1.5. Composition and Numbers of the Fishing Fleet

Commercial catch in 2010 was reported from 240 vessels in South Australia, 92 vessels in NSW, 52 vessels in Tasmania, 54 vessels in Victoria, and 27 vessels in the Commonwealth (Lyle et al., 2012). In South Australia and Tasmania most of these are small vessels, < 6 m in length, and predominantly use hand jigs. In NSW, fish and prawn trawlers land most of the *S. australis* catch. In Victoria, haul seines are predominantly used to target *S. australis*, while the Commonwealth trawlers in the Southern and Eastern Scalefish and Shark Fishery (SESSF) occasionally take *S. australis* as a by-product.

13.1.6. Catch and Effort Data

Total commercial catch across Australia in 2010 was 530 t, with. approximately 65% of this catch (348 t) was harvested from South Australia. The remainder of the catch was taken in Victoria (72 t), Tasmania (54 t) and NSW (48 t), with the Commonwealth accounting for just 8 t (Lyle et al., 2012). Of the total catch, recreational harvest is significant. In Tasmania, recreational fishers accounted for 44.6 t (30%) of the State's total catch in 2007–08 (Lyle et al., 2012). Commercial catch data from 1990 to 2008 shows catch rates in Victoria and Tasmania have been relatively stable (around 50–100 t harvested per year), while NSW catches have declined (Figure 95).

13.1.7. Stock Assessment and Management

Due to the lack of formal stock assessments, there is insufficient information to allow confident classification of the species status across all Australian State jurisdictions.

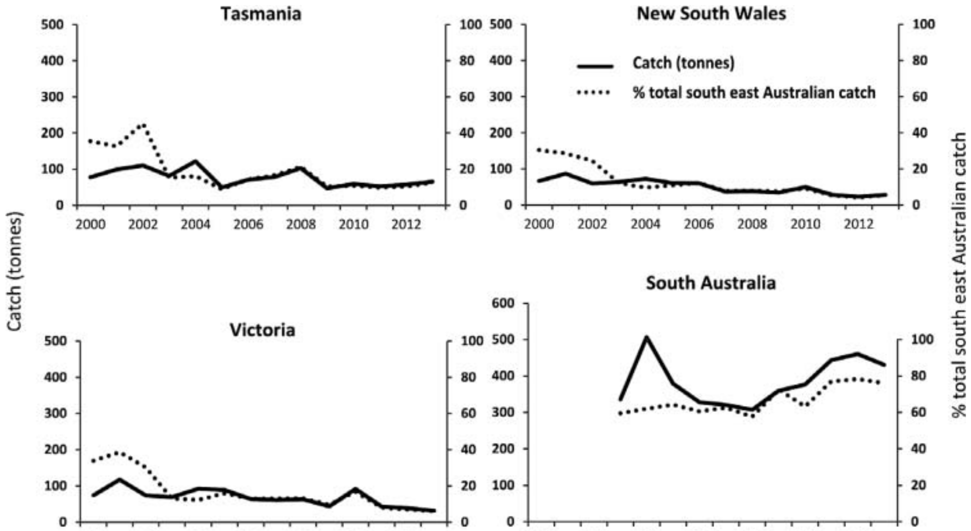

Figure 95. Commercial catch (t) of *Sepioteuthis australis* and contribution by each jurisdiction to total catch in south-east Australia (%) by year for South Australia, Victoria, New South Wales, and Tasmania.

Consequently, *S. australis* is classified as an "undefined" stock in many states, with some jurisdictions relying on performance indicators and limit reference points to describe the relative status of the stock (Lyle et al., 2012).

In Tasmania and South Australia, the stocks are assessed using performance indicators based on commercial catch, effort, and catch rate trends. Comparison of these indicators against limit reference points in both these jurisdictions suggests that *s. austrlis* is currently harvested within sustainable limits (Lyle et al., 2012). In NSW and Victoria, no formal performance indicators are applied, apart from reports of trends in production (including effort and catch rates). In Victoria, the commercial fishery is characterized by decreasing effort and increasing catch and catch rates. In the Commonwealth, *S. australis* is considered a by-product species and little is known about stock structure, biomass, or the effects of fishing pressure (Lyle et al., 2012).

In Tasmania, strategic spatial and temporal closures of the fishery have been instituted during peak spawning in spring/summer to ensure the sustainability of the resource is not compromised (Moltschaniwskyj et al., 2002). Other states have instituted spatial and temporal gear restrictions; however, these are more generic measures and not specific to the harvest of *S. australis*. In South Australia, the quantification of the capture of subadults in the prawn trawl fishery has been used as a means to forecast *S. australis* recruitment strength (Steer et al., 2007). However, there are no early indicators of population size or reproductive potential in other states.

13.1.8. Conservation Measures

A preference for egg deposition on the seagrass *Amphibolis tasmanica* suggests that changes in distribution and abundance of *A. tasmanica* may influence the spatial patterns of spawning and spawning behavior of *S. australis* (Moltschaniwskyj and Steer, 2004). Current environmental pressures on seagrass habitats and inshore communities that have the potential to influence the success of the species include the effects of coastal development, marine pollution, ocean warming, and changing weather patterns (Hobday and Lough, 2011).

Warmer temperatures accelerate embryo development and result in smaller hatchlings (Pecl et al., 2004b). As natural mortality is size-mediated hatchling size determines the relative success of survival (Steer et al., 2003), changes in temperature will affect final size and survival of the individuals. In addition, the predicted increase in intensity and frequency of storm events associated with climate change may potentially increase the loss of eggs from spawning grounds due to the dislodgement of eggs from the seagrass (Moltschaniwskyj et al., 2002). *Sepioteuthis. australis* also have limited capacity to tolerate low salinity conditions and are sensitive to the chemical composition of seawater, for example, the absence of strontium can result in abnormal statolith formation leading to mortality (Hanlon et al., 1989).

The impacts of these environmental stressors (development, pollution, and climate change) on southern calamari may be significant, as *S. australis* populations have the capacity to rapidly respond to a changing environment, whether it is favorable or unfavorable, and subsequently boom or bust (Pecl et al., 2004a). Due to the mobility of the species and its flexible life history, the species may be quite resilient with a high capacity for adaptation (Pecl and Jackson, 2008). However, based on a recent multi-species assessment of the sensitivity to climate change drivers, *S.australis* was designated as "medium-high" sensitivity to climate change (Pecl et al., 2014). Any changes in the distribution and abundance of *S. australis* may cascade through the food chain. While *S. australis* may adapt due to their lack of prey specialization, there may be major trophic impacts on higher order predators, such as marine mammals and large teleosts, with unpredictable effects on inshore communities.

13.2. **Nototodarus gouldi** *(Gould's Flying Squid) and* **N. sloanii** *(Wellington Flying Squid)*

Gould's flying squid and Wellington flying squid are discussed here together, except for the Southern Islands fishery around Auckland and the Campbell Islands (New Zealand), where the two species are managed as a single fishery within an overall TACC.

13.2.1. Stock Identification

Gould's flying squid, *N. gouldi* (McCoy, 1888) is a common ommastrephid species found south of 27°S off Australia and the northern and central coasts of New Zealand (Dunning and Forch, 1998). Collections from six locations around southern Australia (700–4,300 km separation) suggest that the *N. gouldi* population is a single species, with little support that the metapopulation is panmictic (Triantafillos et al., 2004). However, minor stock structuring was evident; with animals on the northern coast of NSW having significant allelic differences compared with Tasmanian and southern NSW animals (Jackson et al., 2003). Comparing the shape of statoliths from squid collected in Victoria to squid collected in the Great Australian Bight suggested significant phenotypic heterogeneity in stocks; whereas elemental composition analysis of the statoliths suggested that *N. gouldi* caught at either location hatched throughout their Australian distribution (Green, 2011).

Based on electrophoresis of the enzyme glycerol-3-phosphate dehydrogenase, morphology of the hectocotylus, and prevalence of parasites, two species of *Nototodarus* are found off New Zealand; *N. gouldi and N. sloanii* (Smith et al., 1981; Smith et al., 1987). Both species mix in waters off the west coast of the South Island and waters off the east coast of the Northern Island; however, *N. gouldi* dominates the west coast of the Northern Island and *N. sloanii* dominates the south and east coasts of the South Island of New Zealand (Uozumi, 1998).

13.2.2. Distribution and Lifecycle

Gould's flying squid typically inhabits waters where surface temperatures range from 11 to 25°C on the continental shelf and slope (50–200 m) to a depth of <500 m, however, are also observed in estuarine habitats during summer periods (Winstanley et al., 1983, Dunning and Forch, 1998, Uozumi, 1998).

In Australia and New Zealand, *N. gouldi* lives up to 12 months; females reach a maximum of 393 mm ML and 1655 g total body weight, and an estimated age of 360 d; while males are smaller, reaching a size of 366 mm ML, 1057 g, and a maximum age of 325 d (Uozumi, 1998, Jackson et al., 2003, Jackson et al., 2005). During cooler months, female *N. gouldi* grow slower and have less gonad investment compared with females caught in warmer months (McGrath Steer and Jackson, 2004). *N. gouldi* collected in 1979–1980 matured at ≈220 mm ML compared with ≈300 mm ML for females (O'Sullivan and Cullen, 1983). In contrast, female squid caught in Tasmania during 1999–2000 matured at ≈328 mm ML (Willcox et al., 2001). Eggs are released in fragile gelatinous spheres up to 1 m in diameter (O'Shea et al., 2004) and drift in oceanic currents probably at a pycnocline (Boyle and Rodhouse, 2005). *Nototodarus gouldi* spawn multiple times, releasing eggs in small batches during their life, with spawning occurring year round (Uozumi, 1998, McGrath and Jackson, 2002, Jackson et al., 2003, Jackson et al., 2005); though fecundity is unknown.

In New Zealand, *N. gouldi* and *N. sloanii* hatch between January and December. Growth of the two species is different among sexes with the mean difference in ML at 300 days of age being 41 and 32 mm for *N. gouldi* and *N. sloanii* respectively; with females growing larger than males. (Uozumi, 1998). The maturation process is also similar among species; however, *N. gouldi* mature about one month earlier (Anon, 2013). At 50–60 days of age, rhynchoteuthion larvae are distributed on the shelf and shallow waters (Uozumi, 1998). No clear difference in the geographical distribution of young adult *N. gouldi* and *N. sloanii,* at three different age groups, indicates that these species do not migrate on a large scale; however, *N. gouldi* may migrate north with maturity (Uozumi, 1998). Both species in New Zealand are thought to migrate to shallower water to spawn. It is assumed that the northern species of *N. gouldi* is a single stock, and that *N. sloanii* around the mainland comprises a unit stock for management purposes, though the detailed structure of these stocks is not fully understood (Anon, 2013).

Growth of *N. gouldi* in Australian waters is spatially variable, with water temperature and productivity thought to be responsible (Jackson et al., 2003). Individuals hatching over summer and autumn grow fastest, possibly due to greater primary production (Jackson et al., 2003). Commercial catches indicate a complex population structure with multiple cohorts. Off the coast of Victoria, up to four *N. gouldi* cohorts were found during one year; however, these cohorts may be a function of four sampling times and not separately spawned animals (Jackson et al., 2005).

Female *N. gouldi* migrate to Tasmanian coastal waters in summer (Willcox et al., 2001), but large scale inshore/offshore migrations associated with reproduction have not been observed with mature males and females found in all sampled locations in southern Australia (Jackson et al., 2003, Jackson et al., 2005). New Zealand *N. gouldi* also display no large inshore / offshore migrations; although, older animals tend to be found offshore (Uozumi, 1998). In Bass Strait (between Victoria and Tasmania), *N. gouldi* move <100 km over 57 d (Dunning and Forch, 1998), and *N. gouldi* do move in and out of bays in south eastern Tasmania (Stark et al., 2005). Analysis of jig caught *N. gouldi* suggest that squid which aggregate on or near the bottom, migrate to shallower waters in response to stratified prey distributions (Nowara and Walker, 1998) which is supported by echo sounding results from a similar area (Evans, 1986). However, larger scale inshore/offshore migratory characteristics of *N. gouldi* are unknown.

13.2.3. Fishing Grounds

Although *N. gouldi* are distributed widely around the coast of southern Australia (Dunning and Forch, 1998), fishing is generally conducted off NSW, Victoria, Tasmania, and South Australia and concentrated near fishing ports for ease of access to fishing grounds. Squid caught inshore by jiggers are larger, consist of a higher M:F ratio and have a greater percentage of mature females that suggested inshore spawning (Green, 2011). Biological differences in the catch composition of *N. gouldi* from Australian waters suggest jig fishers operating inshore catch a larger percentage of the spawning biomass than trawling offshore (Green, 2011). In New Zealand, *Nototodarus spp.* are caught by trawl and jig; however, it is not known whether these different methods and locations of capture catch different proportions of the population.

13.2.4. Economic Importance

In Australia, *N. gouldi* are mainly sold through domestic fish markets as arrow or Gould's squid where wholesale prices range from AUD$1.30 to AUD$1.70 per kg (1991–92). Such low prices have sustained over time with sale price around AUD$1.30 per kg in 2007–08. In 2008, the Southern Squid Jig Fishery (SSJF) recorded its lowest annual catch of 106 t, with 87% of the catch caught near Portland (Victoria). The gross value of production fell by 78% to AUD$236,000 which was thought to be in response to low levels of effort in the fishery. Many fishers found it uneconomical to fish due to the low sale price coupled with increases in fuel cost (Wilson et al., 2009). In 2011/2012, catch increased in the jig fishery and was worth approximately AUD$1.6 million (Woodhams et al., 2012). Influences in both wharf and market prices in Australia and variable catch has meant a decline in the economic importance (McKinna et al., 2011).

In New Zealand, the *N. gouldi*/*N. sloanii* fishery is low-value, high-volume fishery targeted by foreign vessels which are chartered by New Zealand companies. An export value of

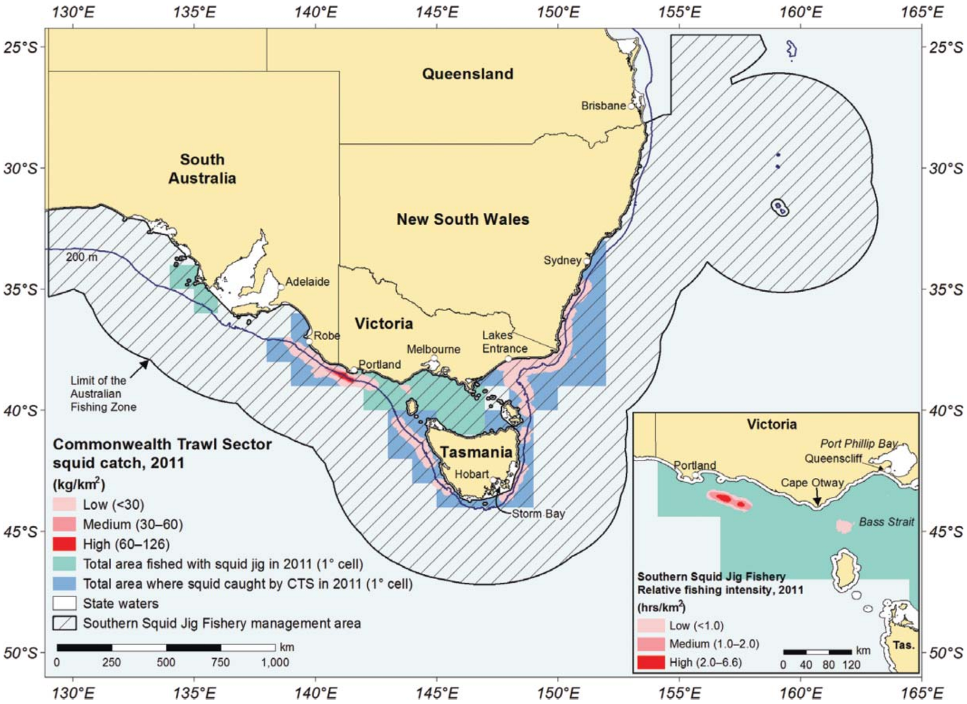

Figure 96. Distribution of Commonwealth Trawl Sector squid catch, 2011; inset: relative fishing intensity in the Southern Squid Jig Fishery, 2011 (Woodhams et al., 2012).

NZ$71m was estimated to be exported to markets in China, Greece, Korea, the USA, Taiwan, Spain, and Italy during 2008. In New Zealand, squid can be purchased in supermarkets in the freezer section.

13.2.5. History, Composition, and the Numbers of the Fishing Fleet

13.2.5.1. Australia. In 1969/1970, the Japanese owned Gollin Gyokuyo Fishing Company conducted feasibility studies around Tasmania, Australia for unexploited fisheries (Willcox et al., 2001). With increased interest from Australian fishers, first commercial catches of *N. gouldi* taken in Australia occurred in the Derwent estuary (Tasmania) in 1972/1973 when around 30 vessels caught 154 t in two months over summer (Wolf, 1973). Realising the potential to establish a fishery, a joint venture between the Japanese Marine Fishery Resources Research Centre was established with a view of (1) exploiting new resources (2) contributing to sound development of a squid fishery and a stable supply of fish products; and (3) contributing to the increased benefit of both Japan and Australia (Machida, 1979). Nineteen vessels caught 3387 t in the first year; whereas 64 vessels caught 7914 t in the second year off South Australia, Victoria and Tasmania (Wilson et al., 2009). Other joint ventures with Australia followed with the inclusion of Korean and Taiwanese jigging vessels fishing between 1983 and 1988, taking between 13 t and 2300 t per year (Wilson et al., 2009).

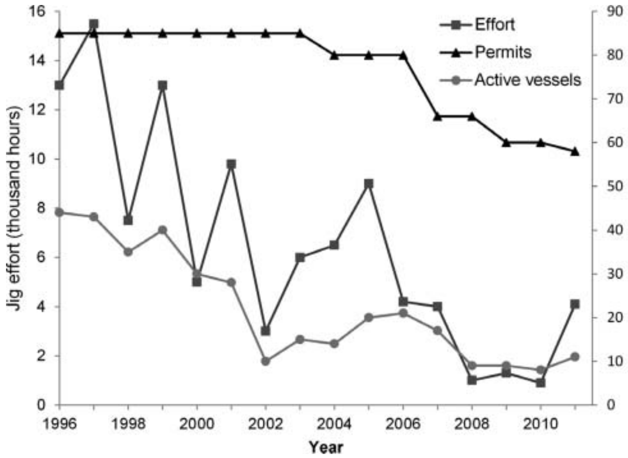

Figure 97. Total number of fishing permits, active vessels and effort in the southern squid jig fishery from 1996 to 2011 (Woodhams et al., 2012).

Although *N. gouldi* are distributed widely around the coast of south eastern Australia (Dunning and Forch, 1998), fishing is generally conducted locally near fishing ports for ease of access to fishing grounds. In 1987, there was only one vessel operating in Bass Strait. From 1988 effort increased and fluctuated between 7 and 17 vessels with catch not exceeding 400 t until 1995 when 1260 t was landed (Wilson et al., 2009). From 1997 to 2009, the number of active vessels and jig effort had decreased. From 1997 to 2007, catch exceeded 1000 t on seven occasions. In 2008 and 2009, jig fishing resulted in 179 t (883 jigging hours) and 308 t (1,229 jigging hours) of squid caught; whereas trawling accounted for 3.5 and 1.8 times more squid caught respectively (Wilson et al., 2010). Only 7% and 3% of the total *N. gouldi* catch in 2008 and 2009 respectively (trawl and jig sectors combined) were caught in the GABTS.

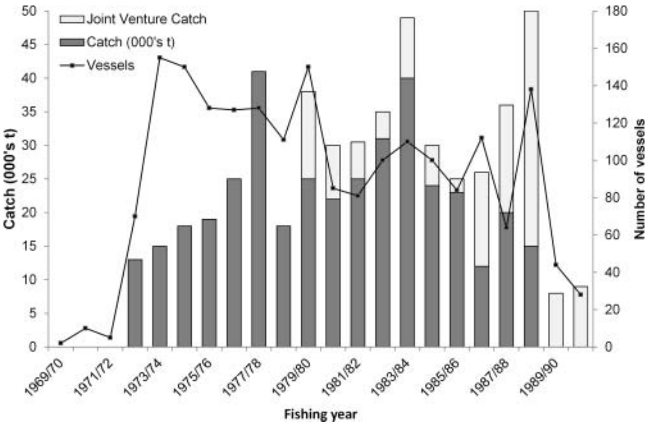

Figure 98. Catch and number of Japanese jig vessels fishing New Zealand waters (Uozumi, 1998).

In Australia, *N. gouldi* are caught and landed by jig and trawl vessels. It is targeted within the SSJF; whereas it is retained as bycatch in the Commonwealth Trawl Sector (CTS) and the Great Australian Bight Trawl Sector of the within the SESSF (Figure 96).

Within the SSJF, there is a relatively large amount of latent effort. In 2011/2012, there were 56 permits and 13 active vessels (Figure 97). Approximately 3,800 jigging hours were used to catch 650 t. In the CTS and GABTS, 735 ts and 14 ts were caught respectively (Woodhams et al., 2012).

13.2.5.2. New Zealand. The fisheries for these species developed in the late 1960s when low catches of Japanese flying squid (*T. pacificus*) in Japan prompted fishers from Kanagawa Prefecture to try squid jigging in New Zealand waters (Kato and Mitani, 2001). Although the squid jig fishery in New Zealand began in the early 1970s, its peak occurred in the early 1980s where greater than 200 squid vessels fished the EEZ (Anon, 2013). The jig fishery was developed by Japanese, Korean and Taiwanese under a joint venture where up to 60,000 t were caught. In the late 1980s, the number of jiggers fishing declined from over 200 in 1983 to around 15 in 1994 (Uozumi, 1998) possibly due to poor prices due to an oversupply in the market (Anon, 2013). Trawling by Russian, Japanese and Korean vessels caught up to 60,000 t annually in the 1980s.

Historically, the New Zealand jig and trawl fisheries display variable catch; however, this is likely attributed to the number of vessels (Figures 98 and 99). The jig catch in SQU 1J declined from 53,872 t in 1988/1989 to 4,865 t in 1992/1993 but increased significantly to over 30,000 t in 1994/1995, before declining to just over 9,000 t in 1997–1998 (Anon, 2013). The jig catch declined to low levels for the next 5 years but has increased in 2004/2005 to 8,981 t. From 1986 to 1998, the trawl catch fluctuated between about 30,000–60,000 t, but in the last few years dropped to much lower levels as the impact of management measures to protect the Hooker's sea lion (*Phocarctos hookeri*) restricted the catch from region SQU 6T (Anon, 2013).

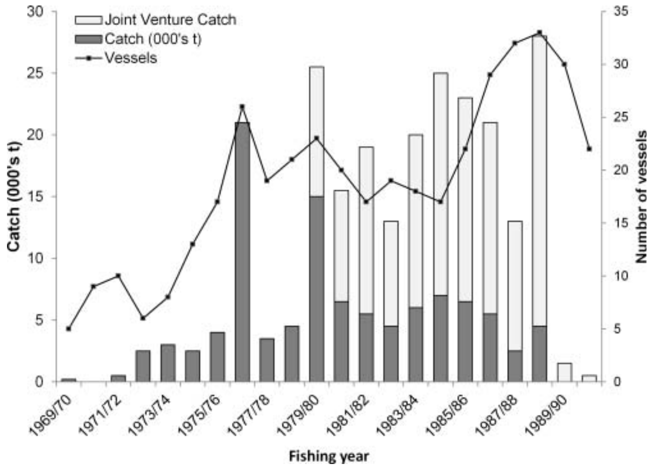

Figure 99. Catch and number of Japanese trawl vessels fishing New Zealand waters (Uozumi, 1998).

In New Zealand, there are three commercial squid fisheries; two trawl fisheries which cover the majority of the EEZ and a region located around the Auckland Islands in the sub-Antarctic; and a squid jigging fishery that covers most of the EEZ (www.newzealand.govt.nz), however, are mostly surrounding the main islands. The fisheries are split in to four fishing zones;

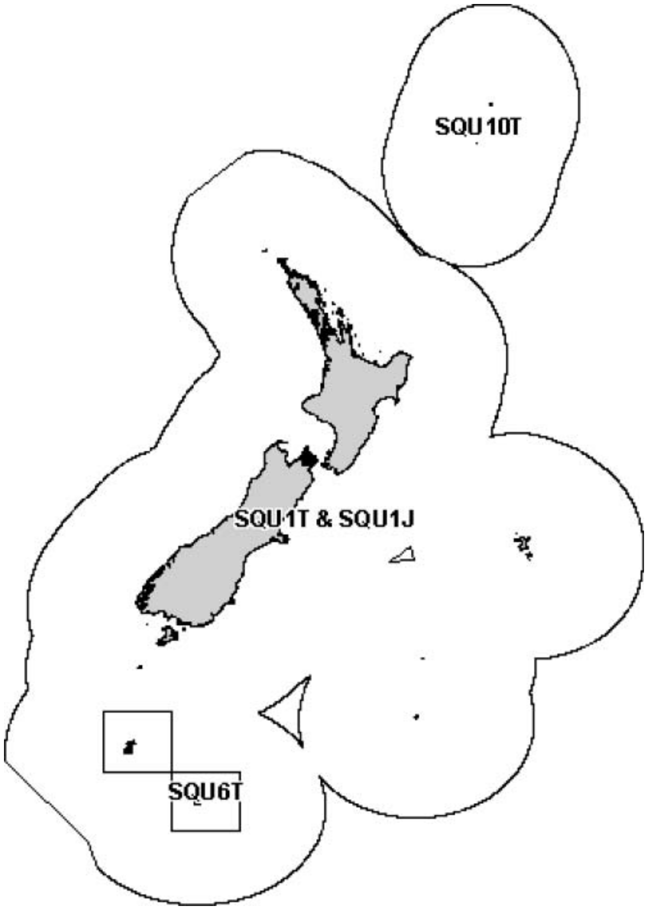

Figure 100. Fishing sectors of the New Zealand squid fishery (Anon, 2013).

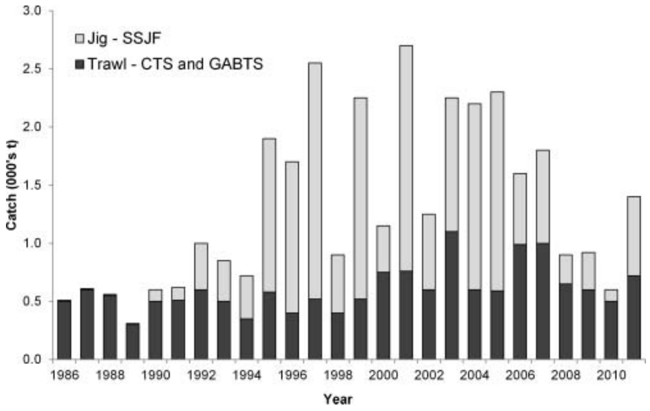

Figure 101. *Nototodarus gouldi* catch history for the Australian southern squid jig fishery, Commonwealth Trawl Sector and Great Australian Bight Trawl Sector from 1986 to 2011 (Woodhams et al., 2012).

SQU10T, SQU1J, SQU1T, and SQU6T (Figure 100). Both species are targeted by mainly Korean and Ukrainian foreign vessels which are chartered by New Zealand companies (www.newzealand.govt.nz).

13.2.6. *Duration of Fishing Period by Fishing Region*

In Australia, fishers operating in the SSJF concentrate most effort in waters of Bass Strait (between Tasmania and Victoria), and near Portland in western Victoria in depths ranging from 60 to 120 m (Larcombe and Begg, 2008). *N. gouldi* are caught using automatic jigging machines normally at night with fishers preferring new moon periods from January to June. Vessels use up to 12 machines consisting of two spools; each consisting of up to 25 jigs that are vertically lowered then lifted. High-powered lights are normally positioned along the midline of the vessels with a function to direct light downward to the sea's surface while casting a shadow underneath the vessel.

New Zealand Catch and effort data from the SQU 1T fishery show that the catch occurs between December and May, with peak harvest from January to April (Anon, 2013).

13.2.7. *Catch and Effort Data*

In Australia from 1988, effort increased and fluctuated between 7 and 17 vessels with catch not exceeding 400 t until 1995 when 1,260 t was landed (Wilson et al., 2009). From 1997 to 2009, the number of active vessels and jig effort has decreased. From 1997 to 2007, catch exceeded 1,000 t on seven occasions. In 2011, total jig catch increased significantly to 650 t from 62 t in 2010; the CTS catch was 735 t, up from 483 t (Figure 101). The majority of catch from both the jig and trawl sectors is *N. gouldi*; however, other ommastrephids are also captured including Antarctic flying squid *Todarodes filippovae* and neon flying squid *O. bartramii* (Larcombe and Begg, 2008). Bycatch in the SSJF is very small; however, barracouta *Thyrsites atun* and blue shark *Prionace glauca* also attack jigs.

In New Zealand during 2012, approximately 35,000 t were landed (sectors combined); however this level was well below the combined quota of 127,332 t. Trawl fishers contributed to 94.8% most catch. Like Australia, the catch is temporally variable (Figure 102). Catch and effort data from the SQU 1T fishery show that the catch occurs between December and May, with peak harvest from January to April (Anon, 2013).

13.2.8. *Stock Assessment and Management*

In Australia, there is insufficient information available to estimate annual biomass and hence determine a TAC for the current year. As a result, the *N. gouldi* resource is managed using total allowable effort restrictions determined annually and a harvest strategy that monitors catch and effort in the jig and trawl sectors within a fishing season (Dowling et al., 2007, Dowling et al., 2008, Smith et al., 2008). Within the SESSF during 2011, 560 standard jig machines are permitted to fish for *N. gouldi* in the SSJF with the CTS and GABTS able to retain squid as a bycatch. The "harvest strategy" uses trigger limits of catch, effort, and CPUE, that when reached, signals the need for assessment (e.g., depletion analysis) and review by the Australian Fisheries Management Authority (AFMA; Larcombe and Begg, 2008, Wilson et al., 2010). Both jig and trawl sectors have separate catch, effort and CPUE trigger limits, as well as trigger limits where both fisheries contribute to limits simultaneously (Wilson et al., 2009). A 4,000 t trigger limit is imposed on the jig sector (2013) which was calculated at half the historical maximum annual catch (8,000 t) from 1977 to 1988 during the Japanese, Taiwanese and Korean joint venture (Sahlqvist, 2007). The combined trigger limit for fisheries combined is 6,000 t (2013). If trigger limits are reached then a set of decision rules are within the harvest strategy are applied to manage the fishery. Apart

Figure 102. Commercial catch and Total Allowable Commercial Catch of arrow squid in three fishing zones (Anon, 2013).

Table 5. Total Allowable Commercial Catch and report catch off *N. gouldi* and *N. sloanii* (combined) caught off New Zealand in 2008/09 (Anon, 2013). J is Jig fishery, T is trawl fishery.

Fish stock	2008/2009 actual TACC (t)	2008/2009 catch (t)
SQU 1J	50,212	1,811
SQU 1T	44,741	18,969
SQU 6T	32,369	14,427
SQU 10T	10	0
Total	127,332	35,207

from assessing the ecological impact of the SSJF (Furlani et al., 2007) and a depletion analysis from 2001 jig data (Triantafillos, 2008), ongoing annual biomass estimates are not calculated to determine TAC for each year. This approach to assessing and managing the *N. gouldi* fishery is primarily due to trigger limits not being reached and financial constraints. Australia's arrow squid fishery is considered not overfished and not subjected to overfishing (Woodhams et al., 2012).

New Zealand fisheries managers consider both *N. gouldi* and *N. sloanii* within the same unit stock. However because of their one year lifecycle and temporal variability in numbers no attempt is made to estimate biomass used to set the TACC. Catch quotas are set according to fish stock (Table 5).

13.2.9. Conservation Measures

Within Australia's SSJF, there are some 216 threatened, endangered or protected species found; however, an Ecological Risk Management assessment revealed that none of these species were assessed as a risk from commercial fishing operations (Hobday et al., 2011). In 2011 no seal interaction was recorded in the SSJF (Woodhams et al., 2012). Observers on jig vessels also noted no significant negative impact on seals from jig fishing (Arnould et al., 2003).

In New Zealand, the trawl sector, squid accounts for 67% of catch with bycatch consisting of barracouta (*Thyrsites atun*), silver warehou (*Seriolella punctata*), jack mackerel (*Trachurus declivis*), and spiny dogfish (*Squalus acanthias*). However, the trawl sector also incidentally catches New Zealand (or Hooker's) sea lions as well as New Zealand fur seals (Abraham, 2011) which are classified as Nationally Critical and Not Threatened, respectively, under the NZ Threat Classification System (Baker et al., 2010). Consequently, sea lion exclusion devices have been implemented in to the arrow squid trawl fishing since 2000–2001. In 2011–2012, 109 observed captures of seabirds were recorded to be incidentally caught in trawls (Anon, 2013). This level of bird captures is relatively low since the introduction of streamer lines, bird bafflers, and warp deflectors.

14. NORTHEAST PACIFIC

The northeast Pacific (FAO area 67) is an area of relatively minor importance for squid fishing. According to FAO data (FAO, 2011), annual landings of squid from this region peaked at approximately 55,600 t in 1987; indeed landings exceeded a few thousand t only during 1982–1992 when Japan reported landings from the area. Since 2007, only the USA has reported squid landings from the area and, since Japan left the fishery, the highest landings (just over 3,000 t) were reported in 1999 and in some years the figure was only a few hundred t.

The coastline of area 67 extends from northern California, through Oregon and Washington to Canada, Alaska and, across the Bering Sea, the eastern tip of Russia. A number of squid species are present. In the northern part of this area, the dominant squid species is the schoolmaster gonate squid (*Berryteuthis magister*). Since 2004, jumbo flying squid, *D. gigas* has invaded the waters of Oregon and Washington states, extending up into Canadian waters. Administrative rules issued by the Oregon Department of Fish and Wildlife define squid fisheries as referring to commercial fisheries for squid species "including, but not limited to: opalescent inshore squid (*D. opalescens*); jumbo flying squid (*D. gigas*); schoolmaster gonate squid (*Berryteuthis magister*); boreopacific armhook squid (*Gonatopsis borealis*); robust clubhook squid (*Moroteuthis robusta*); and boreal clubhook squid (*Onychoteuthis borealijaponicus*)." FAO catch data for area 67 mentions the occurrence of three squid species, namely neon flying squid (*O. bartramii*), opalescent inshore squid (*D. opalescens*, also known as California market squid), and robust clubhook squid (*Onykia robusta*). However, less than 2% of squid landed from the area is identified to species in the FAO records (FAO, 2010), the remainder being classified as "squid nei" (i.e., not identified to species).

Of the above-mentioned species, *D. opalescens*, which occurs all along the Pacific coast from Alaska to BC (Jereb and Roper, 2010), probably has the longest documented history of fishery exploitation: it has been fished in California since the 1860s, although the fishery was of minor importance until the late 1980s when a rise in worldwide demand for squid led to a substantial increase in both effort and landings (Vojkovich, 1998).

Doryteuthis opalescens is essentially a temperate species of the Northeast Pacific system; its occurrence in California and BC is related to the cold-water California current, which originates in the north (and indeed abundance is much reduced in El Niño years (Zeidberg et al., 2006). Nevertheless, much of the information for this species derives from the eastern central Pacific, as might be expected given the existence of the California-based fishery. Indeed, in FAO data, landings of this species in the USA are listed only for area 77 (Central Eastern Pacific), where they reached almost 118,000 t in 2000 (FAO, 2011).

Berryteuthis magister is better known from the northwest Pacific (Section 12.7); Katugin et al. (2013) compares what is known about the species in both regions, also noting that they are genetically distinct from each other. Russian boats take this species in the western part of the Bering Sea, beyond the western limit of FAO area 67. However, there is also some

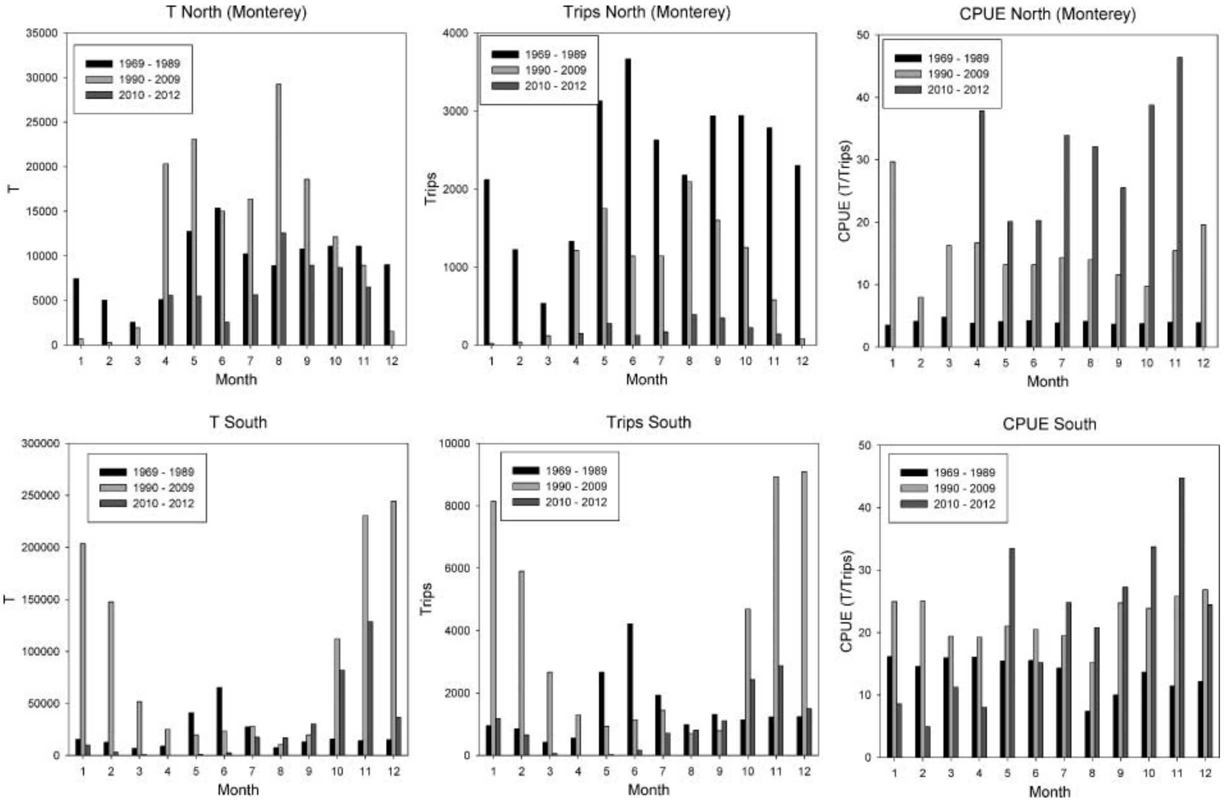

Figure 103. *Doryteuthis opalescens* fishery landings receipt data by month. Tonnage, trips, and catch per unit effort (CPUE) tonnage/trip for the commercial fishery in California 1969–2012. Grouped vertical bars are the sum of tonnage or trips for the periods of 1969–1989 (black, left), 1990–2009 (gray, center), or 2010–2012 (dark gray, right). Note the decrease in winter landings in Southern California, October–February for the period 2010–2012 (dark gray). CPUE is the summed tonnage divided by the summed trips. Point Piedras Blancas 35.7°N is the boundary for North or South classification.

fishing within area 67. In Alaska, it is caught as bycatch in large amounts by the pollock fleet[2] and Connoly et al. (2011) note that the first fishing permits to catch this species were issued in Alaska in 2011.

14.1. *Doryteuthis opalescens* (Opalescent Inshore Squid)

14.1.1. *Stock Identification*

This species is monitored in the state of California as one stock. There have been investigations of morphometry (Kashiwada and Recksiek, 1978), allozymes (Christofferson et al., 1978), and microsatellite DNA (Reichow and Smith, 2001), the latter study extending along 2500 km of the Pacific coast, but to date none have demonstrated significantly different traits for regional stocks. However, trace element analysis of market squid statoliths can distinguish individuals captured from locations less than 100 km apart (Warner et al., 2009), suggesting that some segregation occurs over time scales too short for it to be reflected in genetic markers; this remains a ripe field of study. In addition, there is a temporal difference in the fishery landings from different locations. The majority of landings occur in Southern California during the winter, October–February (Figure 103). About 10% of landings occur near Monterey Bay, emerging in the spring and summer, April–November (Zeidberg et al., 2006).

14.1.2. *Distribution and Lifecycle*

Market squid range throughout the Northeast Pacific, from Southeast Alaska to BC (Wing and Mercer, 1990). *Doryteuthis opalescens* is a coastal species, rarely found in waters deeper than 500 m (Okutani and McGowan, 1969). Eggs are laid on sandy benthic substrates where water temperatures are 10–12°C; the depth of this environment changes with latitude and season (Zeidberg et al., 2012). The females lay 100–300 eggs in a capsule that is attached to the sand by one end so that wave surge can provide ventilation; total fecundity is estimated at around 3000 eggs (reviewed in Zeidberg, 2013). The duration of incubation is temperature-dependent ranging from 75–45 days in water that is 9–13°C, respectively (Zeidberg et al., 2011). Upon emergence hatchlings average 2.5 mm ML and their vertical diel migration causes them to become entrained for a few weeks within three kilometres of shore by tidal fronts (Zeidberg and Hamner, 2002). Juvenile squid are found over the shelf, in the water column at night and in benthic trawls during the day (Zeidberg, 2004). Diets

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[2] See Project 716 final report at http://project.nprb.org

shift with ontogeny, from copepods to krill and then to fish (Karpov and Cailliet, 1979). Adults are usually found at depths down to 500 m during the day and at the surface at night, but are occasionally recorded down to 1,000 m (Hunt, 1996). Adults average 127 mm ML, males are larger, and males and females aggregate in large spawning masses of millions of individuals on the shelf (Leos, 1998). The shift from somatic to reproductive growth probably occurs when the individual has attained a large enough size to compete for mates, or when food is scarce (Ish et al., 2004). This species lives for only a week or two after shifting to reproductive growth and shows no signs of serial spawning (Macewicz et al., 2004). From hatching to spawning the lifespan averages 6 months, range 4–9 months (Butler et al., 1999; Jackson and Domeier, 2003), and there are multiple cohorts throughout the year.

14.1.3. Fishing Grounds

The vast majority of commercial fishing occurs in California, traditionally in shallow waters, less than 70 m, and focuses on spawning adults (Zeidberg et al., 2006). The locations that have yielded the largest tonnage are near the islands of Santa Cruz, Santa Rosa, and Santa Catalina, and just offshore of Port Hueneme and Monterey. Since 1990, the majority of landings have been brought in with purse seines. There is also a fishery for live bait that targets spawning adults with brail nets.

In recent decades, the fishery has also extended northward, into Oregon, Washington and Alaska. Connoly et al. (2011) commented that fishing on market squid in Alaska had been sporadic. The Washington Department of Fish and Wildlife publicizes recreational fishing on the species[3].

14.1.4. Economic Importance

Since 1990, market squid has been the top ranked fishery in terms of tonnage in California for 17 of 22 years. In 2010, the squid fishery had a record ex-vessel value of $73.8 million (Porzio et al., 2012). The ex-vessel price for squid is usually around $500 per ton, thus there is a financial motivation for purse seiners to seek out squid over other coastal pelagic species like Pacific Sardine, which often garner $90 per ton.

14.1.5. Fishing Fleet

Commercial fishing for market squid began in California in 1863. Chinese fishermen in Monterey would encircle spawning squid with nets in small row boats. They would fish at night and use kerosene torch lamps to attract squid to the surface. The product was dried and shipped to China or consumed locally (Scofield, 1924).

In 1905, the use of the lampara net allowed Italian fishermen to take over the lead role of squid fishing in Monterey. The lampara net could land 20 t in a haul, but the average landing was four t (Fields, 1950). Throughout the 1970s and 1980s, there were about 85 vessels in the fleet, and in the 1990s out-of-state fishermen increased the number to 130 (Vojkovich, 1998). In 1998 the California Department of Fish and Wildlife (CDFW) began to require squid fishing permits and initially 200 boats entered the fishery, but few made landings and 95% of the landings were made by 50 boats. Due to limited entry in the fishery management plan, there are now 78 permitted seine vessels and 35 lightboat permits.

For the period 1969–1989, the lampara net was the dominant gear of choice in Central California, and brail nets dominated in Southern California. The average maximum annual landing, a proxy for fleet capacity, for all boats in the fleet was 43 t. In 1990, the fishery shifted to purse seine nets (Figure 104). For 1990–2009, the average maximum annual landing for all boats in the fleet was 82 t. In addition to increasing hold capacity, all modern boats have refrigerated holds and sonar, which allow for increased time at sea and better squid detection. In the 1980s, smaller boats, now called light boats, with sonar and arrays of lights began to attract and hold squid for the seine vessels. Fishing effort has expanded to new areas in the last decade (Zeidberg, 2013).

14.1.6. Duration of Fishing Period by Fishing Region

The Monterey fishery historically has peaks of landings in April–May and a second pulse in August–November. In Southern California peak landings occur in October–February (Zeidberg et al., 2006). Ninety-five percent of landings occur in 15–40 m depth in Monterey and 20–70 m depth in southern California (Zeidberg et al., 2012); in both regions benthic temperatures are 10–12°C. Since 2010, the state wide fleet has captured the annual limit of 118,000 t before the season's end on March 31. As this limit was approached, CDFW shut down the fishery on December 17, 2010, November 18, 2011, and November 21, 2012. Thus the typical winter peak (October-February) of squid in southern California has not been exploited for 3 years (Figure 103).

The fishery is often disrupted by environmental changes with a decrease in landings during large El Niño events and an increase in landings in La Niña years (Zeidberg et al., 2006). The Central and Southern California squid fisheries rebound from ENSO events with differing periodicity. There is no evidence that the squid migrate out of the traditional spawning grounds, rather the evidence shows that the entire population biomass fluctuates (Reiss et al., 2004). Squid that developed during the El Niño when *Thysanoessa spinifera* krill abundance was low (Marinovic et al., 2002) were smaller both on the spawning grounds (Jackson and Domeier, 2003) and in sea lion guts (Lowry and Carretta, 1999). The weak upwelling season of 2005 (Bograd et al., 2009) was followed by a poor or absent squid fishery in central California for 2006–2009 (Young et al., 2011).

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[3] http://wdfw.wa.gov/fishing/shellfish/squid/

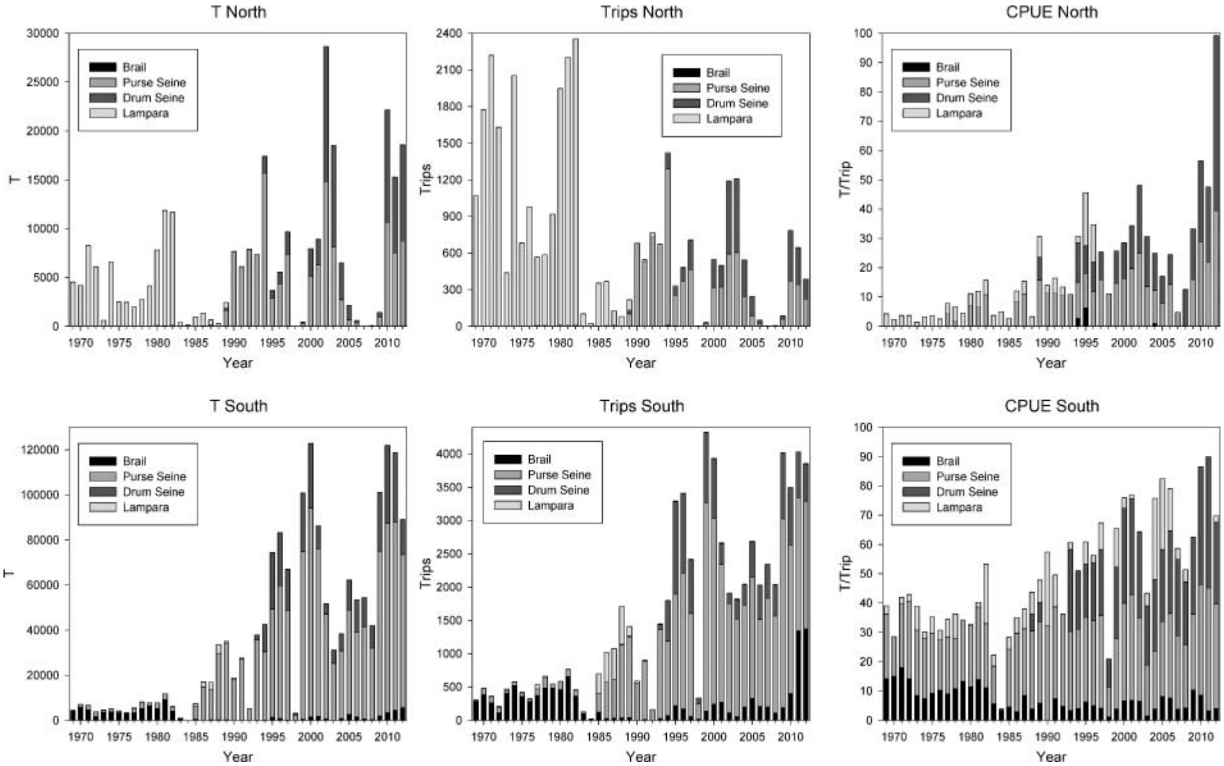

Figure 104. *Doryteuthis opalescens* fishery landings receipt data by year. Tonnage, trips, and catch per unit effort (CPUE) tonnage/trip for the commercial fishery in California 1969–2010. Stacked vertical bars are the annual sum of tonnage or trips for the four most productive types of gear, brail net (black, bottom), purse seine (gray, bottom middle), drum seine (dark gray, top middle), lampara net (light gray, top), and CPUE is the summed tons/summed trips. Point Piedras Blancas 35.7°N is the boundary for North or South classification.

14.1.7. Catch and Effort Data

Since 1990, Monterey has yielded an average of 9,000 t/y, and southern California has yielded 63,000 t/y (Figure 104, Zeidberg, 2013). There were significant differences in the efficiency of the fleet between the two regimes before and after the shift from lampara or brail nets to seine nets in 1990 (Figure 104). Average trips per year decreased in the north but nearly tripled in the south. Landings and CPUE increased in both regions with the transition to seines. The average maximum landing nearly doubled in the southern region and more than doubled in the north after 1990.

14.1.8. Stock Assessment and Management

The authority to manage the squid fishery in California was delegated by the California Legislature to the Fish and Game Commission. A management plan was developed by the CDFW and adopted by the Fish and Game Commission in 2004 (http://www.dfg.ca.gov/marine/msfmp/, accessed December 2014).

Management measures introduced by the state include an annual (April 1–March 30) limit of 118,000 t (107,048 t), spatial closures within MAPs, weekend closures (with no seining allowed noon Friday to noon Sunday), a restricted access program, and a 30,000 watt limit on lights including a shield above the horizontal line of sight. An egg escapement model has been developed but, real-time application has not been implemented (Macewicz et al., 2004).

Landings receipts have recorded tonnage, location, date, and price at California ports since 1916. Since 1999 commercial squid fishermen have been required to maintain logs with greater detail of effort including tonnage estimate, sea surface temperature, time of net deployment, the GPS location of sets, market information, and predators. CDFW implemented a port sampling program, collecting 30 squid for various biometric measurements twelve times a month.

Because market squid is such a short lived species, attempts to develop a stock assessment using traditional methods have been elusive. Since there is a new cohort each month, the development of a Leslie–DeLury depletion model (Agnew et al., 2000) would be difficult for *D. opalescens* (Ish et al., 2004). However, there is scope to develop predictors of abundance based on oceanographic conditions and the abundance of early life stages, similar to the approach used in Japan, where the government integrates remotely sensed oceanographic data along with metrics of early life history of *T. pacificus* to predict the abundance of the fished stock each season (Sakurai, 2000). There are a variety of existing oceanographic sampling programs that capture California market squid as paralarvae (Koslow and Allen, 2011), juveniles (Santora et al., 2012) and acoustic signatures (Vaughn and Recksiek, 1979). Adopting

Figure 105. Fisheries of loliginids landings occur in twelve Mexican States: eight in Pacific ocean and four in the Gulf of Mexico.

such an approach would also facilitate adaptive management, that is, allowing the management regime to respond to changes in abundance. In other squid fisheries, there are effective adaptive management programs, notably in the Southwest Atlantic and Japan (Agnew et al., 2000; Sakurai et al., 2000).

14.1.9. Conservation Measures and Biological Reference Points

Currently there is a biomass estimate derived from the egg escapement model (Dorval et al., 2013). Based upon a regression of fecundity on female ML, the percentage of biomass harvested by the fishery may be estimated (Dorval et al., 2013). The application of these estimates to derive MSY remains an option. The goals of the MSFMP are to ensure long-term resource conservation and sustainability. The tools implemented with the MSFMP to accomplish these goals include: (1) setting a seasonal catch limit of 118,000 short t (107,048 t) to prevent the fishery from overexpanding; (2) maintaining monitoring programs designed to evaluate the effect of the fishery on the resource; (3) continuing weekend closures that provide for periods of uninterrupted spawning; (4) continuing gear regulations regarding light shields and wattage used to attract squid; (5) establishing a restricted access program that produces a moderately productive and specialized fleet; and (6) creating a seabird closure restricting the use of attracting lights for commercial purposes in any waters of the Gulf of the Farallones National Marine Sanctuary. In addition to the specific measures listed above, in California there is a network of MAPs that prohibit all fishing including the take of squid.

15. CENTRAL-EAST PACIFIC

This region is largely comprised of waters of the west coast of Mexico. The Mexican squid fisheries are dominated by the jumbo flying squid, *D. gigas*. Several species of loliginids squids are landed but these are almost entirely bycatch taken by shrimp fishing vessels.

15.1. Mexican Loliginid Squid Fisheries

There are five species of loliginid squid of commercial interest in Mexican Pacific waters: *Lolliguncula (Lolliguncula) panamensis* (Berry, 1911a), *Lolliguncula (Lolliguncula) argus* (Brakoniecki and Roper, 1985), *Lolliguncula (Loliolopsis) diomedeae* (Hoyle, 1904), *D. (Amerigo) opalescens* (Berry, 1911b), and *Pickforditeuthis vossi* (Okutani and McGowan, 1969; Brakoniecki 1996; Okutani, 1995a, Roper et al. 1995; Sanchez, 2003; Jereb et al., 2010)); where fisheries landings occur in eight Mexican Pacific States coasts (Figure 105). These are mostly taken as bycatch in artisanal trawl fisheries for shrimp (Barrientos and Garcia-Cubas, 1997; Alejo-Plata et al., 2001, Sanchez, 2003). Some 1,400 shrimp trawlers report loliginid bycatches, mostly between September and June. Data in Table 6 show landings in the Mexican Pacific and Gulf of Mexico and Mexican Caribbean from 2006 to 2012; the states with highest catches are Baja California Sur (BCS), BC, Sonora and Sinaloa; the largest catch was 27.3 t in 2010 while the lowest catch was 2.03 t in 2006; for the Gulf of Mexico and Mexican Caribbean between 2006 and 2012; Tamaulipas recorded the highest landings of 41.5 t in 2006 and Veracruz the lowest of 5.2 t in 2010 (Figure 106). No assessments of loliginid stocks are made and since it is an incidental fishery no BRPs or conservation measures exist for the Pacific fishery in Mexico.

Table 6. Live weight in kilograms of squid *Loligo* sp. by entities captured in the Mexican Pacific and Gulf of Mexico and Mexican Caribbean from 2006 to 2012 (last updated: Thursday January 24, 2013 by WebMaster CONAPESCA).

	Mexican Pacific								Gulf of Mexico and Mexican Caribbean				
	Baja California	Baja California Sur	Sonora	Sinaloa	Nayarit	Jalisco	Colima	Oaxaca	Tamaulipas	Veracruz	Campeche	Quintana Roo	Yucatán
2006	375,749	1,029,888	294,399	329,599	0	0	556	200	41,490	22,985	5,740	2,303	0
2007	333,095	857,036	553,705	896,975	900	125	2,913	1,198	33,894	23,411	1,642	1,273	0
2008	4,104,831	502,143	205,264	431,184	0	0	2,566	10	16,965	21,127	2,965	0	0
2009	679,485	316,512	1,058,118	208,675	0	0	762	2,598	19,498	8,512	8,799	0	0
2010	8,467,933	17,194,737	1,475,277	144,707	0	0	2,033	4,666	10,758	5,214	1,719	0	1,980
2011	6,038,905	8,084,715	1,990,372	690,430	50	0	8,552	7,382	28,748	12,730	21,336	0	0
2012	1,916,294	8,497,941	169,645	2,506,082	1,000	0	0	6,979	10,253	12,347	0	0	0
Total	21,916,294	36,482,975	5,746,782	5,207,655	1,950	125	17,382	23,033	161,607	106,326	42,201	3,576	1,980

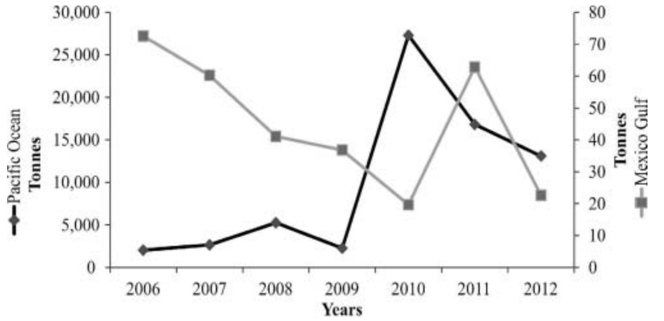

Figure 106. Live weight in kilograms of squid Loligo sp. captured in the Mexican Pacific and Gulf of Mexico from 2006 to 2012. (Last Modified: Thursday January 24, 2013 by WebMaster CONAPESCA).

There are no data on stock structure for the commercial species but there have been proposals to discriminate stocks using morphometric and genetic analysis (Granados-Amores et al., 2013, Granados-Amores, 2013). Detailed studies on the distribution, abundance, reproduction and feeding habits of *Lolliguncula panamensis* have been made by Arizmendi-Rodriguez et al. (2011 and 2012). Basic descriptions of species and distribution maps have been published (Okutani and McGowan, 1969, Young, 1972; Okutani, 1980, Roper et al., 1984, Barrientos and Garcia-Cubas, 1997, Sanchez, 2003; Jereb et al., 2010).

Loliginid bycatch in shrimp trawls is dominated by *L. diomedae* (29–103 mm ML) and *L. panamensis* 25–106 mm ML (Sánchez, 2003). *Doryteuthis opalescens* is also a frequent bycatch. Because loliginids are all caught incidentally they only reported as *Loligo spp.* Catch data for 2006–2012 reported by CONAPESCA (2013) are shown in Table 6. Shrimp trawl hauls may contain several kilos of squid which are sold for human consumption (Hendrickx, 1985), or used as bait in other fisheries (Roper et al., 1984). Sales are made locally throughout the year. Demand is increasing and squid fetch high prices sold fresh, frozen, canned, or dried.

15.2. Dosidicus gigas (Jumbo Flying Squid)

The jumbo flying squid *(D. gigas)* is the largest ommastrephid squid, reaching up to 1200 mm ML and 65 kg in weight. This pelagic squid is endemic to the eastern Pacific Ocean and is particularly abundant in the highly productive waters of the Humboldt and California Current systems, and the Costa Rica Dome upwelling.

15.2.1. Stock Identification

There are genetically separated subpopulations in the two hemispheres (Sandoval-Castellanos et al. 2007; Staaf et al., 2010), probably because the equatorial currents and countercurrents form a natural barrier in the Eastern Tropical Pacific (ETP). Using genetic (RAPD and SSCP) techniques, Sandoval-Castellanos et al. (2007, 2010) suggest that the level of genetic separation between northern and southern locations is significant enough to support the idea that *D. gigas* is undergoing adaptive radiation (Nigmatullin et al., 2001). Sandoval-Castellanos et al. (2010) also argue that spatial pattern as well as the very recent divergence (<10,000 years) among northern and southern subpopulations could be explained by oceanographic and biological factors, in particular those affecting ocean productivity. Yet, only mild divergence between south–north populations were observed by Staaf et al. (2010) using the mitochondrial marker NADH dehydrogenase subunit 2. Ibáñez et al. (2011) also found limited evidence genetic structure within in the Humboldt Current system. According to these authors, *D. gigas* consists of a single large population that experienced a dramatic expansion in the Humboldt Current system associated with rise in sea surface temperature and the reorganization of the oxygen minimum zone (OMZ) in the last 30,000 years, probably associated with the glacial–interglacial transition. Physical, biological, and oceanographic factors in the ETP influence the reproductive interchange between potential subpopulations as well as migratory ecology (Anderson and Rodhouse, 2001), which make the dynamics of the genetic structure of this species complex.

15.2.2. Distribution and Lifecycle

The jumbo flying squid is the most primitive and least oceanic representative of the Ommastrephinae, because it is the only member of this subfamily with a geographical range restricted to just one continental margin (Nigmatullin et al., 2001).Yet, this species exhibits a broad and variable range in the eastern Pacific Ocean and undergoes periodic range extensions. Until the end of the last millennium, the northern and southern limits of its distribution were around 30°N and 40°S, with the highest abundances located in the Gulf of California and in waters off Peru (Nigmatullin et al., 2001).

More recently, the distribution limits shifted to 60°N and 50°S, respectively. In the equatorial region, the distribution may extend as far west as 125°–140°W (Wormuth, 1998; Jereb and Roper, 2010), but this western boundary is not well documented, particularly with regard to the recent range expansion. Little is known about spawning and embryonic development of *D. gigas* which spawns in the relatively inaccessible open sea and, like other ommastrephids, extrudes its eggs in a large, fragile pelagic gelatinous mass. It was only in 2006 that the first natural egg mass was observed during a blue–water dive in the Guaymas Basin of the Gulf of California (at 27°7.1′N–111°16′W) (Staaf et al. 2008). The egg mass was 2–3 m in diameter and neutrally buoyant at ∼16 m deep at a temperature of ∼22°C. With an egg density of 192 to 650 eggs/L, the potential number of eggs in the entire mass ranged from 0.6 to 2 million (Staaf et al., 2008). The recent poleward range expansion of *D. gigas* is probably associated with warmer periods following El Niño/La Niña events, an ongoing expansion of the OMZ in the Eastern Pacific, and changing ecosystem interactions including food availability, competition and predation.

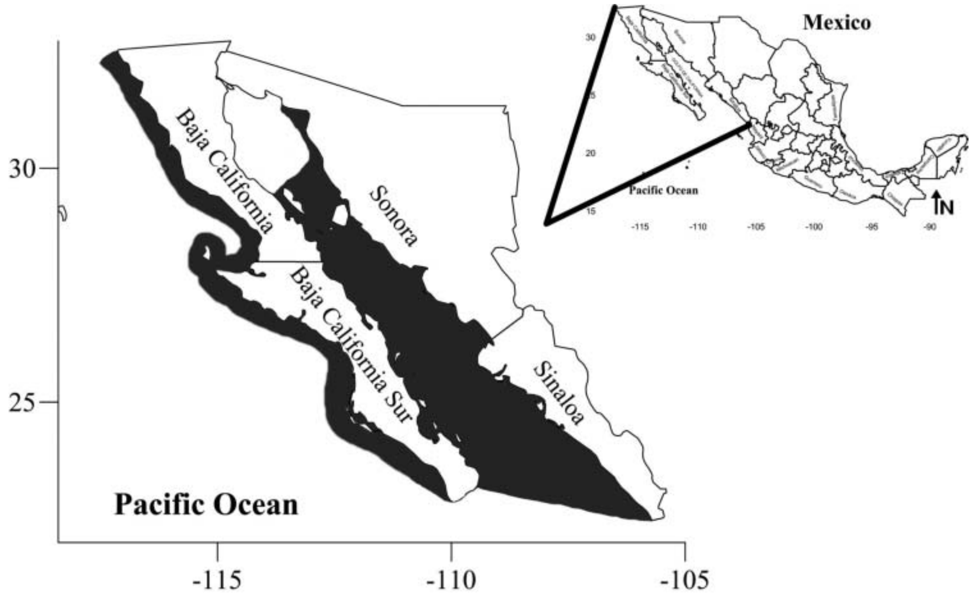

Figure 107. Major areas of commercial fishing for *Dosidicus gigas* in Mexico.

The jumbo flying squid feeds primarily on small mesopelagic (midwater) fishes, crustaceans, and cephalopods, as well as commercially important coastal fishes and squid in their expanded range. Typical daily behavior involves vertical migrations from near-surface waters at nighttime to mesopelagic depths above or within the OMZ during the daytime. A spawning migration from foraging grounds in Canada (50°N) to known spawning areas off BC (27°N: Camarillo-Coop et al., 2006) would cover a distance of ~2500 km. With a lifespan of 1–2 years (Nigmatullin et al., 2001; Markaida et al., 2005), such a migration would be well within the 30–50 km/d migration capability for adult *D. gigas* (Stewart et al. 2012), but suitable spawning habitat may occur much further north.

15.2.3. Fishing Grounds

In Mexico, the main areas of commercial exploitation are bounded by 22° and 30°N and 106° and 114°W, which covers an area inside the Gulf of California, from the mouth of the Gulf to the north of Isla Angel de la Guarda by BC to Puerto Libertad on the coast of Sonora. Although widely distributed in the Mexican Pacific fisheries are mostly located in areas of the Gulf of California (Figure 107). However, in the past 6 years, there has been significant fishing activity off the west coast of the BC peninsula, the catch being landed in Bahia Magdalena, BCS, and the port of Ensenada, BC. In the Gulf of California, the *D. gigas* fishery began in 1974 with an artisanal fleet mainly composed of small open boats with outboard motors, locally known as "pangas," each operated by two fishermen using hand jigs (Nevárez-Martínez et al., 2000). A second fleet arose in 1978, when the shrimp trawler fleet switched to squid during the closed season for shrimp. In 1981, this comprised 285 shrimp boats. Between 1983 and 1987, the stock was greatly reduced and the squid fishery disappeared. From 1989 to 1992, the National Fishery Institute of Mexico conducted exploratory fishing with the participation of 6 Japanese jigging vessels, controlled by Mexican companies, and found significant quantities on the western coast of BC (Klett, 1996).

15.2.4. Economic Importance

D. gigas, together with tuna and small pelagic fishes is one of the most important fishery resources of Mexico, with an average catch of 47,000 t per year in the period 2006–2012 (Figure 108); but there have been years (1996, 1997, and 2002) when it reached 100,000 t. The average catch value represents 1% of foreign incomes from artisanal fisheries in Mexico (de la Cruz-González, et al., 2011). Added value provided by processing increases the value of the fishery by a factor of three or more (de la Cruz-González et al., 2011). The fishery is an important economic activity in the northwestern Mexico. Although *D. gigas* is mainly exported, in recent years the national market has increased. Surveys in six cities in

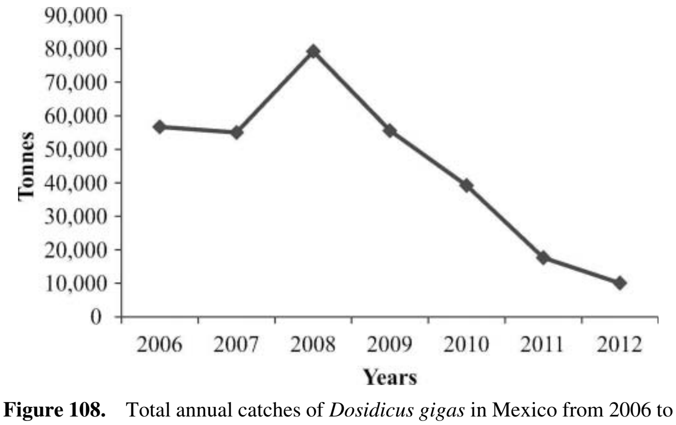

Figure 108. Total annual catches of *Dosidicus gigas* in Mexico from 2006 to 2012.

Northwest Mexico in 2004 and 2006 showed an increase in the consumption of jumbo flying squid and recognition of its nutritional value and accessible price.

The fishery is an important source of employment and foreign exchange. Artisanal fishing is estimated to provide at least 3500 direct jobs and hundreds more indirect jobs. It is a cost effective alternative fishery, so in the Guaymas area it alternates with the shrimp fishery (de la Cruz-González, 2007). In recent years, the fishery has supported economic recovery in places such as Santa Rosalia, BCS. It has provided an important source of quality protein for local consumption (fresh and fresh frozen) and raw material for the production of processed products. It has also provided bait for sport and industrial fishing.

15.2.5. *Composition and Numbers of the Fishing Fleet*

Fishing is with lights and there are two fleets. Firstly, artisanal pangas which are small vessels (length 6–10 m) with outboard motors of 40–75 hp operated by two fishers. Activity in the Santa Rosalia area starts at c. 16:00 and concludes at 02:00 and any one boat usually works from 4–6 hr. In the Sonora area, fishing is usually from dusk to dawn, with any one boat working 8–12 hr per night. In Sinaloa, which is the newest fleet, the boats are 6–8 m in length with engines from 115–200 hp. These vessels can carry up to 2 t and make the trip to the fishing grounds in less than 1 hr. The light systems on the pangas range from car lights to low power decorative-type lights.

The shrimp fleet (vessels 6–8 m length) which is adapted for the *D. gigas* fishery uses single or coupled manual reels for jigging and each vessel may carry up to 10 fishers. They use various lighting systems ranging from lamps of 100 w (6840 lumens) to 2000 w (30,000 lumens). Fleets operate in several regions and discharge catch at different ports as follows: (1) coast of BCS State: in the ports of Santa Rosalia, Mulegé, and Loreto (and to a lesser extent in Bahia Magdalena in the west coast); (2) central Gulf of California: in the ports of Guaymas (to a lesser extent in Yavaros); (3) northeastern Gulf of California: in Bahia Kino and Puerto Libertad located in Sonora State; (4) northwestern Gulf of California: in Bahia de los Angeles; (5) Sinaloa State coast: in the port of Mazatlan located in the south, Dautillos in the central part, and Topolobampo in northern Sinaloa State; and (6) BCS: port of Ensenada located in the west coast. Some boats move between regions depending on resource availability and season. Production units are shown in Table 7. There is no recreational fishery for *D. gigas*.

Table 7. Production units *Dosidicus gigas* in the states of Sonora, Sinaloa, and Baja California Sur. (Source: Federal Delegations of Fisheries, 2010).

Units	Number	Fishermen	Boats	Jigging
*Social sector	60**	1,972	986	3,944
Industrial sector	150	1,200	180	1,600
Total	210	3,172	1,136	5,444

*Artisanal associations.
**Aproximate.

15.2.6. *Catch and Effort Data*

The *D. gigas* fishery started in Mexico as a local artisanal activity at the beginning of the 1970s. The artisanal phase was characterized by 4 years of landings of around 2000 t by small vessels operating during the summer from ports in Santa Rosalia and Loreto, BCS. After the federal government negotiated access to the fishery by Asian vessels, large companies introduced squid boats with the technology and capacity to process squid on board. This influx of specialized vessels began in February 1980 and culminated in November of the same year with landings of 22,464 t. In 1981, the catch declined by one-half and in 1982, the fishery collapsed (Ehrhardt et al., 1983; Ramirez and Klett, 1985). The fishery took off again in 1994 when Korean and Chinese companies began operating in the ports of Guaymas (Sonora), Santa Rosalia and Loreto (BCS) and La Reforma (Sinaloa). Landings reached a historical maximum of 117,351 t in 1997, followed closely by a similar volume in 2002, (Rosa et al., 2013c). Since 2008 catches have declined to a little over 10,000 t in 2012. This decline is most evident in the Gulf of California where the Sonora, Sinaloa and BCS fleets traditionally operate (Figure 109).

15.2.7. *Stock Assessment and Management*

Stock assessment is commonly based on the assumption of annual cohorts (Hernández-Herrera et al. 1998), and therefore, the modeling of this resource depends on initial recruitment levels. Management objectives (recruitment and proportional escapement) depend on catchability, which is computed from indices of relative abundance, namely, CPUE. One published management strategy uses a constant proportional escapement as a reference point (Beddington et al., 1990; Basson et al., 1996). Management is based on retaining 40% of the stock at the end of each season, and effort is controlled by allocation of fishing permits. The Mexican National Fisheries Institute

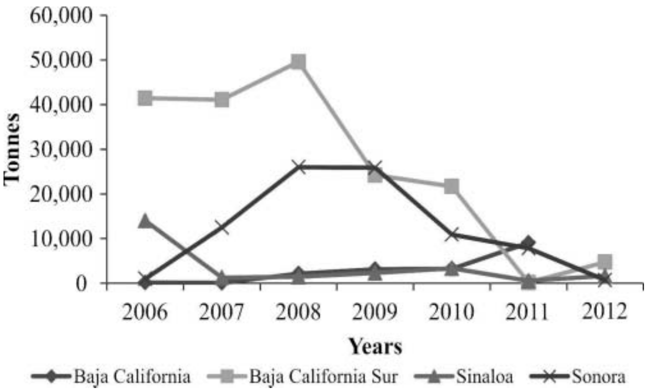

Figure 109. Total catches of *Dosidicus gigas* in Mexico from 2006 to 2012 by State.

bases its estimates and recommendations on the analysis of catch and effort data and information obtained from research cruises.

15.2.8. Conservation Measures

Exploitation has remained at "developing fishery" level. Nevarez-Martinez et al. (2010) reported that fishing mortality (F) and exploitation rate (E) are below 0.5, a level that is considered healthy for an exploited resource. Assessing the impact of fishing through the Thompson-Bell model, it seems that the observed annual fishing mortality is below the FMSY (Fishing mortality consistent with achieving MSY). This is supported by the estimate of proportional escapement, which is greater than the BRP of 40%. This suggests that *D. gigas* is underexploited in Mexico.

16. SOUTH-EASTERN PACIFIC

Squid fisheries in the south-eastern Pacific are pursued off both Peru and Chile where the ommastrephid *D. gigas* and the loliginid *D. gahi* are targeted. The *D. gahi* fisheries are small and artisanal. The *D. gigas* fishery is artisanal and relatively small in Chile but it is a major fishery off Peru where it is exploited both artisanally and industrially. There is also a major fishery for *D. gigas* outside the Peruvian EEZ pursued by vessels from Korea, Taiwan, and China.

Doryteuthis gahi is mostly used for local consumption. *D. gigas* is exported on a large scale, both unprocessed and processed. In spite of the importance of the *D. gigas* fishery, aspects of the biology of the species such as spawning areas and stock structure are poorly understood.

16.1. Doryteuthis gahi (Patagonian Squid)

16.1.1. Stock Identification

Studies to discriminate between stocks of Patagonian squid (*D. gahi*) in the coastal waters of Peru and Chile have been made using genetic and morphometric analysis. Genetic analysis, using mitochondrial gene Cytochrome Oxidase I, detected a significant genetic differentiation of *D. gahi* along its geographical distribution showing two genetic units, a northern population (off Peru), and southern population (off Chile) (Ibáñez et al., 2011a). Squid from the southern region showed higher genetic diversity ($H = 0.34–0.50$) than the northerly population ($H = 0.75–0.80$). The results suggest that the northern population is experiencing, or experienced in the recent past, a demographic expansion some 30,000 years ago, a pattern that was not found in the southern population (Ibáñez et al., 2011a). At a larger geographical scale, microsatellite analysis showed significant differentiation between samples from the Falkland Islands and from Peru, presumably caused by substantial environmental and geographical barriers between the east and west coasts of South America (Shaw et al., 2004).

Analysis of statoliths of male and female *D. gahi* collected in northern Peru and the Falklands islands revealed morphometric differences suggesting the existence of reproductively isolated populations (Vega et al., 2001). Significant differences were also found between three populations (Falkland Islands, Chile, and Peru), when hard structures (gladius, beaks, and statoliths) of males and females were compared separately (Vega et al., 2002).

16.1.2. Distribution and Lifecycle

The Patagonian squid inhabits coastal waters of Peru and Chile in the southeastern Pacific (4°–55°S) and the coastal waters of Argentina and the Falkland Islands in the southwestern Atlantic (38°–55°S) (Jereb and Roper, 2010). In Peruvian waters and in northern Chile spawning takes place in shallow, sandy areas. Lifespan is short (1 year) and there are two peaks of hatching in April and December and a secondary peak between September and October in Peru (Villegas, 2001).

16.1.3. Fishing Grounds

The Patagonian squid is caught off Peru from 03° to 16°S, mainly in bays where the seabed is sandy. Sizes range from 27 to 430 mm ML (mean 178 mm). Males are larger than females.

In Chilean waters *D. gahi* is captured principally in the FAO Regions V (32°S), VIII (37°S) and X (41°S) (Sernapesca). Size is in the range 45–155 mm ML. In both sexes, maturity stages III and IV are the most frequent in spring/summer (Ibáñez et al., 2005).

16.1.4. Economic Importance

The Patagonian squid is consumed locally in Chile and Peru. It is also exported from Peru but information about exports is not available.

16.1.5. Composition and Numbers of the Fishing Fleet

There is no fleet dedicated exclusively to *D. gahi* in either Chile or Peru. In Peru, the fleet that takes *D. gahi* consists of artisanal boats that fish for multiple species. Gear used includes fishing with hooks, purse seine, drift net, mid-water trawl, and "chinchorro." Table 8 shows the number of vessels fishing with each gear type and year in which *D. gahi* was the main catch. Most vessels either used hook and line or purse seines.

In central Chile, *D. gahi* is taken as a bycatch in the artisanal fishery for anchovy and sardine.

16.1.6. Fishing Seasons

Duration of the fishing season is very variable in Peru. Between 3° and 6°S, the fishery operates over about 10 months

Table 8. Number of artisanal boats by year and fishing methods dedicated to catch *D. gahi* in Peruvian waters.

Year	Hooks	Purse seine net	Drift net	Chinchorro*	Midwater trawls	Total
1997	449	142	30	22	8	651
1998	16	15	5	9	17	62
1999	184	88	4	15		291
2000	759	533	3	18		1313
2001	555	310	16	8		889
2002	397	228	14	13	12	664
2003	752	479	3	11	8	1253
2004	436	322	10	14	28	810
2005	458	232	11	12	32	745
2006	372	329	33	11	58	803
2007	532	301	9	4	32	878
2008	329	160	21	5	21	536
2009	518	166	15	5	3	707
2010	292	125	1	2	2	422
2011	353	70	3	3		429
2012	537	233	1	1	2	774

Source: Instituto del Mar del Perú.
*Chinchorro is a large net trawled by cars or men in sandy beach.

Table 9. Annual effort (number of trips) by fishing methods of *D. gahi* in Peruvian waters 1997–2012.

Year	Hook	Purse seine	Chinchorro	Mid water trawls	Drift net	Total
1997	2,494	385	49	8	234	3,170
1998	46	16	15	19	5	101
1999	3,122	271	80	0	4	3,477
2000	5,980	5,393	108	0	3	11,484
2001	3,870	2,854	49	0	25	6,798
2002	2,640	1,372	46	17	16	4,091
2003	8,547	6,622	33	11	3	15,216
2004	6,788	4,484	109	424	11	11,816
2005	6,745	5,193	129	692	15	12,774
2006	4,676	7,107	73	960	38	12,854
2007	8,472	5,745	14	450	9	14,690
2008	2,998	2,083	32	247	28	5,388
2009	4,885	2,036	21	8	15	6,965
2010	5,997	1,433	10	2	1	7,443
2011	3,754	902	8	0	3	4,667
2012	5,915	3,684	5	2	1	9,607

Source: Instituto del Mar del Perú.

per year; between 9° and 12°S, it is highly variable and takes place over 1–6 months. In latitudes 7°–8°S and 13°–16°S, it operates some 5 months of the year. Average catch per season reaches up to 60 t between 04° and 05°S. In other latitudes, catches do not exceed 50 t per season (Figure 110).

16.1.7. *Catch and Effort Data*

Between 1990 and 2010, the annual catch of *D. gahi* in Peru ranged from 287 t in 1998 to 24,548 t in 2000. In Chile annual catches ranged between 0 and 934 t. Table 9 shows fishing effort directed to *D. gahi* in Peru using different methods.

16.1.7.1. Stock assessment and management. There is no stock assessment of *D. gahi* in either Peru or Chile. However, fishing effort, size structure and biological parameters are monitored in Peru during the fishing season.

16.1.8. *Conservation Measures*

In Peru, purse seines for *D. gahi* fishing are prohibited for artisanal, small-scale, and industrial vessels within 5 nautical miles from the shore. There is no minimum size, catch quotas, or BRPs in either Peru or Chile.

16.2. *Dosidicus gigas (Jumbo Flying Squid)*

16.2.1. *Stock Identification*

Studies to discriminate stocks of *D. gigas* in the South East Pacific using genetic analysis (Ibáñez et al., 2011b) have shown no genetic differences among squid in the Humboldt Current off Chile and Peru. However, Randomly Amplified Polymorphic DNA (Sandoval-Castellanos et al., 2007) analysis and mitochondrial DNA analysis (Sandoval-Castellanos

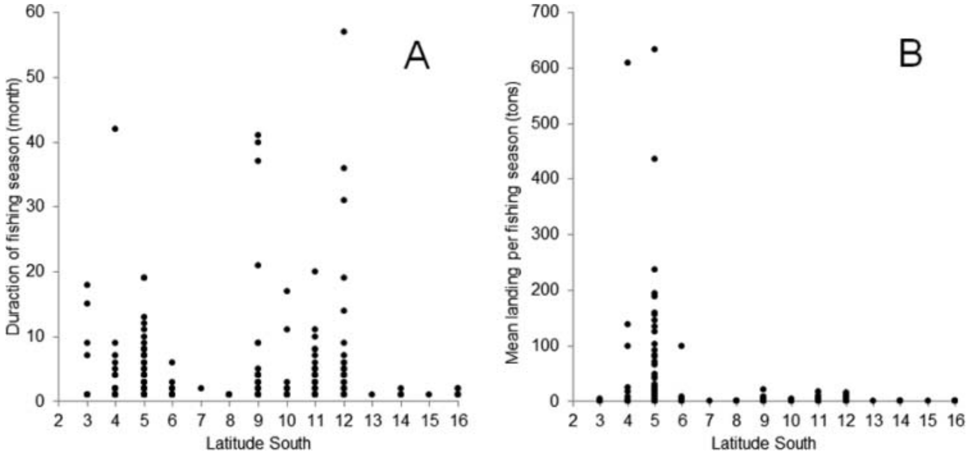

Figure 110. Duration of fishing season (A) and mean landings per fishing season (B) of *Doryteuthis gahi* by latitude in Peruvian waters 1998–2010.

et al., 2010) have been shown that squid from the Northeast Pacific off Mexico and from the Southeast Pacific off Peru belong to two populations separated by oceanographic and biological factors (Staaf et al., 2010).

16.2.2. Distribution and Lifecycle

D. gigas is endemic to the Eastern Pacific Ocean between 37–40°N to 45–47°S, and common between 30°N and 20–25°S (Nesis, 1983; Nigmatullin et al., 2001). Its range fluctuates, both in the northern and southern hemisphere (Nigmatullin et al., 2001; Field et al., 2007; Zeiberg and Robinson, 2007; Ibañez and Cubillos, 2007; Alarcón-Muñoz et al., 2008; Keyl et al., 2008). Its flexible and opportunistic behavior (Markaida, 2006) allows the species to respond quickly to environmental variability (Rodhouse and Nigmatullin, 1996); this is manifested in changes in the distribution, abundance, growth rate, size at maturity and longevity associated with the availability of food and oceanographic conditions (Arguelles et al., 2008). However, high growth rates do not necessarily have a simple relationship to temperature and food availability. Keyl et al. (2011) have shown that fast-growing cohorts with medium longevity and large terminal size occur during moderately cool periods, and long-lived, slow-growing cohorts with small terminal size occur during the extreme ecosystem conditions of the El Niño and La Niña phases of the ENSO cycle.

16.2.2.1. Peruvian Waters. Off Peru, the highest concentrations of *D. gigas* occur between 3°24’S (Puerto Pizarro) and 9°S (Chimbote), and low to medium concentrations are located at 13°42’S (Pisco) and 16°14’S (Atico) (Taipe et al., 2001).

Spawning occurs throughout the year with two main peaks from October to January, and a secondary peak between July and August (Tafur and Rabi, 1997; Tafur et al., 2001). Beyond the Peruvian EEZ spawning also takes place throughout the year (Liu et al., 2013). The main spawning grounds are located between 3° and 8°S, and between 12° and 17°S within Peruvian EEZ (Tafur et al., 2001), while beyond the EEZ spawning occurs at around 11°S (Liu et al., 2010).

Arguelles et al. (2008) have described the interannual variability of the size-at-maturity of *D. gigas* in Peruvian waters, and they related the size-at-maturity with the increment of the mesopelagic fish stocks which are part of the diet of *D. gigas.* Outside the Chilean EEZ spawning grounds were reported between 22° and 34°S (Leiva et al., 1993).

Annual variation of size-at-maturity in Peruvian coastal waters from 1989 to 2011 is shown in Figure 111. Significant variations in size structure were observed to be related to oceanographic changes in the period 1958–2012. During warm years (1997–1998) small and medium-sized groups were observed in the catches, with average sizes between 230 and 440 mm ML; during cold years (2000–2012) a large-sized group predominated with average sizes from 610 to 880 mm ML. From 2001 onward, there has been a significant change in population structure which is dominated by large squid (Keyl et al., 2008; Arguelles et al., 2008; Arguelles and Tafur, 2010).

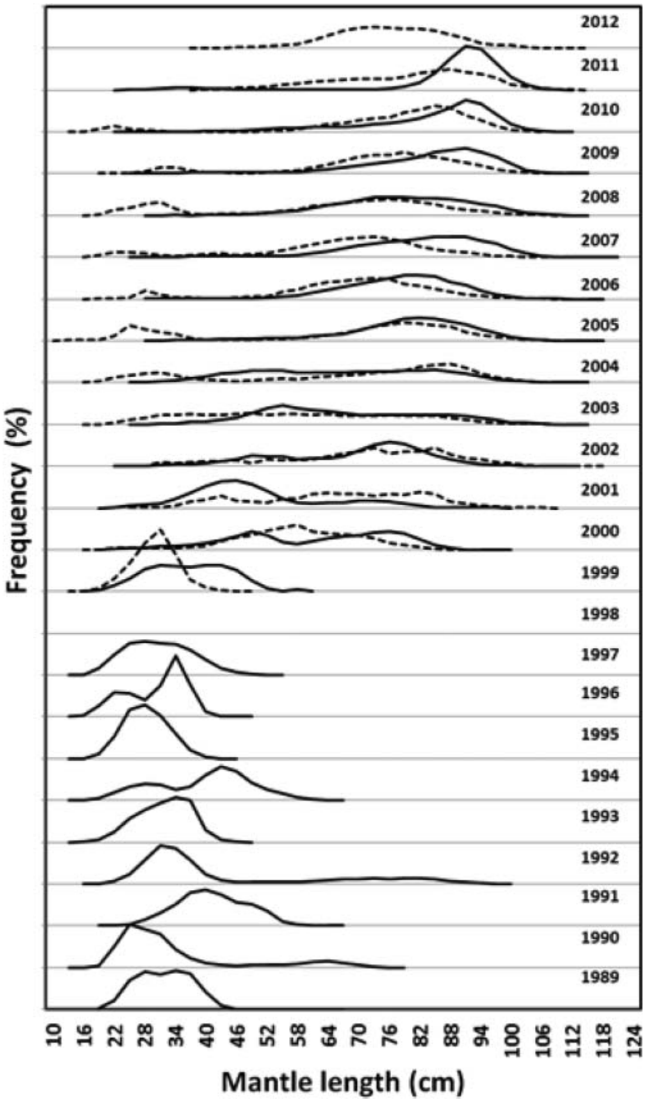

Figure 111. Annual size structure of *Dosidicus gigas* in the artisanal fishery (dashed lines) and industrial (solid lines) for 1989–2012.

During a *D. gigas* survey on the research vessel *Kaiyo Maru* in Peruvian waters during December 2011–January 2012, the largest squid were found to the south of 12°S and near shore (Sakai et al., 2013). However, data from the industrial fishery in Peru show no significant latitudinal differences in size structure of the population, except for some years, for example, 2000 and 2001, in which there was a change from small and medium-sized group to a large-sized group associated with environmental changes from cold to warm conditions (Table 10). Outside the Peruvian EEZ, Liu et al. (2013) reported a wide range of sizes of *D. gigas* (129–1149 mm ML) in the period 2008–2010, with most squid between 350 and 550 mm ML. Variation in the size structure would explain continuous recruitment off the Peruvian coast, mainly from the west where juveniles are concentrated (Sakai et al., 2013).

Table 10. Mean, minimum, and maximum mantle length of *Dosidicus gigas* per latitudinal degree in Peruvian waters from 1991 to 2012.

Year	Latitud (S)	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1991	Min (cm)				27	22	19	18	25	32	24	22		20	37	22	
	Max (cm)				42	58	61	61	95	79	47	41		51	53	58	
	Mean (cm)				36.0	39.0	42.3	39.9	47.5	52.0	35.7	31.5		29.7	47.0	43.1	
1992	Min (cm)	19	22	19	19	10	19	19	22	22	19	16	19	19	22	22	25
	Max (cm)	94	109	109	100	100	94	85	73	46	55	64	70	67	55	55	103
	Mean (cm)	34.4	73.0	58.9	41.5	47.4	34.9	39.8	39.0	32.3	28.6	31.5	34.7	34.7	33.2	34.9	57.4
1993	Min (cm)	15	12	15	14	14	15	20			16	15	17	15	15		59
	Max (cm)	50	50	50	53	55	46	46			86	49	49	96	104		95
	Mean (cm)	34.2	31.4	33.0	29.2	31.3	33.7	32.4			28.6	28.9	27.0	35.6	65.2		82.4
1994	Min (cm)	15	12	14	17	16	18	24						23			
	Max (cm)	67	70	68	66	72	72	46						60			
	Mean (cm)	39.5	40.8	36.0	40.1	44.7	49.9	31.0						36.1			
1995	Min (cm)	13	12	15	15	15	19	22	18		21	19					
	Max (cm)	58	60	53	42	50	48	36	47		41	47					
	Mean (cm)	29.9	27.8	27.3	27.1	27.7	29.3	31.0	32.1		28.6	26.7					
1996	Min (cm)	12	12	17	18	17	15	20	15	15	16	16	17				
	Max (cm)	43	42	42	40	41	35	32	39	38	35	43	39				
	Mean (cm)	23.4	23.6	27.2	27.8	26.7	24.1	26.8	26.0	26.6	25.3	26.3	25.5				
1997	Min (cm)	16	15	28	14	15		18									
	Max (cm)	58	51	52	57	53		42									
	Mean (cm)	31.9	30.1	30.2	30.0	29.6		24.3									
1999	Min (cm)	13	15	15	19												
	Max (cm)	47	48	58	57												
	Mean (cm)	27.3	29.5	36.4	38.9												
2000	Min (cm)	45	30	27	30	36	38	38				20	16	15	21		
	Max (cm)	88	98	98	84	77	56	56				55	50	49	42		
	Mean (cm)	67.3	73.1	69.9	60.7	60.7	47.6	47.3				33.5	31.2	29.9	27.1		
2001	Min (cm)			54	50	28		35	24	40	28	20	21	20	21	22	
	Max (cm)			102	98	100		91	58	99	92	73	104	99	100	91	
	Mean (cm)			79.4	74.4	79.7		52.6	44.1	79.9	48.5	42.0	53.6	65.7	69.7	67.7	
2002	Min (cm)			62	40	63					38	32	33	29	29		32
	Max (cm)			108	109	104					99	103	105	110	96		82
	Mean (cm)			92.3	86.7	88.5					74.3	76.2	74.6	69.9	68.2		67.9
2003	Min (cm)			42	24	19	23	27	30	60			60				
	Max (cm)			99	108	111	113	111	111	106			97				
	Mean (cm)			62.0	62.0	71.7	70.1	65.9	60.5	85.2			78.4				
2004	Min (cm)			20	28	25	24	24	30	28	30	27	22	17	25		
	Max (cm)			117	112	110	110	113	104	109	109	109	116	109	121		
	Mean (cm)			71.7	66.4	63.2	59.9	74.0	63.7	73.4	81.7	76.8	77.1	55.2	52.0		
2005	Min (cm)		42	34	27	26	21	20	34	26	30	25	35	26	32		
	Max (cm)		114	115	113	114	117	113	110	111	117	117	108	115	109		
	Mean (cm)		68.7	70.5	73.8	73.0	77.1	78.3	79.8	83.3	77.4	78.3	80.3	81.5	82.1		
2006	Min (cm)	78	52	30	37	26	24	32	37	30	29	30	33	40	45		
	Max (cm)	101	103	116	113	114	115	114	105	113	110	116	115	106	107		
	Mean (cm)	90.2	85.5	84.5	78.9	69.7	77.4	79.1	66.8	79.9	76.6	77.1	76.0	70.3	75.8		
2007	Min (cm)	44	30	25	27	30	28	49	32	45		48	51	50	40	32	
	Max (cm)	108	114	119	112	113	119	110	112	110	102	102	101	97	101	98	
	Mean (cm)	77.7	77.5	82.8	84.3	82.3	78.2	81.2	82.6	78.6	84.0	79.1	87.1	84.2	52.1	54.5	
2008	Min (cm)		22	21	41	31	31	61	41	40	50	30	31	27	28	50	
	Max (cm)		103	112	116	117	112	103	105	106	99	113	112	118	112	113	
	Mean (cm)		78.3	75.5	78.0	84.9	78.7	87.0	80.9	87.7	77.6	75.7	83.9	78.0	80.8	82.7	
2009	Min (cm)		41	28	23	23	41	34	24	22	42	22	25	37	36	47	62
	Max (cm)		120	122	122	115	15	100	109	103	105	110	110	113	108	97	106
	Mean (cm)		86.4	85.9	77.9	88.2	87.8	73.3	66.0	40.5	77.2	71.3	73.7	78.3	70.3	66.5	85.8
2010	Min (cm)		24	30	16	22	26	40				40	27	33	28	50	23
	Max (cm)		112	119	112	114	112	114				118	115	120	106	109	109
	Mean (cm)		85.0	82.3	75.6	84.6	77.4	65.5				90.0	88.1	85.1	80.1	88.3	83.2
2011	Min (cm)		68	27	33	22	72	30			66	28	30	24	70		76
	Max (cm)		112	112	107	106	106	115			110	111	121	126	115		103
	Mean (cm)		94.1	89.7	90.9	60.9	92.6	56.9			88.2	87.0	89.7	88.7	91.6		89.7

16.2.2.2. Costa Rica Dome. During 2009 and 2010, the jumbo flying squid (*D. gigas*) population was surveyed with the help of Chinese squid jigging vessels off the Costa Rica Dome (4°−11°N, 90°−100°W) (Chen et al., 2013a). The mean ML of the squid was 298 mm for males (211–355 mm) and 306 mm for females (204–429 mm). There was no significant difference between sexes in the relationship between ML (mm) and body weight (g) of the squid. The females and males were of similar maturity, mostly in the maturing and matured stages with a few spent female squid. ML and age at first sexual maturity were 297 mm and 195 days in females and less than 211 mm and 130 days in males. This indicates that off Costa Rica small-sized squid predominate. Longevity off Costa Rica was less than 10 months for females and 8 months for males, while most of those off Chile and Peru are about 1∼1.5 years and a few large individuals reach 1.5∼2 years old. A higher percentage of mature individuals were found off Costa Rica implying the region is a likely spawning ground, while a lower proportion of mature squid off Peru and Chile indicate that spawning may occur outside the area (Liu et al., 2013).

16.2.2.3. Chilean Waters. Data on size structure of *D. gigas* off the Chilean coast (29°–34°S) have been reported for the period 1991–1994 (Fernández and Vásquez, 1995), indicating a size range of between 770 and 1030 mm ML. Chong et al. (2005) reported two size groups of *D. gigas* during the winter of 1993, the first of large (710–980 mm ML) squid and the second of smaller (200–440 mm ML) squid, while in spring 1993, a group of between 260 and 600 mm ML was present. After 2000, Ibáñez and Cubillos (2007) found sizes between 230 and 930 mm ML for the period August 2003–January 2004, and between 280 and 840 mm ML for winter 2003, spring 2003 and summer 2004. In Chilean waters, mature females have been observed all year round (Gonzáles and Chong, 2006), while beyond the Chilean EEZ *D. gigas* spawn all year also with the peak from November to January (Liu et al., 2010).

16.2.2.4. International Waters Outside Chilean EEZ. Three surveys have been conducted in waters outside the EEZ of Chile (20°–41°S and 74°30’–84°W) by the Chinese squid jigging between April 2006 and May 2008 (Liu et al., 2010). The mean ML was 376 mm for males (range 257–721 mm) and 389 mm for females (range of 236–837 mm). Two distinguishable size classes, medium- and large-sized, were identified in this study with the medium-sized group (350–450 mm ML) consisting of 89% of the total catch. Size at first sexual maturity was 638 mm ML for females and 565 mm ML for males. Liu et al. (2010) found that all the individuals examined were hatched during March 2007–February 2008, indicating that *D. gigas* might spawn all year around with the peak spawning time being from November 2007 to January 2008. Most of the stomachs analyzed contained food remains. Prey included three major groups: fish (mainly lanternfish), cephalopods, and crustaceans. There is strong evidence of cannibalism in *D. gigas*.

16.2.3. Fishing Grounds

The jumbo flying squid in the Southeast Pacific is fished mainly off Peru and Chile by artisanal fleets and also by commercial jiggers off Peru.

Off the Peruvian coast the artisanal fleet operates mainly offshore near Talara (4°S) and Paita (5°S) in the north taking 90% of the artisanal catch, 7% is taken offshore near Matarani (16°S) and Mollendo (17°S) to the south. Lower catches Peru (3%) are recorded from the central coast. The largest artisanal catches are recorded within 40 nm from the coast (Figure 112).

Between 1991 and 2009 industrial fishing off Peru was carried out over a wide area between 20 and 200 nm off the coast (Mariátegui and Taipe, 1996; Yamashiro et al., 1997; 1998) and then was restricted to waters more than 80 nm offshore in order to avoid interference with the artisanal fleet. The jigging fleet also worked outside the Peruvian EEZ when squid distribution extended there (Figure 113). Japanese, Chinese and Korean jigging vessels operate in international waters off South America (Chen et al., 2008; Liu et al., 2013).

The highest catch rates (greater than 10 t/d/boat) are between 4°–10°S and 12°–16°S (Mariátegui and Taipe, 1996; Yamashiro et al., 1997; Taipe et al., 2001; Rosa et al., 2013c). In 1996, the fleet moved to the Costa Rica Dome when the availability and abundance of jumbo squid decreased dramatically off Peru (Mariátegui et al., 1997).

Off the Chilean coast, fishing grounds are situated off the Bio Bio region of central Chile (36°–38.5°S), and off Coquimbo and Valparaíso (29°–34°S) to the north (Fernández and Vásquez, 1995; Rosa et al., 2013c). Additionally, Japanese, Korean, and Chinese industrial jiggers exploit jumbo flying squid in international waters off South America. In the waters of the Chilean EEZ, the majority of the catch in the survey was caught within 37°30’–41°S and 78°30’–80°W and by 25°–30°S and 76°–77°30’W. Favorable SSTs for fishing grounds are 14–16°C and 16–19°C, respectively (Liu et al. 2010).

Off the Costa Rica Dome, the daily catch of *D. gigas* by Chinese vessels ranges from 0 to 5.5 t/d and is mostly obtained from the areas defined by 6°−9°N and 91°−94°W and by 6°30′N−7°30′S and 96°−97°W between July and August. The areas yielding the most catch have had sea surface temperatures of 27.5–29°C (Chen et al., 2013a).

16.2.4. Economic Importance

The jumbo flying squid supports considerable economic activity and is one of the major fisheries in the Southeast Pacific. It is fished within the EEZ of Peru (Mariátegui and Taipe, 1996; Mariátegui et al., 1997; Mariátegui, 2009; Kuroiwa, 1998; Yamashiro et al., 1997, 1998; Taipe et al., 2001) and Chile (Rocha and Vega, 2003; Acuña et al., 2006; Arancibia et al., 2007; Zúñiga et al., 2008), and also fished offshore in international waters off the coast by Chinese, Korean and Japanese fleets (Liu et al., 2010, 2013; Rosa et al., 2013c).

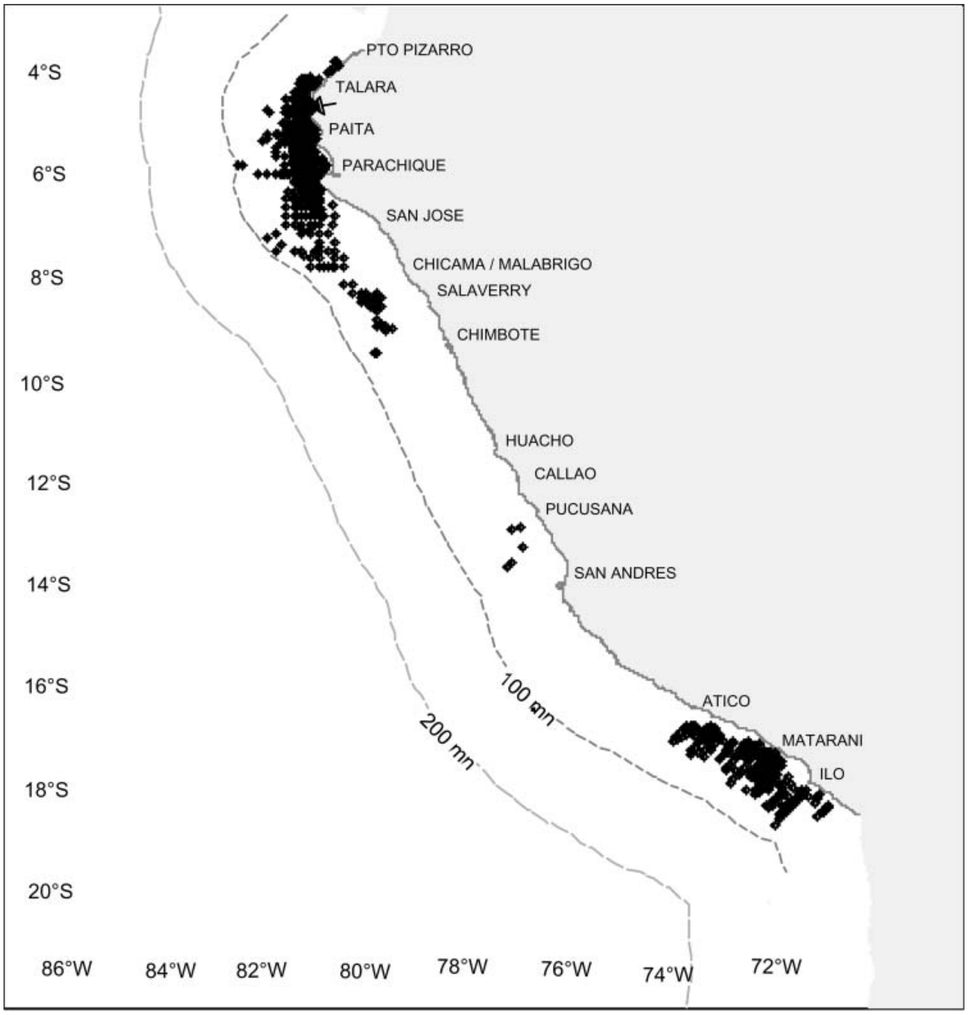

Figure 112. Artisanal fishing areas of *Dosidicus gigas* off Peru in the period 1999–2012.

Annual landings of *D. gigas* in the Southeastern Pacific show an increasing trend since 1990, with two periods of greatest abundance in 1994 and 2000–2012 (Figure 114).

In Peru, the exports of *D. gigas* have increased from 66,818 t in 2000 to 262,845 t in 2012 (Figure 115), due to increased world demand, mainly in China, Spain, Japan, and South Korea (National Customs Superintendent and Tax Administration-SUNAT Peru).

16.2.5. *Composition and Size of the Fishing Fleet*

The artisanal fishing fleet is composed of wooden boats of 1–15 m^3 storage capacity that mostly operate with hand jigs (Rosa et al., 2013c), and other large boats up to 33 m^3 capacity that also catch sharks, mahi mahi, flying fish, and other oceanic fishes, but catch squids when they are available, and when fish abundance decreases. The number of artisanal boats has increased from 292 in 1997 to 3082 in recent years; most of these are between 5 and 15 m^3 capacity representing 79% of the total artisanal fleet. The number of large capacity boats has increased between 2008 and 2011 (Figure 116).

The industrial squid fleet is comprised of jigging vessels of 250 to 1000 m^3 storage capacity; Japanese vessels are slightly larger than the Koreans vessels (Table 11). The number of vessels fluctuated between 31 and 77 in 1991–1995, with maximum numbers in 1993 and 1995 (Mariátegui, 2009). In the following years, the number decreased to between 4 and 15 since 2003 (Figure 117).

16.2.6. *Duration of Fishing Period by Fishing Region*

In Peru, the artisanal fishery is conducted throughout the year along the coast. The industrial fishery is regulated by fishing licenses valid for 1 year.

16.2.7. *Catch and Effort Data*

D. gigas were reported as bycatch during 1964–1971 in the coastal trawl and purse seine fisheries (Benites and Valdivieso, 1986). After 1971, *D. gigas* was absent or scarce in the landings until 1989. Exploratory fishing by the Instituto del Mar del Perú (IMARPE) in 1979 and 1980 indicated low abundance at that time (Benites and Valdivieso, 1986). During

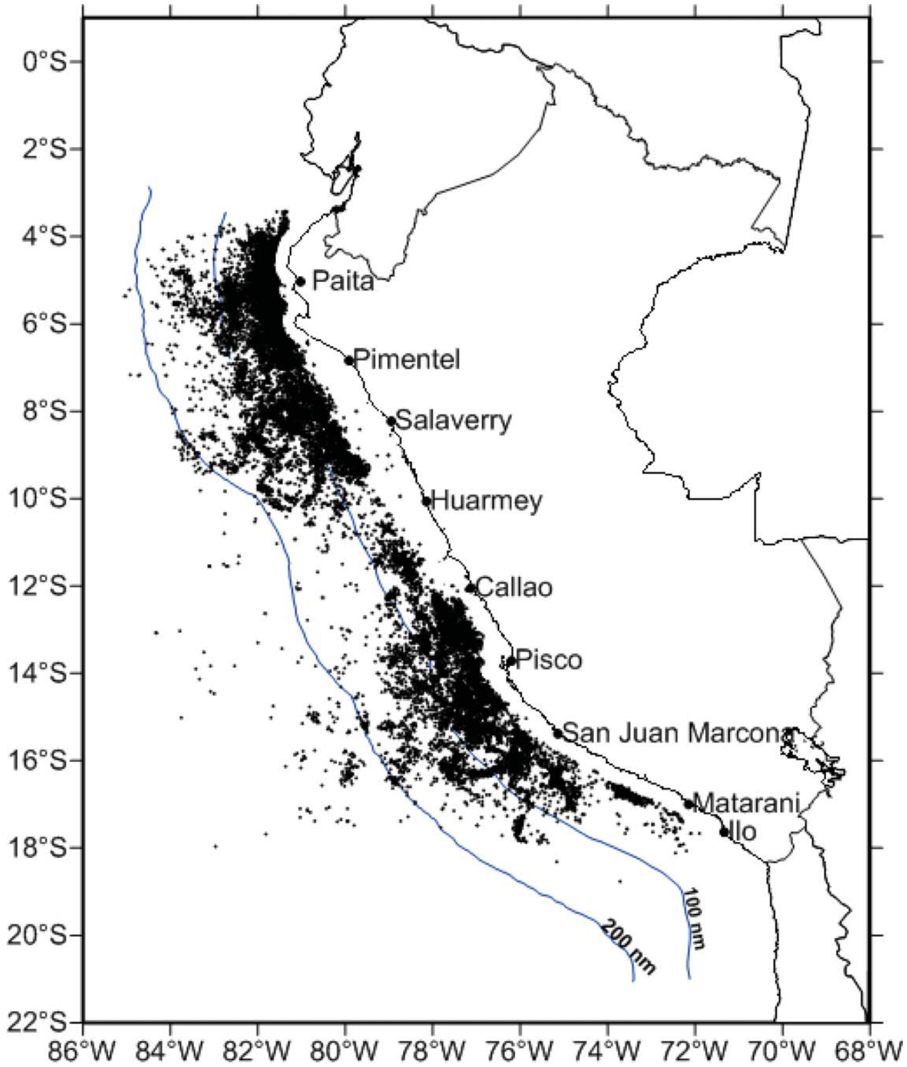

Figure 113. Industrial fishing areas of *Dosidicus gigas* off Peru in the period 1991–2011.

1981–1983 absence was attributed to lack of food during the 1982–1983 El Niño event (Benites, 1985). Research by the Center for Marine Fishery Resources Research of Japan after 1984 revealed the existence of large concentrations outside the Peruvian EEZ (Kuroiwa, 1998) and within the EEZ (Rubio and Salazar, 1992).

The industrial fishery in Peru began in April 1991 with the participation of Japanese and Korean fleets; they operated in

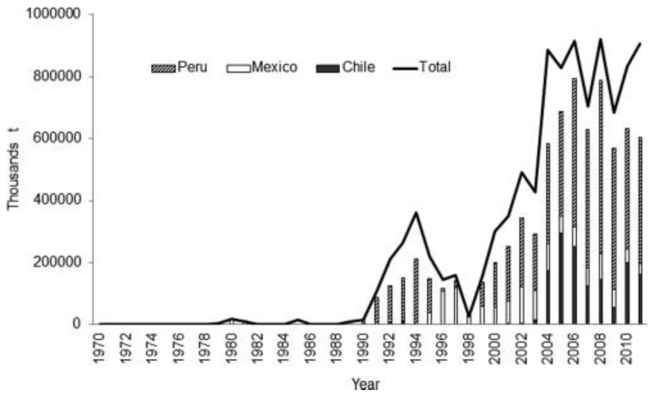

Figure 114. Landings of *Dosidicus gigas* by countries in the Southeast Pacific, 1970–2012.

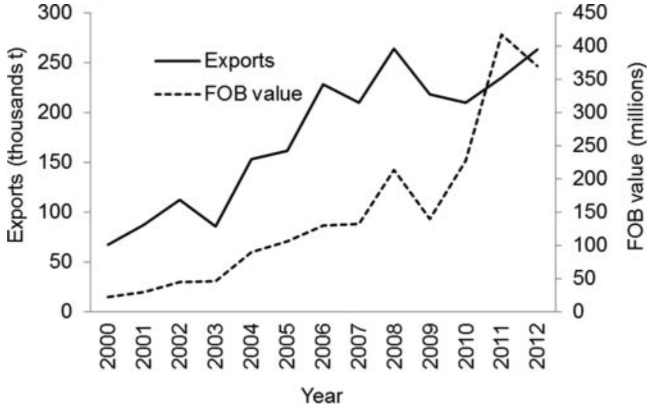

Figure 115. Exports and FOB value of *Dosidicus gigas* in Peru, 2000–2012.

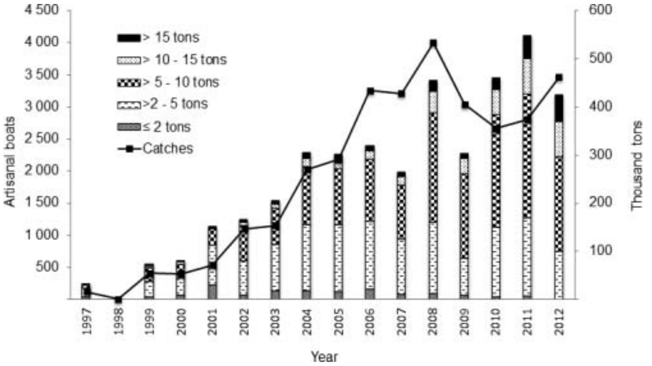

Figure 116. Structure by storage capacity of the artisanal fleet that catch *Dosidicus gigas* by hand jigs in Peru.

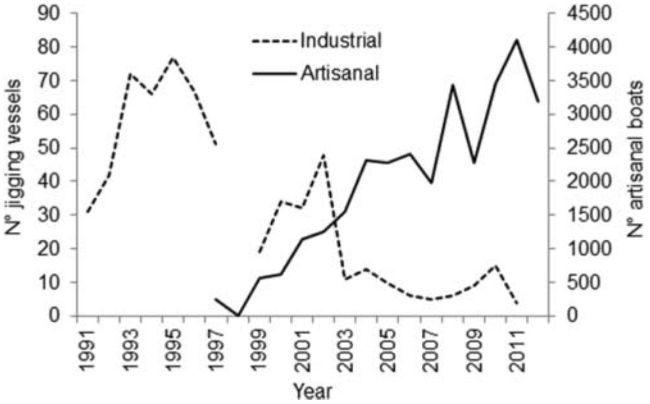

Figure 117. Number of jigging vessels (dotted line) and artisanal boats (black line) that catch *Dosidicus gigas* off Peru in the period 1991–2012.

the EEZ under fishing licenses. The annual catch fluctuated between 57,703 and 164,715 t during 1991–1995 and in the following years (1996–1998), the catches were very low due to oceanographic changes produced by La Niña 1996 and El Niño 1997–1998 (Rosa et al., 2013c). Since 1999, there has been a gradual increase in catches, with greater participation of the artisanal fleet and a reduction in the number of industrial jiggers. The annual catch between 2004 and 2012 ranged from 321,636 to 558,850 t, with the artisanal fleet taking around 90% of the total catch (Table 12, Figure 118).

There is a seasonality in the artisanal landings between 1991 and 2010, with higher values in summer and autumn. Landings tend to decrease in winter and spring, as a result of intensification of upwelling that extend cold coastal waters westward. The industrial fleet shows the opposite trend with higher landings in winter and spring. This is because the resource is more accessible offshore where these vessels operate (Rosa et al., 2013c).

CPUE varies annually, with two periods of highest abundance in 1991–1995 with a maximum value in 1994, and 2000–2012; an intermediate period of lower abundance between 1996 and 1998 was related to the intense ENSO event that had a major impact on recruitment in Peruvian waters. A progressive increase in CPUE has been observed in artisanal fisheries with highest values between 2009 and 2012 (Table 12).

Table 11. Main characteristics of Japanese and Korean squid fleet, 1991–1996.

	Japanese fleet		Korean fleet	
Characteristics	Max	Min	Max	Min
TRN	411	251	481	191
TBR	1096	305	824	323
Storage capacity (m^3)	1000	300	800	250
Length (m)	69	48	57	44.2
Sleeve (m)	10.7	8.7	11.1	7
Strut (m)	9.3	3	4.9	3
Crew number	24	20	36	27
Year of construction	1988	1982	1978	1971
Machines number	56	44	52	42

In Chilean waters, the landings of *D. gigas* have been sporadic (Fernández and Vásquez, 1995). The fishery is artisanal and catches have been generally low with occasional periods of high abundance in the bycatch of demersal and pelagic fisheries. A period of higher abundance occurred from 2002 onward, with a maximum of 296,954 t in 2005, especially from the purse seine and bottom trawl fleets (Rosa et al., 2013c; Figure 119). Zúniga et al. (2008) report a regular seasonal pattern in monthly catch data between 2002 and 2005, and suggest these fluctuations may be related to reproductive success.

Between June and September in 2001, the Chinese squid jigging industry carried out the first survey of the *D. gigas* resource in the high seas off Peru and Costa Rica. This was followed by commercial exploitation, and an annual catch reaching 17,770 t. In 2004, a large number of Chinese jiggers moved to the high seas outside the Peruvian EEZ after April, and annual output reached 205,600 t, with an average output of 1,728 t per vessel. During 2005-2010, the annual catch ranged from 46,000 to 140,000 t. In 2011 and 2012, this increased to 220,000–250,000 t (Figure 120).

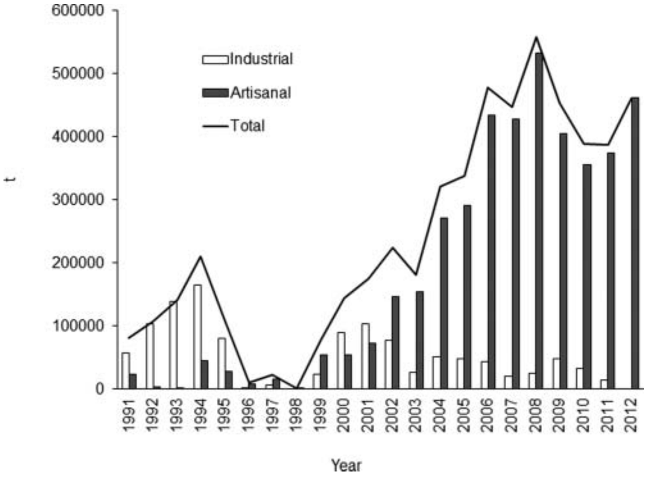

Figure 118. Annual landings of *Dosidicus gigas* off Peru in 1991–2012. Artisanal fleet (gray bars) and industrial fleet (white bars).

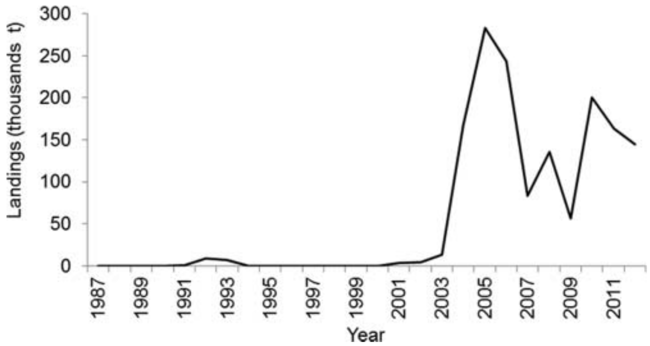

Figure 119. Landings of *Dosidicus gigas* off Chile between 1987 and 2012 (data from SERNAPESCA, Chile).

Between 2002 and 2011, Taiwanese jigging vessels recorded annual catches ranging from 12,000 in 2002 to 39,000 t in 2004, with an average annual production of some 21,000 t (Figure 121). The number of vessels fishing per year ranged from 13 to 29 in the same period. The fishing grounds for Taiwanese vessels are from about 5° to 40°S, particularly around 10°–30°S and 75°–85°W. Fishing seasons for these vessels were from May to August or October between 2002 and 2006, but they have operated throughout year from 2007 to the present.

16.2.8. *Stock Assessment and Management*

The large-scale fishery for *D. gigas* in Peruvian waters has been managed by quotas since the industrial fishery began in 1991. The first quotas were derived using relative abundance data (CPUE) recorded during exploratory fishing carried out from November to December 1989 and June–July 1990. Initially CPUE values were 258.61 kg/hr, 53.83 kg/machine and 8.35 kg/machine/hr, and later 506.8 kg/hr, 117.2 kg/machine, and 9.79 kg/machine/h. With this level of effort an initial quota of 50,000 t was estimated for 1991. It was also set down that (1) the *D. gigas* fishing should be restricted to 30–200 miles off the coast, (2) a maximum of 20 vessels, (3) fishing only with jigs—no nets, (4) minimum ML of 320 mm, with an incidence not more than 20% smaller specimens, (5) no transshipment of catch and, (6) an IMARPE scientific observer in each vessel. In August 1991 using monthly data from jiggers that fished from April to August, combined with production models (Schaefer, Fox) it was determined that the quota for 1991 could be increased to 80,000 t. Quotas for the period 1992–2001 were estimated using production models and allowed totals of 100,000–150,000 t.

From 1999 onward, biomass estimates of *D. gigas* were made in the summer months by acoustic methods. This information was combined with other data to produce an index of abundance of recruits starting in 2002. With this information the catch quotas increased to 300,000 t per year using a projection of the biomass of recruits. From 2010 the Schaefer Biomass Dynamic Model (Hilborn and Walters, 1992) has been used. Catch and CPUE were set assuming variable catchability (based on sea surface temperature) and with constant catchability for the period 1999–2011. The best fits were obtained with varying catchability. Population parameters of *D. gigas* resulting from the Schaefer dynamic model are presented in Table 13.

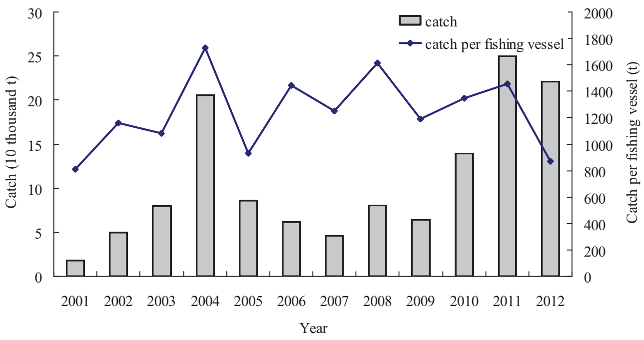

Figure 120. Total catch and catch per fishing vessel of *Dosidicus gigas* for Chinese squid jigging fleets in the southeast Pacific.

The biomass estimates indicates that the stock of *D. gigas* in Peruvian waters for the period 2001–2011 ranged between 2.51 and 2.96 mt, with an estimated MSY of 991,514 t (Table 13). The exploitation intensity measured by fishing mortality (F) has grown steadily since 1999, without exceeding the reference value (FMSY).

16.2.9. *Conservation Measures*

The fishery in Peru is managed through annual catch quotas derived from fishery data and research cruises. Jiggers need a licence issued by the Government which has implemented a satellite tracking system for control and surveillance. They must also carry a scientific observer to record fishery data.

In Chile, the management of the *D. gigas* fishery started in 2012 and includes restricted access, the exclusive use of catches for human consumption, and a modifiable TAC based on the landings of the last 10 years and actual catches divided into an industrial (20%) and an artisanal (80%) part of the catch (Rosa et al., 2013c).

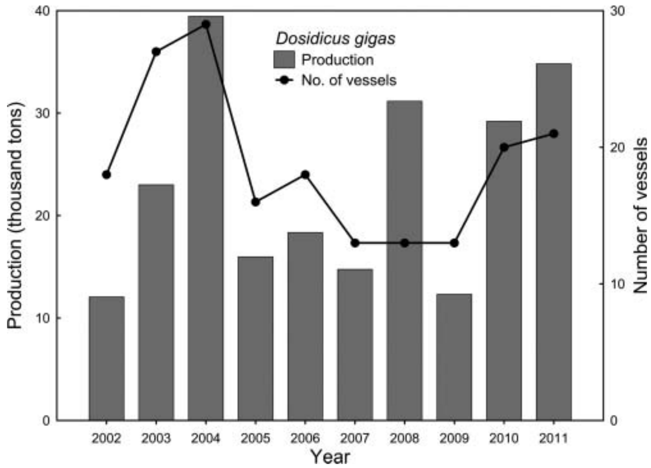

Figure 121. Production of *Dosidicus gigas* and number of vessels for Taiwanese distant-water squid fishery in the Southeast Pacific between 2002 and 2011.

Table 12. Annual landings, effort and CPUE of *Dosidicus gigas* in the artisanal and industrial fleet in 1991–2012

	Artisanal fleet			Industrial fleet		
Year	Landings (t)	Effort (trips)	CPUE (t/trips)	Landings (t)	Effort (days)	CPUE (t/day)
1991	23952			57703	3317	17.4
1992	2762			103785	9114	11.4
1993	2028			138327	11358	12.2
1994	45257			164713	6930	23.8
1995	28347			80808	11599	7.0
1996	8138			1650	2530	0.7
1997	16061			5825	1463	4.0
1998	547					
1999	54647			23731	1347	17.6
2000	53794	29029	1.9	89563	3296	27.2
2001	71833	39327	1.8	103708	3164	32.8
2002	146390	70305	2.1	77328	3690	21.0
2003	153726	53941	2.8	26803	1097	24.4
2004	270368	92731	2.9	51268	1990	25.8
2005	291141	98071	3.0	47254	1594	29.6
2006	434258	123527	3.5	43448	1140	38.1
2007	427591	105880	4.0	20175	923	21.9
2008	533413	119674	4.5	25437	833	30.5
2009	405674	62927	6.4	48108	1523	31.6
2010	355668	50034	7.1	32641	1411	23.1
2011	374639	71810	5.2	13263	834	15.9
2012	461800	62497	7.4			

The South Pacific Regional Fisheries Management Organization (SPRFMO) came into force on 24 August 2012. Three squid species, *D. gigas*, *O. bartramii* and *S. oualaniensis*, in the South Pacific high seas are covered by Conservation Management Measures of the Commission of the SPRFMO. All the fishing vessels are required to follow measures adopted by the SPRFMO Commission. Strict reporting and use of vessel monitoring are currently required.

16.2.10. Development of the Global Market for Jumbo Flying Squid

16.2.10.1. Beginning of utilization of jumbo flying squid. *D. gigas* has become one of the most economically important squids globally. Until the 1980s, it was seldom used because of problems with quality. When the supply of neon flying squid (*O. bartramii*) were reduced following the 1993 moratorium on high seas driftnets set by the UN General Assembly (Miki and Sakai, 2008), *D. gigas* grew in economic importance in Japan and Korea (Miki and Wakabayashi, 2010).

Landings of *O. bartramii* by the Japanese jigging fleet also decreased drastically in the early 1990s and squid processors in Japan began using *D. gigas* caught by the Japanese far-seas jigging fleet or imported from Peru. Initially, the high concentration of ammonium chloride in the meat prevented it from being widely used for traditional squid processing products, but the development in Japan of a method to remove the ammonium chloride (Yamanaka et al., 1995) contributed greatly to the increasing use of *D. gigas* pickled, deep-fried and in the form of steaks. The increasing demand for *D. gigas* has also led to the development in Peru of processed products such as fillets since the mid-1990s. Peru now exports these products to many countries including Japan.

D. gigas is now widely used in Japan for processed products also made from *T. pacificus* such as "sakiika" dried squid jerky, "shiokara" salted/fermented squid, and frozen mixed seafood using squid arms as a substitute for octopus arms (Wakabayashi et al., 2009).

In South Korea, *D. gigas* caught in the far-seas jigging fishery has been used to make "sakiika" since the early-1990s. Since 1994, several Korean companies have constructed squid processing factories in Mexico, shifting to local production of "sakiika" using squid landed by small-scale local fisheries and exporting to South Korea (Miki et al., 2010). The South Korean "sakiika" industries were drastically reduced by the Asian financial crisis in 1997. The center of the "sakiika" industry has now moved from South Korea to China and

Table 13. *Dosidicus gigas* population's parameters estimated with Schaefer Dynamic model.

K (t) =	3,000,000
r =	1.763
q (average) =	0.0000100
MSY (t) =	1,322,019
Optimal effort (days) =	87,880
Biomass (< 200 nm) (t) =	2,032,283
MSY (< 200 nm) (t) =	991,514

Japan. In China especially, the "sakiika" industry has become a major exporter.

16.2.10.2. Expanding the use of jumbo flying squid. Processing methods developed in Japan and South Korea have expanded throughout the world since the late 1990s for several reasons. Firstly, investment in squid processing factories in Peru, Mexico and Chile increased, particularly in Peru where *D. gigas* is most abundant. Secondly, primary products imported from developing coastal countries have been processed into products that meet the demand of countries of final consumption such as Spain and China. China has contributed markedly to global expansion of squid consumption by processing squid caught by Chinese vessels, or imported from coastal countries, and then exporting the products. Spain, which originally supplied processed squid rings of Argentine shortfin squid (*I. argentinus*) to EU markets, has expanded the squid market by processing squid rings made from *D.gigas* which are cheaper than *I. argentinus*. The global demand for *D. gigas* has thus increased.

D. gigas has therefore played an important role in supplying the word market for squid and in expanding global squid consumption. In traditional squid-consuming countries such as Japan, this low-priced species has accelerated development of new processed products, which have led to increased demands, for example, as a substitute for *O. bartramii* (Wakabayashi et al., 2010). In EU countries, where squids are often consumed as rings, there has been a shift to *D. gigas* as a substitute for *I. argentinus*. In both Japan and the EU, the lower price of *D. gigas* was an important reason why processors switched to the species. If the stocks of *O. bartramii* or *I. argentinus* increase and prices go down, the demand for *D. gigas* may decrease. Likewise, the demand for *D. gigas* might decrease if an unutilized and low-valued squid stock such as purpleback flying squid (*S. oualaniensis*) in the Indian Ocean (Yatsu 1997, Yatsu et al., 1998a, Chen et al., 2007) were to be exploited.

17. INTERACTIONS BETWEEN SQUID FISHERIES AND ECOSYSTEMS

Interactions between fisheries and ecosystems operate in two directions. On one hand fisheries can bring about major and persistent changes in ecosystems in a numbers of ways including the damaging effects of fishing gear on the seabed and benthos, removals of bycatch including birds, seals, and cetaceans, unsustainable removals of the target species and the impact of their loss on dependent predators and on the prey of the target species. All these effects impact the natural balance and energy transfer within ecosystems because many species are targeted simultaneously. On the other hand changes in ecosystems driven by anthropogenic and natural climate change and variability, pollution by contaminants, underwater noise, and presence of built structures such as oil and gas rigs, wind farms, etc. all in turn affect fisheries conducted in these ecosystems.

17.1. Effects of Fishing Gear on Ecosystems

The most apparent effect of fisheries on ecosystems is often the direct impact of fishing gear. The world's largest fisheries for ommastrephid squids are pursued by squid jiggers using lights. The power output of the lights of the larger jiggers may be 300 kW or more and fleets of jiggers can be seen in satellite imagery from the United States Defense Meteorological Satellite Programme (Rodhouse et al., 2001). The major light fisheries can be seen in imagery from the northwest Pacific (Kurushio Current), over the continental shelves of the China Sea and the Sunda-Arafura Province (east Asia), around New Zealand, in the Humboldt Current—particularly off Peru—and in the southwest Atlantic over the Patagonian Shelf and shelf edge (Brazil and Falkland Current). Despite the scale of the global light fishery, the jigging gear used for squids seems to cause little damage to ecosystems. The gear does not come into contact with the seabed and there is virtually no bycatch of fish, seabirds, or marine mammals (Gonazález and Rodhouse, 1998; Laptikhovsky et al., 2006). This is partly because jigs are specifically designed to snag squid by the tentacles and do not readily catch other marine organisms and because there is no bait the jigs do not attract seabirds. Also, the catch comes aboard the jiggers undamaged and is generally carried in running seawater directly to the working deck so there is no offal and there are no damaged squid on, or around the vessel to attract predators and scavengers as happens with trawlers. However, squid being hauled upward on a line attract predators such as sharks that may swallow jigs together with squid damaging the lines (Lipinski and Soule, 2007).

The lights, however, do sometimes attract flying seabirds toward the vessels in foggy conditions at night and these may come aboard and remain there until daylight. Swarms of insects are also frequently present, especially if jigging is conducted inshore. This may be detrimental but there are no data to quantify the extent of any damage caused to these populations. Similarly planktonic and nektonic species are attracted toward the lights together with the squid but no data have been collected to test whether there is any effect on these groups. Neither has there been any research on the effects of lights on the phytoplankton, which might be expected to be sensitive locally, or possibly on a larger scale, to the presence at night of powerful lights close to the ocean surface.

Trawl nets are far less discriminating in what they catch. Bottom trawls in particular cause widespread and severe damage to the seabed and the benthos (Løkkeberg, 2005) as well as to the target and bycatch species. While pelagic trawls avoid damage to the seabed and benthos the bycatch issues remain the same. Several squid species are targeted by major trawl fisheries including *N. sloanii*, *D. pealeii*, and *D. gahi*. Particular attention has been drawn to the New Zealand sea lion, *Phocarctos hookeri,* bycatch taken by the trawl fishery for *N. sloanii* which uses bottom and pelagic trawls with high headlines. This sea lion breeds on sub-Antarctic Islands—mostly, the Auckland Islands to the south of New Zealand. It is one of the rarest and most locally distributed pinnipeds in the world. Despite banning trawling by establishing a marine mammal sanctuary out to 12 nm around the Auckland Islands in 1995 and increasing protection by making it a no-take marine reserve in 2003, sea lion pup production declined by 30% in the eight years between 1998 and 2006 (Chilvers, 2008). Currently, a bycatch limit is set annually by government and the fishery is closed when the limit is reached. Recently, a bioeconomic approach has been proposed that would encourage fishing effort to be increased in areas of high squid and low sea lion density (Kahui, 2012).

Trawl fisheries for squid generally present the same bycatch problems as fisheries using trawl gear for fish species. Foreign trawlers fishing for *D. pealeii* and *I. illecebrosus* off the east coast of the USA in the period 1977–1988 were responsible for captures of several cetacean species especially pilot whales and common dolphins but also minke, right and humpback whales (Waring et al., 1990). More recently in the fishery for *L. pealeii* the bycatch of fish species, especially undersized scup, butterfish, and flounders, has been demonstrated to be substantial. These fish are important commercial and recreational species and research on trawl design has enabled bycatch to be reduced by making changes to the gear. These changes exploit differences in the behavior in the net between squid and fish to separate them out and allow the fish to escape (Glass et al., 1999). Nevertheless the difficulties of introducing effective mitigation measures in this fishery show that the problem is more complex than can be solved by gear modifications alone (Powell et al., 2004).

Elsewhere, in the Falkland Islands trawl fishery for *D. gahi,* about 6% of the total catch includes bycatch some half of which is commercial species including red cod, hakes, kingclip, hoki, blue whiting, rays, and the squid *I. argentinus*. The rest of the bycatch is comprised of other fish and invertebrates (Laptikhovsky et al., 2006).

A wide variety of other net types are used for squid (Rathjen, 1991). Some are local, artisanal designs; others are used on a larger scale. The fishery for *D. opalescens* off Southern California largely uses a method introduced from Sicily employing seine nets in conjunction with lights to catch the squid while they are aggregating at the spawning grounds. This lampara net fishery around the Californian Channel Islands has been shown to cause disturbance to nesting seabirds within range of the lights. Evidence that nests were abandoned and chick predation was increased resulted in the Fish and Game Commission requiring vessels to restrict the wattage output of the lights and to shield them (Barsky, 2008: http://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=34405).

During the 1970s, driftnet fishing for the ommastrephid squid *O. bartramii* commenced in the North Pacific and by the 1980s, it peaked at some 400,000 t/y (Murata, 1990). However, this fishing method was very destructive of marine life and was causing high levels of environmental degradation. Large bycatches of other commercial species as well as marine mammals, seabirds and turtles were common and if nets were lost they continued to catch and kill marine life by so-called ghost fishing (Alverson et al., 1994). The fishery was banned by a UN Moratorium in 1991 (http://www.un.org/documents/ga/res/46/a46r215).

17.2. Role of Squid in Ecosystem Change Induced by Overfishing on Groundfish

The short lifespan coupled with the rapid growth and reproductive rates of squid gives them the selective advantage of ecological opportunists which can rapidly increase population size when environmental conditions are favorable. Caddy (1983) first suggested that cephalopods generally may be able to increase population size in ecosystems where overfishing of slower growing and slower reproducing groundfish stocks have been overexploited. Reduced predation pressure from groundfish would enable the cephalopods to fill the vacant ecological niche left by the groundfish themselves. Subsequently, Caddy and Rodhouse (1998) presented evidence from FAO landing statistics that in some heavily overfished regions cephalopod stocks had increased. In one cephalopod fishery (the Saharan Banks), there is more detailed evidence that there have been changes in the community as a result of fishing pressure but that the changes are not as great as the FAO landing statistics suggest (Balguerías et al., 2000). Here, changes seem to have been caused by multiple factors including economic drivers, oceanographic variability and competition for food.

Major changes in species range and size of populations of *D. gigas* in the eastern Pacific since the 1997 ENSO event have been documented by Field et al. (2007). These changes have been linked to climate/oceanographic changes in the region, together with reductions in top fish predators (tuna and billfishes) and Pacific hake caused by high fishing pressure (Zeidberg and Robison, 2007; 2008). Other authors (Watters et al., 2008) have argued that the changes can be explained by bottom up forcing alone and that *D. gigas* numbers increased post 1997 at a time when tuna stocks were at a relatively high level. Modeling results also show that squid are more susceptible to bottom-up rather than top-down control (Watters et al., 2003).

Given the complexity of marine ecosystems, it is perhaps not surprising that when causes of a change in one element (squid in this case) are subjected to close analysis, it becomes difficult to isolate a single driver. Over the last two centuries the most substantial changes in marine ecosystems have almost certainly been caused by direct and indirect removals of fish, seabirds, whales, and seals by targeted fisheries, bycatch or anthropogenic factors driving global climate change. The latter is increasingly driving further change. There is a need to take a holistic, interdisciplinary, approach to observing, and modeling marine ecosystems in order to resolve questions about change in squid populations and fisheries.

17.3. *Ecosystem-Based Fishery Management (EBFM)*

EBFM has its origins in the early 1980s when CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources) was established in response to international concern about the threat to the Southern Ocean ecosystem posed by an Antarctic krill fishery. Concern focused on the threat posed to krill-dependent predators including baleen whales, seals and seabirds. The Commission's objective is conservation (including rational use) of Antarctic marine life according to three principles: ensuring stable recruitment of harvested resources, maintaining ecological relationships and preventing irreversible ecosystem change: http://www.ccamlr.org/en/organisation/camlr-convention-text.

By the turn of the millennium, catches worldwide had been declining for over a decade and it had been clear for some time that conventional fishery management was failing in many areas. This led to calls for radical reappraisal of fishery management (Pauly et al., 2005) and for more holistic approaches to marine resource management and adoption of EBM (Larkin, 1996; Link, 2002, 2010). A decade later this multi-faceted approach is becoming embedded in fishery management thinking and has been widely, but not universally adopted. EBM differs from traditional resource management by defining management strategies for entire systems, not individual components of the ecosystem (Link, 2010). Central to this ecosystem-based perspective is the requirement to account for all factors that can influence resources within and ecosystem, including ecological and economic interactions.

Squid figure in EBFM both as the subject of targeted fisheries themselves and also as key components in ecosystems where the EBFM approach is being applied to the fisheries for other species. Faced with the prospect of a new fishery for the ommastrephid squid *Martialia hyadesi* in the Southern Ocean CCAMLR adopted precautionary management measures based on consumption of this species by predators including odontocetes, seals and seabirds (Rodhouse, 1997). Elsewhere the changing population size of the jumbo flying squid, *D. gigas*, in the Gulf of California is a factor in the EBM of forage fisheries (Bakun, 2009).

EBFM is being applied to the fishery for the loliginid squid *D. opalescens* in the Monterey Bay area, California—http://sanctuaries.noaa.gov/education/voicesofthebay/pdfs/balancepowerpointslides.pdf—in an area where there is a considerable amount of ecological data collected for over six decades by CalCOFI (California Cooperative Oceanic Fisheries Investigations)—http://www.calcofi.org/. Elsewhere cephalopods, including squids, have been included as part of an overall ecosystem approach in relation to fisheries on the Georges Bank off the Northeast coast of the USA (Brodziak and Link, 2002) and in Southeast Australian waters (Smith et al., 2007).

Whether squids are being considered as elements in the ecosystem or as the subject of targeted fisheries there are several issues that need to be considered in relation to EBFM. Firstly, their role in marine food webs, especially as prey for vertebrate predators. Because of the short squid lifecycle, there is an annual cycle of abundance that teuthivorous predators may rely on in a particular season and at a specific geographical location. Natural variability in squid populations will impose pressures on these predators but intensive fishing, which is likely to coincide spatially and temporally with activity of the predators, can be expected to intensify these pressures.

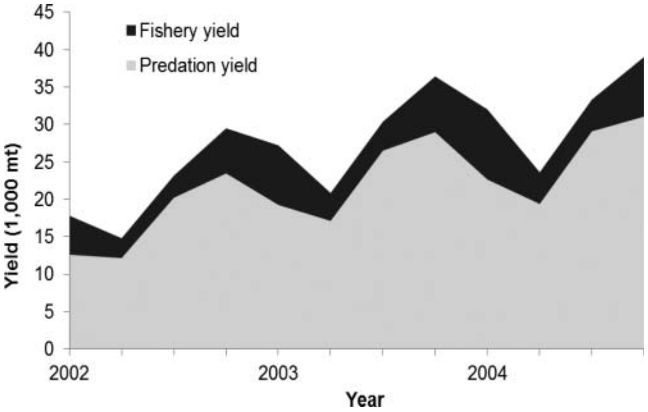

Figure 122. Projected quarterly yield (thousands of metric tons, t) of Northwest Atlantic longfin inshore squid (*Doryteuthis pealei*) fishery for the 5-year average of total mortality. Modified from Moustahfid et al. (2009a).

As stated above forage species such as squid (the prey of many top predators) can occupy middle trophic levels that link lower trophic level energy or biomass to upper trophic levels, by being common prey for a range of species (Rice, 1995). They can be an important source of standing biomass in an ecosystem, and are often subject to both predation pressure and commercial harvesting. Various authors have found that when consumption of particular forage species is calculated, the predation mortality for the species that had been assumed as a part of the total natural mortality in traditional stock assessments were underestimated (e.g., Hollowed et al., 2000; Moustahfid et al., 2009b). Because predation and fishing mortality vary temporally, spatially, and ontogenetically, total mortality rates have the potential to be concentrated during a narrow time-span and cause local depletions (Tsou and Collie, 2001; Staudinger, 2006; Staudinger and Juanes, 2010).

Another consensus among scientists is that, for forage species in particular, careful examination of traditional assumptions regarding predation mortality is needed because the abundance of their major predators (e.g., demersal fish, large pelagics, marine mammals, birds, etc.) can reasonably be expected to increase in the next several years as stocks are rebuilt to meet legal requirements (e.g., Overholtz et al., 2008; Moustahfid et al., 2009a). Figure 122 illustrates the trade-offs between predators and fisheries to be made when managing forage species such as the longfin inshore squid in the northwest Atlantic. It is clear that if timing of high commercial exploitation and predatory removals are not synchronous but dynamic over the year, traditional single species models that assume constant natural mortality rates will overestimate the stock's recovery potential (e.g., Moustahfid et al. 2009 a, b).

The short lifespan, ecological opportunism and sensitivity to environmentally driven variability of squid make it hard to distinguish between natural and fisheries driven reduction in stock size. The *I. illecebrosus* fishery which rose to prominence off the east coast of the USA and Canada in the late 1970s and early 1980s declined rapidly later in the 1980s and it would be easy to assume that fishing pressure was the cause. However, elsewhere major interannual changes in biomass in *T. pacificus*, *I. argentinus*, and *D. gigas* have been accompanied by high fishing pressure which does not seem to have prevented recovery after periods of low biomass. For a rationally based system of EBFM to be effective, it will be necessary to discriminate between the effects of naturally occurring environmental variability and the effect of fishing pressure on biomass variability.

In Marine Protected Areas (MPAs), measures to protect squid stocks will be dependent on the species concerned, in particular, the loliginids and ommastrephids have different lifecycles, habitats, behaviors, and position in the food web. Loliginids are coastal/shelf species, have greater dependence on the sea bed where they spawn and make shorter migrations over the course of the lifecycle. Ommastrephids are more pelagic, more oceanic, spawn in midwater, and make long migrations (Young et al., 2013). Loliginid stocks are likely to spend most or all of their lifecycle within one MPA and protection may need to be focused on conserving spawning grounds, maintaining spawning biomass and regulating bycatch in fisheries for other species. Ommastrephids are likely to move in, out and between MPAs. They may need protection at times in their lifecycle when they are passing through areas of intensive fishing effort and are especially vulnerable. In the interests of their dependent predators, they may need protection when they are in, or approaching, areas where they are preyed on intensively and so are critical in the predator's diet at a particular time of the year.

The under- and unexploited species of squids listed in the Introduction as having potential for fisheries are all large oceanic species. These forage in midwater/pelagic habitats, largely on mesopelgic fish—especially myctophids—in ecosystems which are poorly understood. The effective management of any future fisheries for these species would be dependent on obtaining sound knowledge of their biology and ecology and about the ecology of the systems on which they depend.

18. GENERAL DISCUSSION

The total world catch of squids has increased steadily over several decades but there is now evidence in the FAO data that this has been followed by an apparent stabilization over the last ten years (Table 1). Behind this recent overall stability, however, there has been considerable variation within species. In particular, production of *I. argentinus* varied by a factor of over 5 in the 4 years between 2004 and 2007. It is not possible to determine from the data whether the global pattern is because the current fisheries have approached full exploitation, whether market conditions are playing a part or whether there are environmental effects. Given the role of squids in marine ecosystems, there are good reasons to monitor the global catch in future and explore the reasons for its behavior over time. If it becomes clear that production has levelled off it should highlight the need for careful management of individual stocks in future and also the need to make maximum use of the catch to avoid waste and maximize the economic benefits from an industry which is reaching the limits of growth.

The assessment of squid stocks and management of the fisheries is inconsistent regionally and there would be advantages in moving toward standardising the approach, especially in the major fisheries. The scheme outlined by Caddy (1983) still remains valid today and has the advantage that it is relatively inexpensive to implement and it enables a fishery to be managed in real time, which is especially important in volatile stocks of short-lived species such a squids. It can form a good starting point from which regional solutions can branch out. This approach needs to be underpinned by good scientific knowledge of the lifecycle, migratory patterns, and stock structure of the species being managed. This knowledge is incomplete in many cases and further fundamental research is needed.

Understanding of the environmental influences on recruitment and hence interannual variability in abundance remains sketchy, although important progress was made recently (Rodhouse et al., 2014). Improved knowledge of the effects of environmental variability would open the way to prerecruitment prediction, at least in broad terms, of likely stock size in the coming season. It would also lay the foundations for predicting the possible effects of longer term climate change on squid stocks.

Over the last three decades, a considerable body of knowledge has accumulated on the role of squids in the diet of vertebrate predators. However, there are inconsistencies emerging between data collected using conventional gut contents analysis, the identification and quantification of squid beaks and the biomass they represent, and the use of fatty acid signatures in the fatty tissues of predators, including milk, in mammalian predators (Rodhouse, 2013). There is a need to reconcile these inconsistencies as these data will become increasingly important in the context of ecosystem-based fishery management. Less attention has been given to the role of squids as predators. This is partly because of the difficulty of identifying gut contents of squids but this problem may become more tractable with the use of DNA sequencing for identification of prey.

Pauly et al. (1998) has pointed out that changing patterns in marine fisheries can be interpreted as a forced, quantifiable trend of fishing down the trophic pyramid. This view was first questioned by Caddy and Garibaldi (2000) and then, from a different perspective, by Hilborn (see Pauly et al., 2013). Can cephalopod catches, and especially of squid, be seen as a valid factor in this debate? All three of the most exploited species of squids are excellent examples. Their fisheries have expanded over 100 years in the case of *T. pacificus* (with tremendous fluctuations in abundance), over 30 years in the case of *I. argentinus*) and over 20 years old in the case of *D. gigas*. All three of these species lie toward the middle of the trophic pyramid. It has been argued that the concept of food chain links as applied to opportunistic predators should be revised (Xavier et al., 2014). These three examples of squid fisheries do not necessarily indicate that Pauly et al. (1998) were wrong, but perhaps they took their conclusions too far. Their hypothesis may be specific rather than general, applying to some data and scenarios and not to others (Caddy and Garibaldi, 2000).

More complex interactions between squid fisheries and marine ecosystems involve the effects of removals of squid biomass. They are key prey for vertebrate predators and have substantial seasonal impact on their own prey populations so unsustainable levels of exploitation will have impact throughout much of the food web.

The role of squids in ecosystem change includes their response to change caused by overexploitation of groundfish stocks as well as their response to changes in other predator populations and to environmental variability on various time scales, including long-term climate change. An important scientific challenge for the future will be to discriminate between these interactions in order for fishery managers to respond appropriately to changes in squid stocks.

It is advisable to use information on large-scale oceanographic processes in the management of the renewable resources—including squids—of these systems. It can be envisaged that large and productive systems (such as the Humboldt Current system) might be the first to be managed fully according to the ecosystem approach to fisheries (EAF) principles and strategies. An early task will be to model the energy balance of these systems using different input parameters and under different environmental scenarios. For practical reasons rophic pyramid related controls of the marine ecosystems, food transfer energetics and food web related models are little utilized in squidand fish management. They nevertheless hold the key for understanding ecosystem dynamics generally. As ecosystem-based fishery management develops, squid specialists have a role both in contributing to the holistic understanding of marine ecosystems and the role of squids in them and in developing squid fishery management protocols that are sensitive to the needs of the ecosystem.

FUNDING

Gold Open Access of this paper was generously sponsored by Pharma Marine AS, Norway, processors of omega-3 oils from squid trimmings, for the Nutriceutical market.

SUPPLEMENTAL MATERIAL

Supplemental data for this article can be accessed on the publisher's website. The file includes a list of the authors and the sections of the article to which they contributed.

REFERENCES

ABARES. *Australian fisheries statistics 2010*, Canberra (2011).

Abdussamad, E. M., and K. R. Somayajulu. Cephalopod fishery at Kakinada along the east coast of India: Resource characteristics and stock assessment of *Loligo duvauceli*. *Bangladesh J. Fish. Res.*, **8**(1): 64–69 (2004).

Abraham, E. R. Summary of the capture of seabirds, marine mammals, and turtles in New Zealand commercial fisheries, 1998–99 to 2008–09. *New Zealand Aquatic Environment and Biodiversity*. Report **80** (2011).

Acuña, E., L. Cid, J. C. Villaroel, and M. Andrade. Artisanal catches of jumbo squid *Dosidicus gigas* off Coquimbo, Chile and their relation to environmental variables. In: Report of a GLOBEC-CLIOTOP/PFRP Workshop (16–17 November 2006) Honolulu, Hawai, USA. (Olson J.W, Ed.). *GLOBEC Rep.*, **24**: 57–61 (2006).

Adachi, T. The result of questionnaire survey on catch statistics of big fin reef squid. Fukui prefectural fisheries experimental station (1991) [in Japanese].

Adamidou, A. Commercial fishing gears and methods used in Hellas. **In**: *State of Hellenic Fisheries*, pp. 118–131. (Papaconstantinou, C., A. Zenetos, C. Vassilopoulou and G. Tserpes, Eds.). SoHelFi, HCMR Publications, Athens (2007).

Agnew, D. J., R. Baranowski, J. R. Beddington, S. des Clers, and C. P. Nolan. Approaches to assessing stocks of *Loligo gahi* around the Falkland Islands. *Fish. Res.*, **35**: 155–169 (1998).

Agnew, D. J., S. Hill, and J. R. Beddington. Predicting the recruitment strength of an annual squid stock: *Loligo gahi* around the Falkland Islands. *Can. J. Fish. Aquat. Sci.*, **57**: 2479–2487 (2000).

Akabane, M. K., Takanashi, and T. Suzuki. On the 1978 fishing conditions of neon flying squid. Survey report on development of fishing grounds by squid jigging. *Aomori Pref. Fish. Exp. Sta.* **IV**: 1–21 (1979) [in Japanese].

Akimoto, S. The utilization of the fisheries resources of *Loligo edulis* in Chikuzenkai. *Bull. Fukuoka Fish. Exp. Stn.*, (18): 17–140 (1992) [in Japanese].

Alagarswami, K., and M. M. Meiyappan. Prospects for increasing cephalopod production of India. **In**: *CMFRI Bulletin: National Symposium on Research and Development in Marine Fisheries Sessions I & II 1987, 44 (Part -1)*. pp. 146–155 (1989).

Alarcón-Muñoz, R., L. Cubillos, and C. Gatica. Jumbo squid (*Dosidicus gigas*) biomass off Central Chile: effects on Chilean hake (*Merluccius gayi*). *California Coop. Ocean. Fish. Inv. Rep.*, **49**: 157–166 (2008).

Aldrovandi, Ulysse. De Reliquis Animalibus Exanguibus Libri Quarto. Bologna, Italy (1606).

Alejo-Plata, M. C., G. Cerdenares-Ladrón de Guevara, and J. E. Herrera-Galindo. Cefalópodos loligínidos en la fauna de acompañamiento del camarón. *Ciencia y Mar*, **5**: 43–48 (2001).

Alexeev, D. O. On possible approaches towards fishery management for the commander squid *Berryteuthis magister* stocks with consideration of the functional structure of its populations' distribution areas. **In:** *Proceedings of the All–Russian Conference dedicated to the 80th Anniversary of KamchatNIRO*: 249–257 (2012) (In Russian).

Alidromiti, C., E. Lefkaditou, S. Katsanevakis, and G. Verriopoulos. Age and growth of *Alloteuthis media* (Cephalopoda: Loliginidae) in Thermaikos Gulf. 9th Hellenic Symposium on Oceanography and Fisheries, Patras, Greece, 13–16 May 2009. Proceedings volume: 844–849 [in Greek, with English abstract]. (2009). Available at http://symposia.ath.hcmr.gr/oldver/symposia9/Book2/0844.pdf

Alverson, D. L., M. H. Freeberg, J. G. Pope, and S. A. Murawski. A global assessment of fisheries bycatch and discards. FAO Fisheries Technical Paper. No. 339. Rome, FAO. 233p (1994).

Amaratunga, T. Biology and distribution patterns in 1980 for squid, *Illex illecebrosus*, in Nova Scotian waters. *NAFO SCR Doc. 81/VI/36, Ser. No. N318* (1981b).

Amaratunga, T. The short-finned squid (*Illex illecebsrosus*) fishery in eastern Canada. *J. Shellfish Res.*, **2**(2): 143–152 (1981a).

Amaratunga, T., M. Roberge, and L. Wood. An outline of the fishery and biology of the short-finned squid *Illex illecebrosus* in eastern Canada. **In**: *Proceedings of the workshop on the squid Illex illecebrosus*, pp. (Balch, N., T. Amaratunga, and R. K. O'Dor, Eds.). Dalhousie University, Halifax, Nova Scotia (1978).

Anderson, C. I. H., and P. G. Rodhouse. Life cycles, oceanography and variability: ommastrephid squid in variable oceanographic environments. *Fish. Res.*, **54**: 133–143 (2001).

Anderson, F. E., A. Pilsits, A., S. Clutts, V. Laptikhovsky, G. Bello, E. Balguerias, M. Lipinski, M., C. Nigmatulin, J. M. F. Pereira, U. Piatkowski, J.-P. Robin, A. Salman, and M. G. Tasende. Systematics of *Alloteuthis* (Cephalopoda: Loliginidae) based on molecular and morphometric data. *J. Exp. Mar. Biol. Ecol.*, **364**: 99–109 (2008).

Ando, K., K. Nishikiori, K. Tsuchiya, J. Kimura, J. Yonezawa, H. Maeda, K. Kawabe, and K. Kakiuchi K. Study on the fisheries biology of diamond squid *Thysanoteuthis rhombus* in the Ogasawara Islands waters, southern Japan. *Rep. Tokyo Metrop. Fish. Exp. Stat.*, **213**: 1–22 (2004) [in Japanese].

Andreoli, M. G., N. Campanella, L. Cannizzaro, G. Garofalo, G. B. Giusto, P. Jereb, D. Levi, G. Norrito, S. Ragonese, P. Rizzo, and G. Sinacori. Sampling statistics of southern Sicily trawl fisheries (MINIPESTAT): Data Report. *N. T. R.-I. T. P.P. Special Publication*, **4**(1) (1995).

Anon. Fisheries Assessment Plenary: May 2013: Stock assessments and yield estimates. *Compiled by the Fisheries Science Group, Ministry for Primary Industries*, Wellington, New Zealand, 1357. (2013).

Aoki, M., H. Imai, T. Naruse, and Y. Ikeda. Low genetic diversity of oval squid, *Sepioteuthis cf. lessoniana* (Cephalopoda: Loliginidae), in Japanese waters inferred from a mitochondrial DNA non-coding region 1. *Pac. Sci.*, **62**: 403–411 (2008).

Aramaki, H., S. Noda, and M. Washio. Egg masses swordtip squid found in the Sea of Genkai of Saga Pref. *Report of Ikarui Shigen Kenkyu Kaigi*: 16–19 (2003) [in Japanese].

Arancibia, H., and H. Robotham, Crecimiento y edad del calamar (*Loligo gahi Orbigny*) del la region austral de Chile. *Invest. Pesq.*, **31**: 71–79 (1984).

Arancibia, H., M. Barros, S. Neira, U. Markaida, C. Yamashiro, C. Salinas, L. Icochea, L. Cubillos, Ch. Ibáñez, R. León, M. Pedraza, E. Acuña, A. Cortés, and V. Kesternich. Informe Final proyecto FIP 2005–38. Análisis del impacto de la jibia en las pesquerías chilenas de peces demersales. Universidad de Concepción / Universidad Católica del Norte, 299 pp. (2007).

Araya, H. Migration and distribution of neon flying squid. *Fish. Technol. Manage.*, **272**: 23–33 (1987) [in Japanese].

Araya, H. Resources of common squid, *Todarodes pacificus*, Steenstrup in the Japanese waters. Fisheries Research Series 16, Tokyo, Japan Fisheries Resource Conservation Association (1967).

Arguelles, J., and R. Tafur. New insights on the biology of the jumbo squid *Dosidicus gigas* in the Northern Humboldt Current System: Size at maturity, somatic and reproductive investment. *Fish. Res.*, **106**: 185–192 (2010).

Argüelles, J., R. Tafur, A. Taipe, P. Villegas, F. Keyl, N. Dominguez, and M. Salazar. Size increment of jumbo flying squid *Dosidicus gigas* mature females in Peruvian waters, 1989–2004. *Progr. Oceanogr.*, **79**: 308–312 (2008).

Aristotle. History of Animals. Books 4–6. Loeb Classical Library 438. Harvard University Press, Cambridge (1970).

Aristotle. History of Animals. Books 7–10. Loeb Classical Library 439. Harvard University Press, Cambridge (1991).

Arizmendi-Rodriguez, D. I., C. A. Salinas-Zavala, C. Quiñonez-Velazquez, and A. Mejia-Rebollo. Abundance and distribution of the Panama brief squid, *Lolliguncula panamensis* (Teuthida: Loliginidae), in the Gulf of California. *Cienc. Mar.*, **38**: 31–45 (2012).

Arizmendi-Rodriguez, D. I., V. H. Cruz-Escalona, C. Quiñonez-Velazquez, and C. A. Salinas–Zavala. Feeding habits of the Panama brief squid *Lolliguncula panamensis* in the Gulf of California, Mexico. *J. Fish. Aquat. Sci.*, **6**: 194–201. (2011).

Arkhipkin, A. I. Age and growth of the squid (*Illex argentinus*). *Frente Marítimo* **6**(A), 25–35 (1990) [in Spanish].

Arkhipkin, A. I. Age, growth, stock structure and migratory rate of pre-spawning short-finned squid *Illex argentinus* based on statolith ageing investigations. *Fish. Res.*, **16**: 313–338 (1993).

Arkhipkin, A. I. Age, growth and maturation of the European squid *Loligo vulgaris* (Myopsidae, Loliginidae) on the west Saharan Shelf. *J. Mar. Biol. Assoc. U.K.*, **75**: 593–604 (1995).

Arkhipkin, A. I. Squid as nutrient vectors linking Southwest Atlantic marine ecosystems. *Deep-Sea Res. Pt. II: Topical Studies in Oceanography*, **95**: 7–20 (2013).

Arkhipkin, A. I., J. Barton, S. Wallace, and A. Winter. Close cooperation between science, management and industry benefits sustainable exploitation of the Falkland Islands squid fisheries. *J. Fish Biol.*, **83**: 905–920 (2013).

Arkhipkin, A. I., V. A. Bizikov, V. V. Krylov, and K. N. Nesis. Distribution, stock structure, and growth of the squid *Berryteuthis magister* (Berry, 1913) (Cephalopoda, Gonatidae) during summer and fall in the western Bering Sea. *Fish. Bull.* **94**: 1–30 (1996).

Arkhipkin, A. I., S. E. Campana, J. Fitzgerald, and S. R. Thorrold. Spatial and temporal variation in elemental signatures of statoliths from the Patagonian longfin squid (*Loligo gahi*). *Can. J. Fish. Aquat. Sci.*, **61**: 1212–1224 (2004a).

Arkhipkin, A. I., P. Jereb, and S. Ragonese. Growth and maturation in two sucessive seasonal groups of the short-finned squid, *Illex coindetii* from the Strait of Sicily (central Mediterranean). *ICES J. Mar. Sci.*, **57**: 31–41 (2000).

Arkhipkin, A. I., and V. V. Laptikhovsky. Age and growth of the squid *Todaropsis eblanae* (Cephalopoda: Ommastrephidae) on the north-west African shelf. *J. Mar. Biol. Assoc.U.K.*, **80**: 747–748 (2000).

Arkhipkin, A. I., V. Laptikhovsky, and A. Golub. Population structure and growth of the squid *Todarodes sagittatus* (Cephalopoda: Ommastrephidae) in North-west African waters. *J. Mar. Biol. Assoc. U.K.*, **79**: 467–477 (1999).

Arkhipkin, A. I., V. V., Laptikhovsky, and D. A. J. Middleton. Adaptations for the cold water spawning in squid of the family *Loliginidae: Loligo* gahi around the Falkland Islands. *J. Moll. Stud.*, **66**: 551–564 (2000).

Arkhipkin, A. I., and D. A. J. Middleton. Sexual segregation in ontogenetic migrations by the squid *Loligo gahi* around the Falkland Islands. *Bull. Mar. Sci.*, **71**: 109–127 (2002).

Arkhipkin, A. I., and D. A. J. Middleton. In-situ monitoring of the duration of embryonic development in the squid *Loligo gahi* (Cephalopoda: Loliginidae) on the Falkland shelf. *J. Moll. Stud.*, **69**: 123–133 (2003).

Arkhipkin, A., D. A. J. Middleton, and J. Barton. Management and conservation of a short-lived fishery resource: *Loligo gahi* around the Falkland Islands. *Amer. Fish. Soc. Symp.*, **49**: 1243–1252 (2008).

Arkhipkin, A. I., D. A. J. Middleton, A. M. Sirota, and R. Grzebielec. The effect of Falkland Current inflows on offshore ontogenetic migrations of the squid *Loligo gahi* on the southern shelf of the Falkland Islands. *Estuarine Coastal Shelf Sci.*, **60**: 11–22 (2004b).

Arkhipkin, A. I., and N. Nekludova. Age, growth and maturation of the loliginid squids *Alloteuthis africana and A. subulata* on the West African shelf. *J. Mar. Biol. Assoc. U.K.*, **73**: 949–961 (1993).

Arkhipkin, A. I., and R. Roa. Identification of ontogenetic growth models for squid. *Mar. Freshw. Res.*, **56**: 371–386 (2005).

Arnold, G. P. Squid: a review of their biology and fisheries. Laboratory Leaflet No. 48, Lowestoft: Directorate of Fisheries Research, Ministry of Agriculture and Fisheries and Food (1979).

Arnould, J. P. Y., D. M. Trinder, and C. P. McKinley. Interactions between fur seals and a squid jig fishery in southern Australia. *Aust. J. Mar. Freshwater Res.*, **54**: 979–984 (2003).

Arocha, F. Cephalopod resources of Venezuela. *Mar. Fish. Rev.*, **51** (2): 47–51 (1989).

Arocha, F., L. Marcano, and R. Cipriani. Cephalopods trawled from Venezuelan Waters by the R/V Dr. Fridtjof Nansen in 1988. *Bull. Mar. Sci.*, **49**(1–2): 231–234 (1991).

Arvanitidis, C., D. Koutsoubas, J.-P. Robin, J. Pereira, A. Moreno, M. Cunha, V. Valavanis, and A. Eleftheriou. A comparation of the fishery biology of three *Illex coindetii* Vérany, 1839 (Cephalopoda: Ommastrephidae) populations from the European Atlantic and Mediterranean Waters. *Bull. Mar. Sci.*, **71**: 129–146 (2002).

Au, D. W. Considerations on squid (*Loligo and Illex*) population dynamics and recommendations for rational exploitation. *ICNAF Res. Doc. 75/61*, Ser. No. **3543**, 13 p. (1975)

Augustyn, C. J. Biological studies on the chokker squid *Loligo vulgaris reynaudii* (Cephalopoda: Myopsida) on spawning grounds off the south-east coast of South Africa. *S. Afr. J. mar. Sci.*, **9**: 11–26 (1990).

Augustyn, C. J. Systematics, life cycle and resource potential of the chokker squid *Loligo vulgaris reynaudii*. PhD Thesis, University of Port Elizabeth, Port Elizabeth, South Africa (1989).

Augustyn, C. J. The biomass and ecology of chokka squid *Loligo vulgaris reynaudii* off the west coast of South Africa. *S. Afr. J. Zool.*, **26**: 164–181 (1991).

Augustyn, C. J., and B. A. Roel. Fisheries biology, stock assessment, and management of the chokka squid (*Loligo vulgaris reynaudii*) in South African water: an overview. *CCOFI Rep.*, **39**: 71–80 (1998).

Augustyn, C. J., B. A. Roel, and K. L. Cochrane. Stock assessment in the chokka squid *Loligo vulgaris reynaudii* fishery off the coast of South Africa. **In**: *Recent Advances in Fisheries Biology*, pp 3–14 (T. Okutani, R. K. O'Dor and T. Kubodera, Eds.). Tokyo: Tokai University Press (1993).

Augustyn, C. J., M. R. Lipinski, and W. H. H. Sauer. Can the Loligo squid fishery be managed effectively? A synthesis of research on *Loligo vulgaris reynaudii*. *S. Afr. J. mar. Sci.*, **12**: 903–918 (1992).

Auteri, R., P. Mannini, and C. Volpi. Biological parameters estimation of *Alloteuthis media* (Linnaeus, 1758) (Cephalopoda, Loliginidae) sampled off Tuscany coast. *Quad. Mus. Stor.Natur. Livorno*, **8**: 119–129 (1987).

Azarovitz, T. R. A brief historical review of the Woods Hole Laboratory trawl survey time series. **In**: *Bottom trawl surveys. Canadian Special Publication of Fisheries and Aquatic Sciences 58*, pp. 62–67 (W. G. Doubleday and D. Rivard, Eds.). (1981).

Baker, S. L., B. L. Chilvers, R. Constantine, S. DuFresne, R. H. Mattlin, A. van Helden, and R. Hitchmough. Conservation status of New Zealand marine mammals (suborders Cetacea and Pinnipedia), 2009. *N. Z. J. Mar. Freshwater. Res.*, **44**: 101–115 (2010).

Bakun, A., and J. Csirke. Chapter 6. Environmental processes and recruitment variability. **In**: *Squid recruitment dynamics: the genus Illex as a model, the commercial Illex species and influences of variability*, pp. 105–124 (P. G. Rodhouse, E. G. Dawe, and R. K. O'Dor, Eds.). *FAO Fish. Tech. Pap.*, **376** (1998).

Bakun, A., E. A. Babcock, S. E. Lluch-Cota, C. Santora, and C. J. Salvadeo. Issues of ecosystem-based management of forage fisheries in ''open'' non-stationary ecosystems: the example of the sardine fishery in the Gulf of California. *Rev. Fish. Biol. Fisheries.*, **20**: 9–29 (2009).

Balch, N., R. K. O'Dor, and P. Helm. Laboratory rearing of rhynchoteuthions of the ommastrephid squid *Illex illecebrosus* (Mollusca: Cephalopoda). *Vie et Milieu*, **35**: 243–246 (1985).

Balguerías, E., M. E. Quintero, and C. L. Hernandez-Gonzalez. The origin of the Saharan Bank cephalopod fishery. *ICES J. Mar. Sci.*, **57**: 15–23 (2000).

Barrientos, G., and A. Garcia-Cubas. Distribución y abundancia de la familia Loliginidae (Mollusca:Cephalopoda) en aguas mexicanas del Golfo de México. *Rev. Soc. Mex. Hist. Nat.*, **47**: 123–139 (1997).

Basson, M., J. R. Beddington, J. A. Crombie, S. J. Holden, L. V. Purchase, and G. Tingley. Assessment and management techniques for migratory annual squid stocks: the *Illex argentinus* fishery in the Southwest Atlantic as an example. *Fish. Res.*, **28**: 3–27 (1996).

Battaglia, P., T. Romeo, P. Consoli, G. Scotti, and F. Andaloro. Characterization of the artisanal fishery and its socio-economic aspects in the central Mediterranean Sea (Aeolian Islands, Italy). *Fish. Res.*, **102**: 87–97 (2010).

Beddington, J. R., A. A. Rosenberg, J. A. Crombie, and G. P. Kirkwood. Stock assessment and the provision of management advice for the short fin squid fishery in Falkland Islands waters. *Fish. Res.*, **8**: 351–365 (1990).

Belcari, P., and P. Sartor. Bottom trawling teuthofauna of the northern Tyrrhenian Sea. *Sci. Mar.*, **57**: 145–152 (1993).

Belcari, P., P. Sartor, N. Nannini N., and S. De Ranieri. Length-weight relationship of *Todaropsis eblanae* (Cephalopoda: Ommastrephidae) of the northern Tyrrhenian Sea in relation to sexual maturation. *Biol. Mar. Mediter.*, **6**: 524–528 (1999).

Bello, G. *Ommastrephes bartramii* (Cephalopoda, Teuthida, Ommastrephidae) in the Gulf of Taranto, eastern Mediterranean Sea. *Basteria*, **71**: 97–100 (2007).

Benincá, E. M. As pescarias industriais de arrasto-duplo em Santa Catarina – Brazil: dinâmica vs. permissionamento. MSc. Thesis, Universidade do Vale do Itajaí, Itajaí, Brazil (2013).

Benites, C. Resultado de las investigaciones biológico-pesqueras de la jibia *Dosidicus gigas* (d'Orbigny, 1835) en el litoral peruano de julio 1983 a marzo 1984, pp. 10–15. **In**: Anales del Congreso Nacional de Biología Pesquera 1984 (A. E. Tresierra, Ed.) Trujillo, Perú (1985).

Benites, C., and V. Valdivieso. Resultados de la pesca exploratoria de 1979/80 y desembarque de cefalópodos pelágicos en el litoral peruano. *Bol. Inst. Mar Perú.*, **10**: 107–138 (1986).

Bergman, A. M. Phylogeography of *Sepioteuthis lessoniana* (the bigfin reef squid) and *Uroteuthis duvauceli* (the Indian squid). Honors Theses, Southern Illinois University, Carbondale, United States of America (2013).

Berry, S. S. A note on the Genus *Lolliguncula*. *Proc. Acad. Nat. Scien. Philadelphia*, **63**: 100–105 (1911a).

Berry, S. S. Notes on some cephalopods in the collection of the University of California. *Univ. California Publ. Zool.*, **8**: 301–310 (1911b).

Bettencourt, V., Coelho, M. L., Andrade, J. P., and Guerra, Á. Age and growth of *Loligo vulgaris* of south of Portugal by statolith analysis. *J. Moll. Stud.*, **62**: 359–366 (1996).

Bigelow, H. B. Plankton of the offshore waters of the Gulf of Maine. *Bull. U.S. Bur. Fish.*, **40** (Part II): 1–509 (1924).

Bizikov, V. A. Distribution and stock abundance of the commander squid in the northwestern Bering Sea. **In**: *Commercial Aspects of Biology of the Commander Squid Berryteuthis magister and of Fishes of Slope Communities in the Western Part of the Bering Sea*, pp. 82–87 (A. A. Elizarov, Ed.) Moscow, Russia: VNIRO (1996) [In Russian].

Bjarnason, B. A. Handlining and squid jigging. Rome: Food and Agriculture Organization of the United Nations (1992).

Bjørke, H., and H. Gjøsæter. Who eats the larger *Gonatus fabricii* (Lichtenstein) in the Norwegian Sea? *ICES Document CM* 1998/M: 10. 11 pp (1998).

Black, G. A. P., T. W. Rowell, and E. G. Dawe. Atlas of the biology and distribution of the squids *Illex illecebrosus* and *Loligo pealei* in the Northwest Atlantic. *Can. Spec. Publ. Fish. Aquat. Sci.*, **100**: 1–62 (1987).

Blanc, M., and M. Ducrocq. Exploratory squid fishing in New Caledonia: nothing rough about these diamonds! *SPC Fisheries Newsletter*, **138**: 2–3 (2012).

Bograd, S.J, I. Schroeder, N. Sarkar, X. Qiu, W. J. Sydeman, and F. B. Schwing. Phenology of coastal upwelling in the California Current. *Geophys. Res. Lett.*, **36**: L01602 (2009).

Boletzky, S. v. Whence and whiter: Mediterranean cephalopod studies through the 20th century. *Turk. Jour. Aquat. Life*, **2**(2): 217–228 (2004).

Boltovskoy, D. (Ed.) *South Atlantic zooplankton*. Backhuys Publishers, Leiden (1999).

Boongerd, S., and S. Rachaniyom. *Squid trap fishing*. *Tech Pap 1/1990, Fish. Tech. Subdiv., Mar. Fish. Div., Dept. Fish.* (1990).

Boonsuk, S., A. Kongprom, S. Hoimuk, M. Sumontha, and K. Tat-a-sen. Stock assessment of squids, *Photololigo chinensis* (Gray, 1849) and *P. duvaucelii* (d'Orbigny, 1835) along the Andaman Sea coast of Thailand. *Tech. Pap., Mar. Fish. Res. Dev. Bur., Dept. Fish.* (2010).

Boonwanich, T., S. Tossapornpitakkul, and U. Chotitummo. Reproductive biology of squid *Loligo duvauceli* and *L. chinensis* in the southern Gulf of Thailand. *Tech. Pap. 1/1998, South. Mar. Fish. Dev. Cent., Mar. Fish. Div., Dept. Fish.* (1998).

Booth, A. J., and T. Hecht. Changes in the Eastern Cape demersal inshore trawl fishery between 1967 and 1995. *S. Afr. J. Mar. Sci.* **19**: 341–353 (1998).

Bower, J. R., and K. Miyahara. The diamond squid (*Thysanoteuthis rhombus*): a review of the fishery and recent research in Japan. *Fish. Res.*, **73**: 1–11 (2005).

Bower, J. R., and T. Ichii. The red flying squid (*Ommastrephes bartramii*): a review of recent research and the fishery in Japan. *Fish. Res.* **76**: 39–55 (2005).

Boyle, P. R., and M. A. K. Ngoile. Assessment of maturity state and seasonality of reproduction in *Loligo forbesi* (Cephalopoda: Loliginidae) from Scottish waters. **In**: *Recent Advances in Cephalopod Fisheries Biology*, pp. 37–48. (T. Okutani, R. K. O'Dor, and T. Kubodera, Eds). Tokyo: Tokai University Press (1993a).

Boyle, P. R., and M. A. K. Ngoile. Population variation and growth in Loligo forbesi (Cephalopoda: Loliginidae) from Scottish waters. **In**: *Recent Advances in Cephalopod Fisheries Biology*, pp. 49–59. (T. Okutani, R. K. O'Dor, and T. Kubodera, Eds). Tokyo: Tokai University Press (1993b).

Boyle, P. R., and G. J. Pierce. Fishery biology of Northeast Atlantic squid: an overview. *Fish. Res.*, **21**: 1–15 (1994).

Boyle, P. R., G. J. Pierce, and L. C. Hastie. Flexible reproductive strategies in the squid *Loligo forbesi*. *Mar. Biol.*, **121**: 501–508 (1995).

Boyle, P. R., and P. G. Rodhouse. *Cephalopods: ecology and fisheries*. Blackwell, Oxford, 452 pp. (2005).

Brakoniecki, T. F. A revision of the genus *Pickfordiateuthis* Voss, 1953 (Cephalopoda: Myopsida). *Bull. Mar. Sci.*, **58**: 9–28 (1996).

Brakoniecki, T. F., and C. F. E. Roper. *Lolliguncula argus*, a new species of loliginid squid (Cephalopoda: Myopsida) from the Tropical Eastern Pacific. *Proc. Biol. Soc. Wash.*, **98**: 47–53 (1985).

Breiby, A., and M. Jobling. Predatory role of the flying squid (*Todarodes sagittatus*) in North Norwegian waters. NAFO Scientific Council Studies, **9**: 125–132 (1985).

Brierley, A. S., J. P. Thorpe, G. J. Pierce, M. R. Clarke, and P. R. Boyle. Genetic variation in the neritic squid *Loligo forbesi* (Myopsida: Loliginidae) in the northeast Atlantic. *Mar. Biol.*, **122**: 79–86 (1995).

Brodziak, J. Revised biology and management of long-finned squid (*Loligo pealei*) in the Northwest Atlantic. *Calif. Coop. Ocean. Fish. Inv. Rep.*, **39**: 61–70 (1998).

Brodziak, J., and L. C. Hendrickson. An analysis of environmental effects on survey catches of squids, *Loligo pealei* and *Illex illecebrosus*, in the Northwest Atlantic. *Fish. Bull.*, **97**: 9–24 (1999).

Brodziak, J., and J. Link. Ecosystem-based fishery management: what is it and how can we do it. *Bull. Mar. Sci.*, **70**: 589–611 (2002).

Brodziak, J. K. T., and W. K. Macy, III. Growth of long-finned squid, *Loligo pealei*, in the northwest Atlantic. *Fish. Bull.*, **94**: 212–236 (1996).

Brodziak, J. K. T., and A. A. Rosenberg. A method to assess squid fisheries in the north-west Atlantic. *ICES J. Mar. Sci.*, **50**: 187–194 (1993).

Brunetti, N. Evolucion de la pesqueria de *Illex argentinus* (Castellanos, 1960). *Inf. Tecn. Inv. Pesq.*, **155**: 3–19 (1990).

Brunetti, N. E. Contribucion al conocimiento biologico pesquero del calamar argentino (Cephalopoda, Ommastrephidae, *Illex argentinus*). Trabajo de Tesis presentado para optar al grado de Doctor en

Ciencias Naturales, Universidad de la Plata, Buenos Aires, Argentina (1988).

Brunetti N.E, M. L. Ivanovic, A. Aubone, and G. Rossi. III. Recursos a mantener. Calamar (*Illex argentinus*). *Pesquerias de Argentina, 1997–1999*, pp. 103–116. INIDEP, Mar del Plata (2000).

Brunetti, N., and M. Ivanovic. *Ommastrephes bartramii*: a potential target for the squid fishery in the Southwest Atlantic. *Rev. Inv. Desarr. Pesq.*, **16**: 51–66 (2004).

Bruno, I. Short-finned squid fishery landings of the Spanish fishing fleet operating in the northern Atlantic off the Iberian Peninsula. **In**: Report of the Working Group on Cephalopod Fisheries and Life History (WGCEPH), by Correspondence, Annex 4: Working Document, pp. 37–49. ICES Document CM 2008/LRC: 14. Copenhagen: International Council for the Exploration of the Sea (2008).

Bruno, I., and M. Rasero. Short-finned squid fishery based in commercial landings on Northern Iberian Peninsula (NE Atlantic). *Revista de Investigación Marina, AZTI Technalia*, **3**: 241–242 (2008).

Bruno, I., G. J. Pierce, and G. Costas. Analysis of spatiotemporal patterns in CPUE and size distribution of ommastrephid (*Illex coindetii and Todaropsis eblanae*) landings in the northern Atlantic of the Iberian Peninsula. **In**: ICES Report of the Working Group on Cephalopod Life History and Fisheries (WGCEPH), 27–30 April 2009, Vigo, Spain, Working Document 3, pp. 86–98. ICES Document CM 2009/LRC:06. Copenhagen: International Council for the Exploration of the Sea (2009).

Buresch, K. C., G. Gerlach, and R. T. Hanlon. Multiple genetic stocks of longfin squid *Loligo pealeii* in the NW Atlantic: stocks segregate inshore in summer, but aggregate offshore in winter. *Mar. Ecol. Prog. Ser.*, **310**: 263–270 (2006).

Butler J. L., D. Fuller, and M. Yaremko. Age and growth of market squid (*Loligo opalescens*) off California during 1998. *Calif. Coop. Ocean. Fish. Inv. Rep.*, **40**: 191–195 (1999).

Cabanellas-Reboredo, M., J. Alós, D. March, M. Palmer, G. Jordà, and M. Palmer. Where and when will they go fishing? Understanding fishing site and time choice in a recreational squid fishery. *ICES J. Mar. Sci.*, doi:10.1093/icesjms/fst206 (2014a).

Cabanellas-Reboredo, M., J. Alós, M. Palmer, and B. Morales-Nin. Environmental effects on recreational squid jigging fishery catches. *ICES J. Mar. Sci.*, **69**(10), 1823–1830 (2012b).

Cabanellas-Reboredo, M., J. Alós, M. Palmer, D. March, and R. O'Dor. Movement patterns of the European squid *Loligo vulgaris* during the inshore spawning season. *Mar. Ecol. Prog. Ser.*, **466**: 133–144 (2012a).

Cabanellas-Reboredo, M., M. Calvo-Manazza, M. Palmer, J. Hernández-Urcera, M. E. Garci, Á. F. González, Á. Guerra, and B. Morales-Nin. Using artificial devices for identifying spawning preferences of theEuropean squid: Usefulness and limitations. *Fish. Res.*, **157**: 70–77 (2014b).

Caddy, J. F. The cephalopods: factors relevant to their population dynamics and to the assessment and management of stocks. **In**: Advances in assessment of world cephalopod resources. *FAO Fish. Tech. Pap.*, **231**: 416–457, Rome (1983).

Caddy, J. F. Some future perspectives for assessment and management of Mediterranean fisheries. *Sci. Mar.*, **57**: 121–130 (1993).

Caddy, J. F., and L. Garibaldi. Apparent changes in the trophic composition of world marine harvests: the perspective from the FAO capture database. *Ocean Coastal Manage.*, **43**: 615–655 (2000).

Caddy, J. F., and R. Mahon. Reference points for fisheries management. FAO Fisheries Technical Paper No. 347, Rome: FAO (1995).

Caddy, J. F., and P. G. Rodhouse. Cephalopod and groundfish landings: evidence for ecological change in global fisheries? *Rev. Fish Biol. Fisher.*, **8**: 431–444 (1998).

Cadrin, S. X., and E. M. C. Hatfield. Stock assessment of longfin inshore squid, *Loligo pealeii*. NEFSC Reference Document, 99–12. 72 pp. (1999).

Camarillo-Coop, S., R. De Silva-Davila, M. E. Hernandez-Rivas, and R. Durazo-Arvizu. Distribution of *Dosidicus gigas* paralarvae off the west coast of the Baja California peninsula, Mexico. **In**: *Report of a GLOBEC-CLIOTOP/PFRP workshop, 16–17 November 2006, Honolulu* (R. J. Olson and J. W. Young, Eds.). Hawaii, USA. GLOBEC Report 24 (2006).

Carpenter, K. E., and V. H. Niem. FAO species identification guide for fishery purposes. The living marine resources of the Western Central Pacific, 2, Cephalopods, crustacean, holothurians and sharks. Rome: FAO (1998).

Carvalho, G. R., and K. H. Loney. Biochemical genetic studies on the Patagonian squid *Loligo gahi* d'Orbigny. I. Electrophoretic survey of genetic variability. *J. Exp. Mar. Biol. Ecol.*, **126**: 231–241 (1989).

Carvalho, G. R., and T. J. Pitcher. Biochemical genetic studies on the Patagonian squid *Loligo gahi* d'Orbigny. II. Population structure in Falkland Island waters using isozymes, morphometrics and life history data. *J. Exp. Mar. Biol. Ecol.*, **126**: 243–258 (1989).

Casali, P., G. Manfrin Piccinetti, and S. Soro. Distribuzione di cefalopodi in alto e medio Adriatico. *Biol. Mar. Medit.*, **5**(2): 307–317 (1998).

Castellanos, Z. J. A. Una nueva especie de calamar Argentino, *Ommastrephes argentinus* sp. nov. (Mollusca, Cephalopoda). *Neotropica*, **6**: 55–58 (1960).

Castro, M. P. G., M. H. Carneiro, G. J. M. Servo, C. M. D. Mucinhato, and M. R. de Souza. Dinâmica da frota de arrasto de parelhas do Estado de São Paulo. **In**: *Dinâmica das frotas pesqueiras comerciais da região Sudeste-Sul do Brasil*, pp. 41–59 (C. L. D. B. Rossi-Wongtschowski, R. A. Bernardes and M. C. Cergole, Eds.). São Paulo, Brazil: Série Documentos REVIZEE – SCORE Sul. São Paulo, Instituto Oceanográfico, USP (2007).

Cavanna, P., L. Lanteri, E. Beccornia, and G. Relini. Accrescimento di *Illex coindetii* (Verany, 1839) e *Todaropsis eblanae* (Ball, 1841) in mar Ligure. *Biol. Mar. Mediterr.*, **15** (1): 320–321 (2008).

Ceriola, L., N. Ungaro, and F. Toteda. Some information on the biology of *Illex coindetii* Verany, 1839 (Cephalopoda, Ommastrephidae) in the south-western Adriatic Sea (central Mediterranean). *Fish. Res.*, **82**: 41–49 (2006).

Challier, L., G. J. Pierce, and J. – P. Robin. Spatial and temporal variation in age and growth in juvenile Loligo forbesi and relationships with recruitment in the English Channel and Scottish (UK) waters. *J. Sea Res.*, **55**: 217–229 (2006).

Challier, L., M. Dunn, and J.–P. Robin. Trends in age-at-recruitment and juvenile growth of cuttlefish, *Sepia officinalis*, from the English Channel. *ICES J. Mar. Sci.*, **62**: 1671–1682 (2005).

Chantawong, P. Squid light luring fishery in Phuket and Phang-Nga Province. *Tech Pap 20/1993, Andaman Sea Fish. Dev. Cent., Mar. Fish. Div., Dept. Fish.* (1993).

Charuchinda, M. Preliminary report of the experiments on various mesh-sizes in squid-fishing with light. *Tech. Pap. 3/1987, East. Mar. Fish. Dev. Cent., Mar. Fish. Div., Dept. Fish.* (1987).

Charuchinda, M. Experiment on the optimum mesh-size in squid-fishing with light. *Tech. Pap. 7, East. Mar. Fish. Dev. Cent., Mar. Fish. Div., Dept. Fish.* (1988).

Chen, C. S. Abundance trends of two neon flying squid (*Ommastrephes bartramii*) stocks in the North Pacific. *ICES J. Mar. Sci.*, **67**: 1336–1345 (2010).

Chen, C. S., and T. S.Chiu. Variations of life history parameters in two geographical groups of the neon flying squid, *Ommastrephes bartramii*, from the North Pacific. *Fish. Res.* **63**: 349–366 (2003).

Chen, C. S., T. S. Chiu, and W. B. Huang. Spatial and temporal patterns of *Illex argentinus* abundance in the southwest Atlantic and environmental influences. *Zool. Stud.*, **46**: 111–122 (2007a).

Chen, C. S., W. B. Huang, and T. S. Chiu. Different spatiotemporal distribution of Argentine short-finned squid (*Illex argentinus*) in the southwest Atlantic during high abundance and its relationship to sea temperature. *Zool. Stud.*, **46**: 362–374 (2007b).

Chen, C. S., G. J. Pierce, J. Wang, J.-P. Robin, J. C. Poulard, J. Pereira, A. F. Zuur, A. F., P. R. Boyle, N. Bailey, D. J. Beare, P. Jereb, S. Ragonese, A. Mannini, and L. Orsi-Relini. The apparent disappearance of *Loligo forbesi* from the south of its range in the 1990s: Trends in *Loligo spp*. abundance in the northeast Atlantic and possible environmental influences. *Fish. Res.*, **78**: 44–54 (2006).

Chen, X., J. Cao, Y. Chen, B. Liu, and S. Tian. Effect of the Kuroshio on the spatial distribution of the red flying squid *Ommastrephes bartramii* in the Northwest Pacific Ocean. *Bull. Mar. Sci.* **88**: 63–71 (2012)

Chen, X., Y. Chen, S. Tian, B. Liu, and W. Qian. An assessment of the west winter–spring cohort of neon flying squid (*Ommastrephes bartramii*) in the Northwest Pacific Ocean. *Fish. Res.* **92**: 221–230 (2008a).

Chen X. J., J. H. Li, B. L. Lin, Y. Chen, G. Li, Z. Fang, and S.Q Tian. Age, growth and population structure of jumbo flying squid, *Dosidicus gigas*, off the Costa Rica Dome. *J. Mar. Biol. Assoc. U.K.*, **93**: 567–573 (2013a).

Chen, X. J., B. L. Liu, and Y. Chen. A review of the development of Chinese distant-water squid jigging fisheries. *Fish. Res.*, **89**: 211–221 (2008b).

Chen, X. J., B. L. Liu, S. Q. Tian, W. G. Qian, and X. H. Zhao. Fishery biology of purpleback squid, *Sthenoteuthis oualaniensis*, in the northwest Indian Ocean. *Fish. Res.*, **83**: 98–104 (2007c).

Chen, X. J., Y. G. Wang, and W. G. Qian. The important economic cephalopods resources and Fisheries in Chinese offshore waters. Beijing: Science Press (2013b).

Chen, X. J, X. H. Zhao, and Y. Chen. El Niño/La Niña influence on the western winter-spring cohort of neon flying squid (*Ommastrephes bartramii*) in the northwestern Pacific Ocean. *ICES J. Mar. Sci.*, **64**: 1152–1160 (2007d).

Chenkitkosol, W. Small scale squid cast net with light luring fishery around artificial reef area in Pranburi and Samroiyod District Prachuap Khiri Khan Province. *Tech. Pap., Mar. Fish. Bur., Dept. Fish.* (2003).

Chesalin, M. V., and G. V. Zuyev. Pelagic cephalopods of the Arabian Sea with an emphasis on *Sthenoteuthis oualaniensis*. *Bull. Mar. Sci.*, **71**: 209–221 (2002).

Chilvers, B. L. New Zealand sea lions Phocarctos hookeri and squid trawl fisheries: bycatch problems and management options. *Endanger. Species Res.*, **5**: 193–204. (2008).

Choi, K.-S. Reproductive biology and ecology of the loliginid squid, *Uroteuthis (Photololigo) duvauceli* (Orbigny, 1835), in Hong Kong waters. MSc Thesis, University of Hong Kong, Hong Kong, China (2007).

Chong, J., C. Oyarzún, R. Galleguillos, E. Tarifeño, R. Sepúlveda, and C. Ibáñez. Parámetros biológico-pesqueros de la jibia, *Dosidicus gigas* (Orbigny, 1835) (Cephalopoda: Ommastrephidae). *Gayana.*, **69**: 319–328 (2005).

Chotiyaputta, C. Spawning season of *Sepioteuthis lessoniana*. *Ann. Rep. 1984, Invertebr. Sect., Mar. Fish. Div., Dept. Fish.* (1984).

Chotiyaputta, C. Reproductive biology of bigfin reef squid from squid trap. *Tech. Pap. 5, Mar. Life Hist. Sect., Mar. Fish. Div., Dept. Fish.* (1988).

Chotiyaputta, C. Distribution and abundance of juvenile and adult squids in the western Gulf of Thailand. Proceedings of the NRCT-JSPS Joint Seminar on Marine Science, Songkhla, Thailand, December 2–3, 1993. pp. 200–207 (1993).

Chotiyaputta, C. Biology of cephalopods. **In**: *Biology and Culture of Cephalopods*, pp. 27–49 (J. Nabhitabhata, Ed.). Rayong, Thailand: Rayong Coastal Aquaculture Station (1995a).

Chotiyaputta, C. Juvenile and adult taxonomy and fishery biology if neritic squids in Thai Waters. PhD Dissertation, Tokyo University of Fisheries, Tokyo, Japan (1995b).

Christofferson, J. P., A. Foss, W. E. Lanbert, and B. Welge. An electrophoretic study of select proteeins from the market squid, *Loligo opalescens Berry*. *Calif. Dep. Fish. Game. Fish. Bull.*, **169**: 123–134 (1978).

Chuksin, Y. V. From Cape Hatteras to Cabot Strait: the story of the soviet fishery on the Atlantic continental shelf of the United States and Canada. U.S. Dept. of Commerce. *NOAA Tech. Memo. NMFS-F/SPO-71* (2006).

Chung, W.-S. Effects of temperature, salinity and photoperiod on the deposition of growth increments in statoliths of the oval squid *Sepioteuthis lessoniana* Lesson, 1830 (Cephalopoda: Loliginidae) during early stages. MSc thesis, National Sun Yat-sen University, Kaohsiung, Taiwan (2003).

Chyn, S. S., K. T. Lee, and C. H. Liao. Aggregative behavior of the Swordtip squid (*Loligo edulis*) under fishing lights in the coastal waters of northern Taiwan. *J. Fish. Soc. Taiwan.*, **25**: 1–15 (1998).

Ciavaglia, E., and C. Manfredi, C. Distribution and some biological aspects of cephalopods in the north and central Adriatic. *Boll. Malacol.*, **45**(Suppl. 8): 61–69 (2009).

Clarke, M. R. Economic importance of North Atlantic squids. *New Scientist*, **17**(330): 568–570 (1963).

Clarke, M. R. A review of the systematics and ecology of oceanic squids. *Adv. Mar. Biol.*, **4**: 91–300 (1966).

Clarke, M. R. Cephalopod biomass - estimation from predation. *Mem. Natl. Mus. Victoria.*, **44**: 95–107 (1983).

Clarke, M. R. (Ed.): The role of cephalopods in the world's oceans. *Philos. T. Roy. Soc. B.*, **351**: 977–1112 (2006).

Clarke M. R., E. J. Denton, and J. B. Gilpin-Brown. On the use of ammonium for buoyancy in squids. *J. Mar. Biol. Ass. U.K.*, **59**: 259–276 (1979).

Cochrane, K., B. Oliver, and W. H. H. Sauer. An evaluation of alternative allocation strategies for the chokka squid fishery in the Eastern Cape: an assessment of current economic and social data. Unpublished report (2012).

Coelho, M. L., and R. K. O'Dor. Maturation, spawning patterns and mean size at maturity in the short-finned squid *Illex illecebrosus*. **In**: *Recent advances in fisheries biology*, pp. 81–91 (T. Okutani, R.

K. O'Dor, and T. Kubodera, Eds.). Tokyo, Japan: Tokai University Press (1993).

Coelho, M. L. Review of the influence of oceanographic factors on cephalopod distribution and life cycles. *NAFO Sci. Coun. Studies*, **9**: 47–57 (1985).

Cohen, A. C. The systematics and distribution of *Loligo* (Cephalopoda: Myopsida) in the western North Atlantic with descriptions of two new species. *Malacologia*, **15**: 229–367 (1976).

Collins, M. A., P. R. Boyle, G. J. Pierce, L. N. Key, S. E. Hughes, and J. Murphy. Resolution of multiple cohorts in the Loligo forbesi population from the west of Scotland. *ICES J. Mar. Sci.*, **56**: 500–509 (1999).

Collins, M. A., and G. J. Pierce. Size selectivity in the diet of *Loligo forbesi* (Cephalopoda: Loliginidae). *J. Mar. Biol. Assoc. U.K.*, **76**: 1081–1090 (1996).

Collins, M. A., G. J. Pierce, and P. R. Boyle. Population indices of reproduction and recruitment in *Loligo forbesi* (Cephalopoda: Loliginidae) in Scottish and Irish waters. *J. Appl. Ecol.*, **34**: 778–786 (1997).

Colloca, F., V. Crespi, S. Cerasi, and S. R. Coppola. Structure and evolution of the artisanal fishery in a southern Italian coastal area. *Fish. Res.*, **69**: 359–369 (2004).

CONAPESCA. Landings data: http://www.conapesca.gob.mx (2013).

Costa, J. A. S., and F. C. Fernandes. Seasonal and spatial changes of cephalopods caught in the Cabo Frio (Brazil) upwelling ecosystem. *Bull. Mar. Sci.*, **52**(2): 751–759 (1993).

Costa, P. A. S., and M. Haimovici. A pesca de lulas no litoral de Rio de Janeiro. *Ciência e Cultura*, **42**(12): 1124–1130 (1990).

Craig, S. Environmental conditions and yolk biochemistry: factors influencing embryonic development in the squid *Loligo forbesi* (Cephalopoda: Loliginidae) Steenstrup 1856. PhD thesis, Aberdeen: University of Aberdeen (2001).

Csirke, J. The Patagonian fishery resources and the offshore fisheries in the South-West Atlantic. *FAO Fish. Tech. Pap.*, **286**: 1–75 (1987).

Cuccu, D., P. Addis, F. Damele, and G. Manfrin Piccinetti. Primo censimento della teutofauna dei mari circondanti la Sardegna. *Biol. Mar. Medit.*, **10**(2): 795–798 (2003).

Cuccu, D., P. Jereb, P. Addis, A. A. Pendugiu, A. Sabatini, and A. Cau. Eccezionali catture di *Todarodes sagittatus* nei mari sardi. *Biol. Mar. Medit.*, **12**: 500–503 (2005).

Cunha, M. M., and A. Moreno. Recent trends in the Portuguese squid fishery. *Fish. Res.*, **21**: 231–242 (1994).

Cuvier, G. Memoires pour Servir a l'Histoire et a l'Anatomie des Mollusques. Paris (1817).

DAFF. 2009/2010 Performance review of fishing right holders. Overall report/summary: Limited commercial and full commercial rights holders. Department of Agriculture, Forestry and Fisheries, South Africa; 89 pp (2009/2010).

Daly, H. I., G. J. Pierce, M. B. Santos, J. Royer, S. K. Cho, G. Stowasser, J. P. Robin, and S. M. Henderson. Cephalopod consumption by trawl caught fish in Scottish and English Channel waters. *Fish. Res.*, **52**: 51–64 (2001).

Dawe, E. G. Development of the Newfoundland squid (*Illex illecebrosus*) fishery and management of the resource. *J. Shellfish Res.*, **1**: 137–142 (1981).

Dawe, E. G., and P. C. Beck. Distribution and size of short-finned squid (*Illex illecebrosus*) larvae in the Northwest Atlantic from winter surveys from 1969, 1981 and 1982. *J. Northwest Atl. Fish. Sci.*, **6**: 43–55 (1985).

Dawe, E. G., and P. C. Beck. Population structure, growth and sexual maturation of short-finned squid at Newfoundland, Canada, based on statolith analysis. *Can. J. Fish. Aquat. Sci.*, **54**: 137–146 (1997).

Dawe, E. G., P. C. Beck, H. J. Drew, and G. H. Winters. Long distance migration of a short-finned squid, *Illex illecebrosus*. *J. Northwest Atl. Fish. Sci.*, **2**: 75–76 (1981).

Dawe, E. G., E. B. Colbourne, and K. F. Drinkwater. Environmental effects on recruitment of short-finned squid (*Illex illecebrosus*). *ICES J. Mar. Sci.* **57**: 1002–1013 (2000).

Dawe, E. G., and L. C. Hendrickson. A review of the biology, population dynamics, and exploitation of short-finned squid in the northwest Atlantic Ocean, in relation to assessment and management of the resource. *NAFO SCR Doc. 98/59, Ser. No. N3051*, 33 p. (1998).

Dawe, E. G., L. C. Hendrickson, E. B. Colburne, K. F. Drinkwater, and M. A. Showell. Ocean climate effects on the relative abundance of short-finned (*Illex illecebrosus*) and long-finned (*Loligo pealeii*) squid in the Northwest Atlantic Ocean. *Fish. Oceanogr.* **16** (4): 303–316 (2007).

Dawe, E. G., and Y. Natsukari. Light microscopy. **In**: *Squid Age Determination Using Statoliths*, pp. 83–95 (P. Jereb, S. Ragonese and S. v. Boletzky, Eds.). Palermo, Italy: NTR-ITPP Spec Pub No. 1 (1991).

de la Cruz-González F. J., E. A. Aragón-Noriega, J. I. Urciaga-García, C. A. Salinas-Zavala, M. A. Cisneros-Mata, and L. F. Beltrán-Morales. Análisis socioeconómico de las pesquerías de camarón y calamar gigante en el Noroeste de México. *Interciencia (INCI)*, **32**: 144–150 (2007).

de la Cruz-González, F. J., L. F. Beltrán-Morales, C. A. Salinas-Zavala, M. A. Cisneros-Mata, E. A. Aragón-Noriega, and G. Avilés-Polanco. Análisis socioeconómico de la pesquería de calamar gigante en Guaymas, Sonora. *Economía, Sociedad y Territorio*, **11**: 645–666 (2011).

Demir, M. The Invertebrate Benthos of the Bosphorus and of the Littoral of the Sea of Marmara closer to the Bosphorus. *Hidrobiol. Mecm. Ser. A*, **2**: 615 pp. (1952).

Denis, V., J. Lejeune, and J. – P. Robin. Spatio-temporal analysis of commercial trawler data using General Additive models: patterns of Loliginid squid abundance in the northeast Atlantic. *ICES J. Mar. Sci.*, **59**: 633–648 (2002).

Department of Fisheries (DOF). Definition and classification of fishing gear in Thailand. Bangkok: Department of Fisheries (1997).

Department of Fisheries. Evolution of Fishing Gear in Thailand. Bangkok, Thailand: Marine Fisheries Research and Development Bureau (2006).

Department of Fisheries (DOF). Fisheries Statistics 2010. www.fisheries.go.th/it-stat./ Accessed 15 February 2013 (2013).

Dickson, J. O., R. V. Ramiscal, and B. Magno. Diamondback squid (*Tysanoteuthis rhombus*) exploration in the South China Sea, Area III: Western Philippines. Pp. 32–38. **In**: *Proceedings of the third technical seminar on marine fishery resources survey in the South China Sea, Area III: Western Philippines*. Special Paper No. SEC/SP/41, pp. 32–38. Bankok, Thailand: Southeast Asian Fisheries Development Center (2000).

Diegues, A. C. S. Pescadores, camponeses e trabalhadores do mar. São Paulo: Editora Ática (1983).

Dillane, E., P. Galvin, J. Coughlan, M. Lipinski, and F. T. Cross. Genetic variation in the lesser flying squid *Todaropsis eblanae*

(Cephalopoda, Ommastrephidae) in east Atlantic and Mediterranean waters. *Mar. Ecol. Prog. Ser.*, **292**: 225–232 (2005).

Dillane, E., P. Galvin, J. Coughlan, P. Rodhouse, and F. T. Cross. Polymorphic variable number of tandem repeat (VNTR) loci in the ommastrephid squid, *Illex coindetii and Todaropsis eblanae*. *Mol. Ecol.*, **9**: 1002–1004 (2000).

Diogenes Laertius. Lives of Eminent Philosophers. Loeb Classical Library 184–185. Harvard University Press, Cambridge (1925).

Doi, T., and T. Kawakami. Biomass of Japanese common squid *Todarodes pacificus* Steenstrup and the management its fishery. *Bul. Tokai Reg. Fish. Res. Lab.*, **99**: 65–83 (1979).

Donati, A., and P. Pasini (Curators). Pesca e pescatori nell'antichità. Leonardo Arte srl Milano, Elemond Editori Associati e CIRSPE, Roma 179 pp. (1997).

Dowling, N. A., D. C. Smith, and A. D. M. Smith. Finalisation of Harvest Strategies for AFMA's Small Fisheries Final report for Project 2007/834. *Australian Fisheries Management Authority, Canberra.*, (2007).

Dowling, N. A., D. C. Smith, I. Knuckey, A. D. M. Smith, P. Domaschenz, H. M. Patterson, and W. Whitelaw. Developing harvest strategies for low-value and data-poor fisheries: Case studies from three Australian fisheries. *Fish. Res.*, **94**: 380–390 (2008).

Downey, N. J., M. J. Roberts, and D. Baird. An investigation of the spawning behaviour of the chokka squid *Loligo reynaudii* and the potential effects of temperature using acoustic telemetry. *ICES J. Mar. Sci.*, **67**: 231–243 (2010).

Dudarev, V. A., V. D. Didenko, and M. A. Zuev. The study of fishery and stock abundance of the commander squid (*Berryteuthis magister* Berry, 1913) in the Russian Far Eastern Fishery Basin. **In:** *Proceedings of the All–Russian Conference dedicated to the 80th Anniversary of KamchatNIRO*: 128–138 (2012) [In Russian].

Dunning, M., and E. C. Forch. A review of the systematics, distribution, and biology of the Arrow squids of the genus *Nototodarus* Pfeffer, 1912 (Cephalopoda: Ommastrephidae). **In**: *Systematics and biogeography of cephalopods*. Volume **2**. pp. 393–404 (N. Voss, M. Vecchione, R. B. Toll, and M. J. Sweeney, Eds.). *Smithson. Contrib. Zool.*, **586**. Washington: Smithsonian Institution Scholarly Press (1998).

Dunning, M. C., and J. H. Wormuth. The ommastrephid squid genus *Todarodes*: a review of systematics, distribution, and biology (Cephalopoda: Teuthoidea). **In**: *Systematics and biogeography of cephalopods*. Volume **2**. pp. 385–391 (N. Voss, M. Vecchione, R. B. Toll, and M. J. Sweeney, Eds.). *Smithson. Contrib. Zool.*, **586**. Washington: Smithsonian Institution Scholarly Press (1998).

Dunning, M., K. Yeomans, and S. Mckinnon. Development of a northern Australian squid fishery. Department of Primary Industries, Queensland. Brisbane (2000).

Durward, R. D., E. Vessey, R. K. O'Dor, and T. Amaratunga. Reproduction in the squid, *Illex illecebrosus*: first observations in captivity and implications for the life cycle. *Int. Comm. Northwest Atl. Fish. Sel. Pap.*, **6**: 7–13 (1980).

Ehrhardt, N. M., P. S. Jaquemin, B. F. García, D. G. González, B. J. M. López, C. J. Ortiz, and N. A. Solís. On the fishery and biology of the giant squid *Dosidicus gigas* in the Gulf of California, Mexico. **In**: *Advances in assessment of world cephalopod resources* (J. F. Caddy, Ed.). *FAO Fish. Tech. Pap.* **231**: 306–340 (1983).

Erlandson, J. M., and T. C. Rick. Archaeology meets marine ecology: the antiquity of maritime cultures and human impacts on marine fisheries and ecosystems. *Ann. Rev. Mar. Sci.*, **2**: 231–251 (2010).

Escánez Pérez, A., R. Riera Elena, A. F. González González, and A. Guerra Sierra. On the occurrence of egg masses of the diamond-shaped squid *Thysanoteuthis rhombus* Troschel, 1857 in the subtropical eastern Atlantic (Canary Islands). A potential commercial species? *ZooKeys*, **222**: 69–76 (2012).

Evans, K. Arrow squid behaviour and vulnerability to netting techniques. *Department of Sea Fisheries Tasmania*. 0817–3680 (1986).

Falkland Islands Government. *Fishery Statistics 16*. Fisheries Department, Stanley, Falkland Islands (2012).

FAO Yearbook. *Fishery and Aquaculture statistics*. Rome, FAO. (2010).

FAO. FAO Fisheries and Aquaculture Department, Statistics and Information Service. FishStatJ: Universal software for fishery statistical time series. Rome: FAO (2011).

FAO. FAO Fisheries and Aquaculture Department, Statistics and Information Service. FishStatJ: Universal software for fishery statistical time series. Rome: FAO (2014).

FAO. Fisheries and aquaculture software. FishStatJ (2.0.0) - Software for fishery statistical time series. FAO Fisheries and Aquaculture Department [online]. Rome. (2011–2013). http://www.fao.org/fishery/statistics/software/fishstatj/en

FAO. International Guidelines for Securing Sustainable Small-scale Fisheries. Zero Draft: 31pp. FAO, Rome (2012).

Farrugio, H. Current situation of small-scale fisheries in the Mediterranean and Black Sea: strategies and methodologies for an effective analysis of the sector. **In**: *Report of the First Regional Symposium on Sustainable Small-Scale Fisheries in the Mediterranean and Black Sea, 27–30 November 2013, St. Julian's, Malta* (GFCM Eds.). (2013). http://www.ssfsymposium.org

Farrugio, H., P. Oliver, and F. Biagi. An overview of the history, knowledge, recent and future research trends in Mediterranean fisheries. *Sci. Mar.*, **57**: 105–119 (1993).

Fedorets, Yu. A. Seasonal distribution of the squid Berryteuthis magister in the western Bering Sea. **In**: *Systematics and Ecology of the Cephalopod Mollusks*, pp. 129–130. Leningrad (1983) [In Russian].

Fedorets, Yu. A. Commander squid *Berryteuthis magister* (Berry, 1913) in the Bering and Okhotsk seas (distribution, biology, fishery). Ph. D. Thesis, Institute of Marine Biology, Far Eastern Branch of the Russian Academy of Sciences, Vladivostok, Russia. (2006) [In Russian].

Fedorets, Yu.A., V. D. Didenko, P. P. Raiko, and N. E. Kravchenko. Biology of the squid *Berryteuthis magister* on the spawning grounds near the Commander Islands. *Izvestiya TINRO (TINRO Proceedings)*, **122**: 393–429 (1997b) [In Russian].

Fedorets, Yu.A., and O. A. Kozlova. Reproduction, fecundity and abundance of the squid Berryteuthis magister (Gonatidae) in the Bering Sea. **In**: Resources and Perspectives of the Use of Squids in the World Ocean, pp. 66–80 (B. G. Ivanov, Ed.) Moscow, Russia: VNIRO (1986) [In Russian, English summary].

Fedorets, Yu. A., V. A. Luchin, V. D. Didenko, P. P. Raiko, and N. E. Kravchenko. Conditions for formation of aggregations of the squid Berryteuthis magister off the Kuril Islands. Izvestiya TINRO (TINRO Proceedings), **122**: 361–374 (1997a) [In Russian].

Fedulov, P. P., and T. Amaratunga. On dates of short-finned squid, *Illex illecebrosus*, immigration onto the Scotian Shelf. *NAFO SCR Doc. 81/VI/32, Ser. No. N311* (1981).

Fernández, F., and J. A. Vásquez. La jibia gigante *Dosidicus gigas* (Orbigny, 1835) en Chile: Análisis de una pesquería efímera. *Estud. Oceanol.*, **14**: 17–21 (1995).

Field, J. C., K. Baltz, A. J. Phillips, and W. A. Walker. Range expansion and trophic interactions of the jumbo squid, *Dosidicus gigas*, in the California Current. *Calif. Coop. Oceanic Fish. Invest. Rep.*, **48**: 131–146 (2007).

Fields, W. G. A preliminary report on the fishery and on the biology of the squid, *Loligo opalescens*. *Calif. Dep. Fish. Game. Fish. Bull.*, **36**: 366–377 (1950).

Fishery Agency of Japan. Report on cruise of the R/V Shoyo Maru in the north Arabian Sea Survey, in cooperation with the IOP, FAO, to assess the pelagic fish stocks 2 October 1975 - 14 January 1976. Research and development division, Fishery Agency of Japan (1976).

Folsom W. B., D. J. Rovinsky, and D. M. Weidner. Western Europe and Canada (fishing fleets). **In**: *World Fishing Fleets: An Analysis of Distant-water Fleet Operations. Past-Present-Future*. Volume **VI**. Office of International Affairs, National Marine Fisheries Service, NOAA, U.S. Department of Commerce. Silver Spring, Maryland, (1993).

Fonseca, T., A. Campos, M. Afonso-Dias, P. Fonseca, and J. Pereira. Trawling for cephalopods off the Portuguese coast - fleet dynamics and landings composition. *Fish. Res.*, **92**: 180–188 (2008).

Food and Agriculture Organization (FAO). Report on the First and Second THAILAND/FAO/DANIDA Workshops on Fishery Research Planning Held at Phuket, 28 October to 8 November 1991 and Songkhla, 15 to 26 February 1993 for the Project "Training in Fish Stock Assessment and Fishery Research Planning". *GCP/INT/392/Den Report on Activities No. 35 and 41* (1993).

Frandsen, R. P., and K. Wieland. Cephalopods in Greenland Waters. Pinngortitaleriffik: Greenland Institute of Natural Resources Technical Report 57. 19 pp. (2004).

Furlani, D., A. J. Hobday, S. Ling, J. Dowdney, C. Bulman, M. Sporcic, and M. Fuller. Ecological Risk Assessment for the Effects of Fishing: Southern Squid Jig Sub-fishery. *Report for the Australian Fisheries Management Authority, Canberra* (2007).

Furuta, H. Swordtip squid in Chikzenkai fishing ground and distribution. *Rep. Fukuoka Fish. Exp. Stn. Research Reports for* 1974: 50–56 (1976) [in Japanese].

Furuta, H. Fishing grounds. *Report on a Survey of the Ecology and Stock of Swordtip Squid in the Western Japanese Waters*: 47–54 (1978a) [in Japanese].

Furuta, H. Dorsal mantle length composition. *Report on a Survey of the Ecology and Stock of Swordtip Squid in the Western Japanese Waters*: 31–39 (1978b) [in Japanese].

Furuta, H. Fishing season. *Report on a Survey of the Ecology and Stock of Swordtip Squid in the Western Japanese Waters*: 31–39 (1978c) [in Japanese].

Furuta, H. Swordtip squid in Chikzenkai V. Spawning ground and bottom sediment. *Fukuoka Fish. Exp. Stn. Research Reports for* 1978: 1–6 (1980) [in Japanese].

García Tasende, M., F. Quintero Fernández, R. Arnáiz Ibarrondo, R. Bañón Díaz, J. M. Campelos Álvarez, F. Lamas Rodriguez, A. Gancedo Baranda, M. E. Rodríguez Moscoso, and J. Ribó Landin. La pesquería de calamar (*Loligo vulgaris*) y puntilla (*Alloteuthis spp*) con boliche en las Rías Baixas gallegas (1999–2003). Los Recursos Marinos de Galicia. Serie Técnica No. 3. Santiago de Compostela: Unidad Técnica de Pesca de Bajura (UTPB), Consellería de Pesca e Asuntos Marítimos, Xunta de Galicia (2005).

Garoia, F., I. Guarniero, A. Ramsak, N. Ungaro, N. Landi, C. Piccinetti, P. Mannini, and F. Tinti, F. Microsatellite, DNA variation reveals high gene flow and panmictic populations in the Adriatic shared stocks of the European squid and cuttlefish (Cephalopoda). *Heredity*, **93**: 166–174 (2004).

Gasalla, M. A. Women on the water? The participation of women in seagoing fishing off southeastern Brazil. **In**: *Gender, Fisheries and Aquaculture: Social Capital and Knowledge for the Transition Towards Sustainable Use of Aquatic Ecosystem*, pp. 10 (S. B. Williams, A. M. Hochet-Kibongui, and C. E. Nauen). ACP–EU Fishery Research Report, 16 (2005).

Gasalla, M. A., A. Migotto, and R. S. Martins. First occurrence of *Doryteuthis plei* (Blainville, 1823) egg capsules off São Sebastião, Southeastern Brazil, and characteristics of embryos and newly-hatched paralarvae. **In**: *International Symposium Coleoid Cephalopod Through Time*, Vol. **4**, pp. 29–31. Stuttgart, Germany: Staaliches Museum fuer Naturkunde Stuttgart (2011).

Gasalla, M. A. A., J. A. A. Perez, C. A. Marques, A. R. G. Tomás, D. C. de Aguiar, and U. C. Oliveira. *Loligo sanpaulensis*. **In**: *Análise das Principais Pescarias Comerciais da Região Sudeste-Sul do Brasil. Dinâmica Populacional das Espécies em Explotação*, pp. 69–73 (M. C. Cergole, A. O. Ávila-da-Silva and C. L. D. B. Rossi-Wongtschowski, Eds.). São Paulo, Brazil: Série Documentos REVIZEE - SCORE SUL: Ed. Ulhoa Cintra (2005b).

Gasalla, M. A., F. A. Postuma, and A. R. G. Tomás. Captura de lulas (Mollusca: Cephalopoda) pela pesca industrial desembarcada em Santos: comparação após 4 décadas. *Braz. J. Aquat. Sci. Technol.*, **9**(2): 5–8 (2005a).

Gasalla, M. A., A. R. Rodrigues, and F. A. Postuma. The trophic role of the squid *Loligo plei* as a keystone species in the South Brazil Bight ecosystem. *ICES J. Mar. Sci.* **67**: 1413–1424 (2010).

Gentiloni, P., S. Agnesi, and C. Gargiulo. Dati sulla distribuzione e biologia del cefalopode *Illex coindetii* (Verany, 1839) nel mar Tirreno centrale. *Biol. Mar. Mediter.*, **8**: 715–719 (2001).

Gerlach, G., K. C. Buresch, and R. T. Hanlon. Population structure of the squid *Doryteuthis pealeii* on the eastern coast of the USA: Comment on Shaw et al. (2010). *Mar. Ecol. Prog. Ser.*, **450**: 281–283 (2012).

Gesner, C. Historiae Animalium. Carolinum, Zurich (1551–1558).

GFCM. FAO General Fisheries Commission for the Mediterranean. Report of the thirty-first session. Rome, 9–12 January 2007. *GFCM Report*, **31**. Rome, FAO. 80 pp. (2007).

Giordano, D., and P. Carbonara. Nota sulla distribuzione dei molluschi cefalopodi nel Tirreno centro-meridionale. *Biol. Mar.Medit.*, **6**(1): 573–575 (1999).

Glass, C. W., B. Sarno, H. O. Milliken, G. D. Morris, and H. A. Carr. Bycatch reduction in Massachusetts inshore squid (*Loligo pealeii*) trawl fisheries. *MTS Journal*, **33**: 35–42 (1999).

Glazer, J. P., and D. S. Butterworth. Some refinements of the assessment of the South African squid resources, *Loligo vulgaris reynaudii*. *Fish. Res.*, **78**: 14–25 (2006).

Golikov, A. V., R. M. Sabirov, P. A. Lubin, and L. L. Jørgensen. Changes in distribution and range structure of Arctic cephalopods due to climatic changes of the last decades. *Biodiversity*, **14**: 28–35 (2013).

Gong, Y., Y.-S. Kim, and D. H An. Abundance of neon flying squid in relation to oceanographic conditions in the North Pacific. *Bull. Int. North Pacific Fish. Comm.* **53**: 191–204 (1993a).

Gong, Y., Y. S. Kim, and S.-J. Hwang. Outline of the Korean squid gillnet fishery in the North Pacific. *Bull. Int. North Pacific Fish. Comm.*, **53**: 45–69 (1993b).

Gonzáles, P., and J. Chong. Biología reproductiva de *Dosidicus gigas* D'Orbigny 1835 (Cephalopoda, Ommastrephidae) en la zona norte-centro de Chile. *Gayana.*, **70**: 65–72 (2006).

González, A. F., B. G. Castro, and A. Guerra. Age and growth of the short-finned squid *Illex coindetii* in Galician waters (NW Spain) based on statolith analysis. *ICES J. Mar. Sci.*, **53**: 802–810 (1996).

González, Á. F., M. Rasero, and Á. Guerra. Preliminary study of *Illex coindetii* and *Todaropsis eblanae* (Cephalopoda: Ommastrephidae) in northern Spanish Atlantic waters. *Fish. Res.*, **21**: 115–126 (1994).

González, A. F., and P. G. Rodhouse. Fishery biology of the seven star flying squid *Martialia hyadesi* at South Georgia during winter. *Polar Biol.*, **19**: 231–236 (1998).

González, M., and Sánchez, P. Cephalopod assemblages caught by trawling along the Iberian Peninsula Mediterranean coast. *Sci. Mar.*, **66**(Suppl. 2): 199–208 (2002).

Goss, C., D. Middleton, and P. G. Rodhouse. Investigations of squid stocks using acoustic survey methods. *Fish. Res.*, **54**: 111–121 (2001).

Goss, G., P. G. Rodhouse, J. Watkins, and A. Brierley. Attribution of acoustic echoes to squid in the South Atlantic. *CCAMLR Sci.*, **5**: 259–271 (1998).

Goto, T. Paralarval distribution of the ommastrephid squid *Todarodes pacificus* during fall in the southern Sea of Japan and its implication for locating spawning grounds. *Bull. Mar. Sci.*, **71**: 299–312 (2002).

Granados-Amores, J. Taxonomía de calamares de la familia Loliginidae en el Pacífico mexicano. Ph.D. Dissertation. CIBNOR, La Paz. 165 p. (2013).

Granados-Amores, J., F. Hochberg, and C. A. Salinas-Zavala. New records of *Lolliguncula* (*Lolliguncula*) argus Brakoniecki & Roper, 1985 (Myopsida: Loliginidae) in northwestern Mexico. *Lat. Am. J. Aquat. Res.*, **41**: 595–599 (2013).

Green, C. P. Influence of environmental factors on population structure of arrow squid *Nototodarus gouldi*: implications for stock assessment. PhD, University of Tasmania (2011).

Green, C. P., L. Morris, L. Brown, G. Parry, K. L. Ryan, and S. Conron. Victoria's Bay and Inlet Calamari Stock Assessment 2008. *Fisheries Victoria Internal Report Series No. 24.* (2012).

Guerra, Á., and F. Rocha. The life history of *Loligo vulgaris* and *Loligo forbesi* (Cephalopoda: Loliginidae) in Galician waters (NW Spain). *Fish. Res.*, **21**: 43–69 (1994).

Guerra, Á., P. Sánchez, and F. Rocha. The Spanish fishery for *Loligo*: recent trends. *Fish. Res.*, **21**: 217–230 (1994).

Haefner, P. A., Jr. Morphometry of the common Atlantic squid, *Loligo pealei*, and the brief squid, *Lolliguncula brevis*, in Delaware Bay. *Chesapeake Sci.*, **5**: 138–144 (1964).

Haimovici, M., N. E. Brunetti, P. G. Rodhouse, J. Csirke, and R. H. Leta. *Illex argentinus*. **In**: Squid *Illex* recruitment dynamics: The genus *Illex* as a model, the commercial *Illex* species and influences on variability, pp. 27–58 (P. G. Rodhouse, E. G. Dawe and R. K. O'Dor, Eds.). *FAO Fish. Tech. Pap.* **376**, FAO, Rome (1998).

Haimovici, M., M. C. Cergole, R. P. Lessa, L. S. P. Madureira, S. Jablonski, and C. L. D. B. Rossi-Wongstchowski. Capítulo 2. Panorama Nacional. **In**: *Programa REVIZEE. Avaliação do Potencial Sustentável de Recursos Vivos na Zona Econômica Exclusiva. Relatório Executivo*, pp. 79–127. Brasília, Brazil: *Ministério do Meio Ambiente* (2006).

Haimovici, M., and J. A. A. Perez. Coastal cephalopod fauna of southern Brazil. *Bull. Mar. Sci.*, **49**: 221–230 (1991a).

Haimovici, M., and J. A. A. Perez. Abundância e distribuição de cefalópodes em cruzeiros de prospecção pesqueira demersal na plataforma externa e talude continental do sul do Brasil. *Atlântica, Rio Grande*, **13**: 189–200 (1991b).

Haimovici, M., C. L. D. B. Rossi-Wongstchowski, R. A. Bernardes, L. G. Fisher, C. M. Vooren, R. A. dos Santos, A. R. Rodrigues, and S. dos Santos. Prospecção pesqueira de espécies com rede de arrasto-de-fundo na região sudeste-sul do Brasil. São Paulo, Brazil: Série Documentos REVIZEE, Score Sul, Instituto Oceanográfico, USP (2008).

Haimovici, M., R. A. Santos, and L. G. Fischer. Class Cephalopoda. **In**: *Compendium of Brazilian Sea Shells*, pp. 610–649 (E. C. Rios, Ed.). Rio Grande, Brazil: Evangraf (2009).

Hamabe, M. Observations of early development of a squid, *Loligo bleekeri* Keferstein. Ann. Rep. *Jap Sea Reg. Fish. Res. Lab.*, **6**: 149–155 (1960).

Hamabe, M., and T. Shimizu. Ecological studies on the common squid *Todarodes pacificus* STEENSTRUP, mainly in the southwestern waters of the Japan Sea. *Bull. Jap. Sea Reg. Fish. Res. Lab.*, **16**: 13–55 (1966).

Hamabe, M., C. Hamuro, and M. Ogura. Squid jigging from small boats. FAO Fishing Manual. Farnham: Fishing News Books (1982).

Hamada, H. Population Analysis of kensaki squid *Loligo edulis* in Genkai-nada, sea of northern Kyushu. *Bull. Fukuoka Fisheries Mar. Technol. Res. Cent.*, (8): 15–29 (1998) [in Japanese].

Hamada, H., and H. Uchida. Promotion for fisheries resources management (2) survey on natural resources. *Fukuoka Fisheries Mar. Technol. Res. Cent. Research Reports for* 1996: 62–72 (1998) [in Japanese].

Hanlon, R. T., J. P Bidwell, and R. Tait. Strontium is required for statolith development and thus normal swimming behaviour of hatchling cephalopods. *J. Exp. Biol.*, **141**: 187–195 (1989).

Hanlon, R. T., and J. B. Messenger. Cephalopod Behaviour. Cambridge: Cambridge University Press (1996).

Hastie, L. C., J. B. Joy, G. J. Pierce, and C. Yau.. Reproductive biology of *Todaropsis eblanae* (Cephalopoda: Ommastrephidae) in Scottish coastal waters. *J. Mar. Biol. Assoc. U.K.*, **74**: 367–382 (1994).

Hastie, L. C., M. Nyegaard, M. A. Collins, A. Moreno, J. M. F. Pereira, U. Piatkowski, and G. J. Pierce. Reproductive biology of the loliginid squid, *Alloteuthis subulata*, in the north-east Atlantic and adjacent waters. *Aquat. Living Resour.*, **22**: 35–44 (2009b).

Hastie, L. C., G. J. Pierce, C. Pita, M. Viana, J. M. Smith, and S. Wangvoralak. Squid fishing in UK waters. A Report to SEA-FISH Industry Authority. Aberdeen: University of Aberdeen (2009).

Hastie, L. C., G. J. Pierce, J. Wang, I. Bruno, A. Moreno, U. Piatkowski, and J. – P. Robin. Cephalopods in the north-east Atlantic: species, biogeography, ecology, exploitation and conservation. *Oceanogr. Mar. Biol.*, **47**: 111–190 (2009a).

Hatanaka, H. Growth and life span of short-finned squid, *Illex argentinus*, in the waters off Argentina. *Bull. Japan. Soc. Sci. Fish.*, **52**: 11–17 (1986).

Hatanaka, H. Feeding migration of short-finned squid *Illex argentinus* in the waters off Argentina. *Nippon Suisan Gakkaishi*, **54**: 1343–1349 (1988).

Hatanaka, H., and T. Sato. Outline of Japanese squid fishery in Subareas 3 and 4 in 1979. *NAFO SCR Doc. 80/II/8, Ser. No. N040* (1980).

Hatanaka, H., S. Kawahara, and Y. Uozumi. Comparison of life cycles of five ommastrephid squids fished by Japan: *Todarodes pacificus, Illex illecebrosus, Illex argentinus, Nototodarus sloani sloani, and Nototodarus sloani gouldi*. *NAFO Sci. Coun. Studies*, **9**: 59–68 (1985a).

Hatanaka, H., A. M. T. Lange, and T. Amaratunga. Geographical and vertical distribution of shortfinned squid (*Illex illecebrosus*) larvae in the northwest Atlantic. *NAFO Sci. Coun. Studies*, **9**: 93–99 (1985b).

Hatfield, E. M. C. Post-recruit growth of the Patagonian squid Loligo gahi (d'Orbigny). *Bull. Mar. Sci.*, **49**: 349–361 (1991).

Hatfield, E. M. C. Do some like it hot? Temperature as a possible determinant of variability in the growth of the Patagonian squid, *Loligo gahi* (Cephalopoda, Loliginidae). *Fish. Res.*, **47**: 27–40 (2000).

Hatfield, E. M. C., and S. X. Cadrin. Geographic and temporal patterns in size and maturity of the longfin inshore squid (*Loligo pealeii*) off the northeastern United States. *Fish. Bull.*, **100**: 200–213 (2002).

Hatfield, E. M. C., and S. des Clers. Fisheries management and research for *Loligo gahi* in the Falkland Islands. *Calif. Coop. Ocean. Fish. Inv. Rep.*, **39**: 81–91 (1998).

Hatfield, M. C., R. T. Hanlon, J. W. Forsythe, and E. P. M. Grist. Laboratory testing of a growth hypothesis for juvenile squid *Loligo pealeii* (Cephalopoda: Loliginidae). *Can. J. Fish. Aquat. Sci.*, **58**: 845–857 (2001).

Hatfield, E. M. C., P. G. Rodhouse, and J. Porebski. Demography and distribution of the Patagonian squid (*Loligo gahi*, d'Orbigny) during the austral winter. *J. Cons. int. Explor. Mer.*, **46**: 306–312 (1990).

Hayashi, S. Fishery biological studies of firefly squid, *Watasenia scintillans* (Berry), in Toyama Bay. *Bull. Toyama Pref. Fish. Res. Inst.*, **7**: 1–128 (1995b).

Hayashi, S. Spawning time of the day of firefly squid, *Watasenia scintillans*, assumed from set net catch. *Bull. Toyama Pref. Fish. Res. Inst.*, **6**: 17–23 (1995a).

Hendrickson, L. C. Population biology of Northern shortfin squid (*Illex illecebrosus*) in the Northwest Atlantic Ocean and initial documentation of a spawning area. *ICES J. Mar. Sci.*, **61**: 252–266 (2004).

Hendrickson, L. C. Distribution of Northern shortfin squid (*Illex illecebrosus*) in Subarea 3 based on multi-species bottom trawl surveys conducted during 1995–2005. *NAFO SCR Doc. 06/45, Ser. No. N5270* (2006).

Hendrickson, L. C. Effects of a codend mesh size increase on size selectivity and catch rates in a small-mesh bottom trawl fishery for longfin inshore squid, *Loligo pealeii*. *Fish. Res.*, **108**: 42–51 (2011).

Hendrickson, L. C., E. G. Dawe, and M. A. Showell. Assessment of Northern shortfin squid (*Illex illecebrosus*) in Subareas 3+4 for 2001. *NAFO SCR Doc. 02/56, Ser. No. N4668* (2002).

Hendrickson, L. C., and D. R. Hart. An age-based cohort model for estimating the spawning mortality of semelparous cephalopods with an application to per-recruit calculations for the northern shortfin squid, *Illex illecebrosus*. *Fish. Res.*, **78**: 4–13 (2006).

Hendrickson, L. C., and E. M. Holmes. Essential fish habitat source document: northern shortfin squid, *Illex illecebrosus*, life history and habitat characteristics, 2nd Ed. *NOAA Tech. Memo. NMFS-NE-191* (2004).

Hendrickson, L. C., and M. A. Showell. Assessment of Northern shortfin squid (*Illex illecebrosus*) in Subareas 3+4 for 2012. *NAFO SCR Doc. 13/31, Ser. No. N6185* (2013).

Hendrickx, M. E. Diversidad de los macroinvertebrados bentónicos Acompañantes del Camarón en el Área del Golfo de California y su importancia como Recurso Potencial. **In**: Recursos Pesqueros Potenciales de México: La pesca Acompañante del Camarón, pp. 95–148. (A. Yañez-Arancibia, Ed.). *Progr. Univ. de Alimentos, Inst. Cienc. del Mar y Limnol., UNAM -Inst. Nal. de Pesca* (1985).

Herke, S. W., and D. W. Foltz. Phylogeography of two squid (*Loligo pealei and Loligo plei*) in the Gulf of Mexico and northwestern Atlantic Ocean. *Mar. Biol.*, **140**: 103–115 (2002).

Hernández-Herrera, A., E. Morales-Bojorquez, M. A. Cisneros-Mata, M. O. Nevarez-Martinez, and G. I. Rivera-Parra. Management strategy for the giant squid (*Dosidicus gigas*) Fishery in the GC, Mexico. *Calif. Coop. Ocean. Fish. Inv. Rep.*, **39**: 212–218 (1998).

Herrera, A., L. Betancourt, M. Silva, P. Lamelas, and A. Melo. Coastal fisheries of the Dominican Republic. **In**: *FAO Fisheries and Aquaculture Technical Paper. No. 544. Coastal fisheries of Latin America and the Caribbean*, pp. 175–217 (S. Salas, R. Chuenpagdee, A. Charles, and J. C. Seijo, Eds). Rome, Italy: FAO (2011).

Hibberd, T., and G. T. Pecl. Effects of commercial fishing on the population structure of spawning southern calamary (*Sepioteuthis australis*). *Rev. Fish Biol. Fisher.*, **17**: 207–221 (2007).

Hilborn, R., T. A. Branch, B. Ernst, A. Magnusson, C. V. Minte-Vera, M. D. Scheuerell, and J. L. Vlero. State of the worlds fisheries. *Annu. Rev. Environ. Resourc.*, **28**: 359–399 (2003).

Hilborn, R., and C. Walters. Quantitative Fisheries Stock Assessment. Choice, Dynamics and Uncertainty. Chapman and Hall Press, New York, 570 pp. (1992).

Hobday, A. J., and J. M. Lough. Projected climate change in Australian marine and freshwater environments. *Mar. Freshwater Res.*, **62**: 1000–1014 (2011).

Hobday, A. J., A. D. M. Smith, I. C. Stobutzki, C. Bulman, R. Daley, J. M. Dambacher, R. A. Deng, J. Dowdney, M. Fuller, D. Furlani, S. P. Griffiths, D. Johnson, R. Kenyon, I. A. Knuckey, S. D. Ling, R. Pitcher, K. J. Sainsbury, M. Sporcic, T. Smith, C. Turnbull, T. I. Walker, S. E. Wayte, H. Webb, A. Williams, B. S. Wise, and S. Zhou. Ecological risk assessment for the effects of fishing. *Fish. Res.*, **108**: 372–384 (2011).

Hollowed, A. B., J. N. Ianelli, and P. A. Livingston. Including predation mortality in stock assessments: a case study for Gulf of Alaska walleye pollock. *ICES J. Mar. Sci.*, **57**: 279–293 (2000).

Holme, N. A. The biology of *Loligo forbesi* Steenstrup (Mollusca: Cephalopoda) in the Plymouth area. *J. Mar. Biol. Assoc. U.K.*, **54**: 481–503 (1974).

Hoyle, W. E. Reports on the Cephalopoda. *Bull. Museum Comp. Zool. Harvard*, **43**: 1–72 (1904).

Hu, O. Chuugoku no ika tsuri gyogyou—genjou to kongo no tenbou [The squid jigging fishery of China—present situation and future prospect]. **In**: *Surumeika no sekai—shigen, gyogyou, shiyou*, p.293–306 *[The World of the Japanese Common Squid (Todarodes pacificus)—Resources, Fishery and Utilization]*. (T. Arimoto, H. Inada, Eds.), Seizando Shoten Publishing Co., Tokyo (2003) [in Japanese].

Hunsicker, M. E., T. E. Essington, R. Watson, and U. R. Sumaila. The contribution of cephalopods to global marine fisheries: can we have our squid and eat them too? *Fish Fish.*, **11**: 421–438 (2010).

Hunt, J. C. *The behavior and ecology of midwater cephalopods from Monterey Bay: submersible and laboratory investigations*. PhD thesis, University of California, Los Angeles, USA (1996).

Hurley, G. V. Recent developments in the squid, *Illex illecebrosus* fishery of Newfoundland, Canada. *Mar. Fish. Rev.*, **42**(7–8): 15–22 (1980).

Ibáñez, C., J. Arguelles, C. Yamashiro, L. Adasme, R. Cespedes, and E. Poulin. Spatial genetic structure and demographic inference of the Patagonian squid *Doryteuthis gahi* in the south-eastern Pacific Ocean. *J. Mar. Biol. Assoc. U.K.*, **92**: 197–203 (2011a).

Ibáñez, C. M., J. Chong, and M. C. Pardo-Gandarillas. Relaciones somatométricas y reproductivas del calamar *Loligo gahi* Orbigny, 1835 en bahía Concepción, Chile. *Invest. Mar.*, **33**: 211–21 (2005).

Ibáñez, C. M., and L. A. Cubillos. Seasonal variation in the length structure and reproductive condition of the jumbo squid *Dosidicus gigas* (d'Orbigny, 1835) off central-south Chile. *Sci. Mar.*, **71**: 123–128 (2007).

Ibáñez, C., L. A. Cubillos, R. Tafur, J. Argüelles, C. Yamashiro, and E. Poulin. Genetic diversity and demographic history of *Dosidicus gigas* (Cephalopoda: Ommastrephidae) in the Humboldt Current System. *Mar. Ecol. Progr. Ser.*, **431**: 163–171 (2011b).

ICES. Report of the Working Group on Cephalopod Fisheries and Life History (WGCEPH), 9–11 March 2010, Sukarrieta, Spain. ICES CM 2010/SSGEF:09. Copenhagen: International Council for the Exploration of the Sea (2010).

ICES. Report of the Working Group on Cephalopod Fisheries and Life History (WGCEPH), 28 February–03 March 2011, Lisbon, Portugal. ICES CM 2011/SSGEF:03. Copenhagen: International Council for the Exploration of the Sea (2011).

ICES. Report of the Working Group on Cephalopod Fisheries and Life History (WGCEPH), 27–30 March 2012, Cadiz, Spain. ICES Document CM 2012/SSGEF:04. Copenhagen: International Council for the Exploration of the Sea (2012).

ICES. Report of the Working Group on Cephalopod Fisheries and Life History (WGCEPH), 11–14 June 2013, Caen, France. ICES CM 2013/SSGEF:13. Copenhagen: International Council for the Exploration of the Sea (2013).

Ichii, T., *Kitataiheiyou kaiiki* [*The North Pacific Ocean sea area]*. **In**: *Ika—sono seibutsu kara shouhi made* [*Squids—From the Animal to Consumption]* 3rd ed., pp. 195–209 (K. Nasu, T. Okutani, and M. Ogura, (Eds.), (Seizando Shoten: Tokyo (2002) [in Japanese].

Ichii, T., K. Mahapatra, H. Okamura, and Y. Okada. Stock assessment of the autumn cohort of neon flying squid (*Ommastrephes bartramii*) in the North Pacific based on past large-scale high sea driftnet fishery data. *Fish. Res.*, **78**: 286–297 (2006).

Igarashi, S. Studies on the mechanization of squid angling fishery IV. Development of an automatic squid angling machine. *Bull. Facult. Fish. Hokkaido Univ.*, **29**: 250–258 (1978).

Inada, H. Technological aspects on the present fishing system of squid jigging (the future prospects and problems in squid fisheries). *Nippon Suisan Gakkaishi*, **65**: 119–120 (1999) [in Japanese].

Inada, H., and M. Ogura. Historical changes of fishing light and its operation in squid jigging fisheries. *Rep Tokyo Univ. Fish.*, **24**: 189–207 (1988).

Inamura, O. Hotaruika no hanashi. Uozu: Uozu Printing Co. Ltd. (1994).

Instituto de Pesca. Instituto de Pesca/ APTA/ SAA/ SP, www.pesca.sp.gov.br (2013)

Isahaya, T., and T. Takahashi, On one type of squid eggs (No. 5). 1-Spawning box of the spear squid. *Hokusuishi Junpo*, **248**: 7–8 (1934).

Ish, T., E. J. Dick, P. V. Switzer, and M. Mangel. Environment, krill and squid in the Monterey Bay: from fisheries to life histories and back again. *Deep Sea Res. Part II*, **51**: 849–862 (2004).

Ishida, S. Oogata ikatsuri gyogyou no rekishi – Souseiki kara genzai made [A history of large vessel jigging fishery – From the initial stage to present]. Japan Squid Fisheries Association, Tokyo (2008) [in Japanese].

Ishii, M., and M. Murata Some information on the fishery and the ecology of the squid, *Doryteuthis bleekeri* Keferstein, in the Coastal water of the Shiribeshi District in Hokkaido. *Bull. Hokkaido Reg. Fish. Res. Lab.*, **41**: 31–48 (1976).

Ito, K. Studies on migration and causes of stock size fluctuations in the northern Japanese population of spear squid, *Loligo bleekeri*. *Bull. Aomori Pref. Fish. Res. Cent.*, **5**: 11–75 (2007) [in Japanese with English abstract].

Ito, K., T. Yanagimoto, Y. Iwata, H. Munehara, and Y. Sakurai. Genetic population structure of the spear squid *Loligo bleekeri* based on mitochondrial DNA. *Nippon Suisan Gakkaishi*, **72**: 905–910 (2006).

Iwata, Y., H. Munehara, and Y. Sakurai. Dependence of paternity rates on alternative reproductive behaviors in the squid *Loligo bleekeri*. *Mar. Ecol. Prog. Ser.*, **298**: 219–228 (2005).

Izuka, T., S. Segawa, and T. Okutani. Biochemical study of the population heterogeneity and distribution of the oval squid complex in southwestern Japan. *Amer. Malac. Bull.*, **12**: 129–135 (1996).

Izuka, T., S. Segawa, T. Okutani, and K. Numachi. Evidence on the existence of three species in the oval squid *Sepioteuthis lessoniana* complex in Ishigaki Island, Okinawa, southwestern Japan, by isozyme analyses. *Venus*, **53**: 217–228 (1994).

Jackson, G. D. Advances in defining the life histories of myopsid squid. *Mar. Fresh. Res.*, **55**: 357–365 (2004).

Jackson, G. D., and H. Choat. Growth in tropical cephalopods: an analysis based on statolith microstructure. *Can. J. Fish. Aquat. Sci.*, **49**: 218–228 (1992).

Jackson G. D., and M. D. Domeier. The effects of an extraordinary El Niño/La Niña event on the size and growth of the squid *Loligo opalescens* off Southern California. *Mar. Biol.*, **142**: 925–935 (2003).

Jackson, G. D., and J. W. Forsythe. Statolith age validation and growth of *Loligo plei* (Cephalopoda: Loliginidae) in the north-west Gulf of Mexico during spring/ summer. *J. Mar. Biol. Ass. U.K.*, **82** (4): 677–678 (2002).

Jackson, G. D., B. McGrath Steer, S. Wotherspoon, and A. J. Hobday. Variation in age, growth and maturity in the Australian arrow squid *Nototodarus gouldi* over time and space - what is the pattern? *Mar. Ecol. Prog. Ser.*, **264**: 57–71 (2003).

Jackson, G. D., and N. A. Moltschaniwskyj. Spatial and temporal variation in growth rates and maturity in the Indo-Pacific squid

Sepioteuthis lessoniana (Cephalopoda: Loliginidae). *Mar Biol.*, **140**: 747–754 (2002).

Jackson G. D., and G. T. Pecl. The dynamics of the summer spawning population of the loliginid squid *Sepioteuthis australis* in Tasmania, Australia - a conveyor belt of cohorts. *ICES J. Mar. Sci.*, **60**: 290–296 (2003).

Jackson, G. D., S. Wotherspoon, and B. L. McGrath-Steer. Temporal population dynamics in arrow squid *Nototodarus gouldi* in southern Australian waters. *Mar. Biol.*, **146**: 975–983 (2005).

Jacobson, L. Essential fish habitat source document: longfin inshore squid, *Loligo pealeii*, life history and habitat characteristics, Second Edition. *NOAA Tech. Memo. NMFS-NE-193* (2005).

Jantzen, T. M., and J. N. Havenhand. Reproductive behavior in the squid *Sepioteuthis australis* from South Australia: interactions on the spawning grounds. *Biol. Bull.*, **204**: 305–317 (2003).

Japan Large Squid Jigging Boats Association. A history of Japanese large jigging fishery – from founding period to present. Japan Large Squid Jigging Boats Association, 606 pp. Tokyo (2008) [in Japanese].

Jatta, G. I cefalopodi viventi nel Golfo di Napoli. *Fauna Flora Golf Neaples, monogr.* **23** (1986).

Jereb, P., and S. Agnesi. Current state of knowledge on exploited cephalopods in the Italian waters. *Boll. Malacol.*, **45** (Suppl. 2009): 111–116 (2009).

Jereb, P., A. L. Allcock, E. Lefkaditou, U. Piatkowski, L. C. Hastie, and G. J. Pierce (Eds). Cephalopod biology and fisheries in European waters: species accounts. Co-operative Research Report. Copenhagen: International Council for the Exploration of the Sea (In press).

Jereb, P., and S. Ragonese. Sui cefalopodi di scarso o nullo interesse commerciale. *Oebalia*, **16**: 689–692 (1990).

Jereb, P., and S. Ragonese. The association of the squid *Illex coindetii* (Cephalopoda) with target species trawled in the Sicilian Channel. *Bull. Mar. Sci.*, **49**: 664 (Abstract) (1991).

Jereb, P., and S. Ragonese. The Mediterranean teuthofauna: Towards a biogeographical coverage by regional census. II: Strait of Sicily. *Boll. Malacol.* **30**: 161–172 (1994).

Jereb, P., and S. Ragonese. An outline of the biology of the squid *Illex coindetii* in the Sicilian Channel (central Mediterranean). *J. Mar. Biol. Ass. UK*, **75**: 373–390 (1995).

Jereb, P., S. Ragonese, A. Arkhipkin, A. Bonanno, M. Gioiello, M. Di Stefano, U. Morara, and M. Bascone. Sicilian Channel squid stocks: *Loligo forbesii* Steenstrup, 1856. Project MED 93/010, Final Report, 233 pp., 6 App. (1996).

Jereb, P., and C. F. E. Roper. Cephalopods of the Indian Ocean. A Review. Part I. Inshore squids (Loliginidae) collected during the International Indian Ocean Expedition. *Proc. Biol. Soc. Washington*, **119**: 91–136 (2006).

Jereb, P., and C. F. E. Roper (Eds). *Cephalopods of the world. An annotated and illustrated catalogue of cephalopod species known to date*. Volume **2**. Myopsid and Oegopsid Squids. FAO Species Catalogue for Fishery Purposes. No. 4, Vol. 2. Rome, FAO, (2010).

Jereb, P., M. Vecchione, and C. F. E. Roper. Family Loliginidae. **In**: *Cephalopods of the world. An annotated and illustrated catalogue of species known to date. Volume* **2**. *Myopsid and Oegopsid Squids. FAO Species Catalogue for Fishery Purposes. No. 4, Vol. 2*, pp. 38–117 (P. Jereb and C. F. E. Roper, Eds.). Rome, Italy: FAO (2010).

JICA (Japan International Cooperation Agency). Field Report. Study on Formulation of Master Plan on Sustainable Use of Fisheries Resources for Coastal Community Development in the Caribbean. Accessed August 1, 2014. http://www.caricom-fisheries.com/LinkClick.aspx?fileticket=73gHxPuo%2Fh0%3D&tabid=214 (2010).

Jones, J. B. Environmental impact of trawling on the seabed: a review. *New Zeal. J. Mar. Fresh.*, **26**: 59–67 (1992).

Jonsson, E. Study of European flying squid, *Todarodes sagittatus* (Lamarck) occurring in deep waters south of Iceland. ICES Document CM 1998/M: 48. Copenhagen: International Council for the Exploration of the Sea (1998).

Joy, J. B. The fishery biology of *Todarodes sagittatus* in Shetland waters. *Journal of Cephalopod Biology*, **1**: 1–19 (1990).

Juanicó, M. Contribuição ao estudo da biologia dos Cephalopoda Loliginidae do Atlântico Sul Ocidental, entre Rio de Janeiro e Mar del Plata. PhD Thesis, Instituto Oceanográfico, Universidade de São Paulo, São Paulo, Brazil (1972).

Juanicó, M. Developments in South American squid fisheries. *Mar. Fish. Rev.*, July-August 1980: 10–14 (1980).

Juanicó, M. Squid spatial patterns in a two species mixed fisheries off southern Brazil. **In**: *Proceedings of the International Squid Symposium*, pp. 69–79. Boston (1981).

Kahui, V. A. Bioeconomic model for Hooker's sea lion bycatch in New Zealand. *Austral. J. Agr. Resour. Econ.*, **56**: 22–41 (2012).

Kalnay, E., M. Kanamitsu, R. Kistler, and W. Collins. The NCEP/NCAR 40-year reanalysis project. *Bull. Amer. Meteor. Soc.* **77**: 437–471 (1996).

Kaplan, M. B., T. A. Mooney, D. C. McCorckle, and A. C. Cohen. Adverse effects of ocean acidification on early development of squid (*Doryteuthis pealeii*). *PLoS ONE*, **8** (5): e63714 (2013).

Karnicki Z. S., T. Pintowski, and J. Latanowicz. Polish squid industry present state and future. **In**: The first world cephalopod conference (March 13–15 1989, Lisbon, Portugal) p. 80–84. London: AGRA Europe Ltd (1989).

Karpov, K. A., and G. M. Cailliet. Prey composition of the market squid, *Loligo opalescens* Berry, in relation to depth and location of capture, size of squid, and sex of spawning squid. *Calif. Coop. Ocean. Fish. Inv. Rep.*, **20**: 51–57 (1979).

Kasahara, S. Descriptions of offshore squid angling in the Sea of Japan, with special reference to the distribution of common squid (*Todarodes pacificus* Steenstrup); and on the techniques for forecasting fishing conditions. *Bull. Jap. Sea Reg. Fish. Res. Lab.*, **29**: 179–199 (1978).

Kasahara, S. Spear squid fisheries in the Sea of Japan. **In**: Report of the 2004 Meeting on Squid Resources, pp. 110–122 (Japan Sea National Fishery Research Institute (JSNFRI), Eds.). Niigata, Japan, JSNFRI (2004) [in Japanese].

Kashiwada, J., and C. W. Recksiek. Possible morphological indicators of population structure in the market squid, *Loligo opalescens*. *Calif. Dep. Fish. Game Fish. Bull.*, **169**: 99–112 (1978).

Katağan, T., A. Salman, and H. A. Benli. The cephalopod fauna of the Sea of Marmara. *Isr. J. Zool.*, **39**: 255–261 (1993).

Kato, M., and I. Mitani. Comparison of catch CPUE, and sea surface temperature in the fishing ground between good and poor fishing years for the squid jigging fishery target new Zealand southern arrow squid *Nototodarus sloanii* in New Zealand waters. *Bull. Kanagawa Pref. Fish. Res. Inst.*, **6**: 35–45 (2001). [in Japanese]

Katsanevakis, S., E. Lefkaditou, S. Galinou-Mitsoudi, D. Koutsoubas, and A. Zenetos. Molluscan species of minor commercial interest in

Hellenic seas: distribution, exploitation and conservation status. *Mediter. Mar. Sci.*, **9**: 77–118 (2008).

Katsanevakis, S., C. D. Maravelias, V. Vassilopoulou, and J. Haralabous. Boat seines in Greece: landings profiles and identification of potential métiers. *Sci. Mar.*, **74**: 65–76 (2010).

Katugin, O. N. Commander squid *Berryteuthis magister* (Berry, 1913): intraspecific variation, spatial and taxonomic differentiation. Abstract from the Ph. D. Thesis. Institute of Biology and Soils, Far Eastern Branch of the Russian Academy of Sciences, Vladivostok, Russia (1998) [In Russian].

Katugin, O. N. Intraspecific genetic variation and population differentiation of the squid *Berryteuthis magister* in the North Pacific Ocean. *Russian J. Mar. Biol.*, **25**(1): 34–45 (1999).

Katugin, O. N. Patterns of genetic variability and population structure in the North Pacific squids *Ommastrephes bartramii, Todarodes pacificus and Berryteuthis magister*. *Bull. Mar. Sci.* **71**(1): 383–420 (2002).

Katugin, O. N., A. M. Berkutova, and G. E. Gillespie. Morphometric variation in the gladii of the squid *Berryteuthis magister* (Berry, 1913) from different regions of the North Pacific. **In**: *Mollusks of the Northeastern Asia and Northern Pacific: Biodiversity, Ecology, Biogeography and Faunal History, Abstracts of the Conference*. Vladivostok, Russia: 62–66 (2004).

Katugin, O. N., and V. V. Kulik. The analysis of stock fluctuations of the commander squid (*Berryteuthis magister*) near the Kuril Islands using deterministic and stochastic approaches. **In:** *Proceedings of the All–Russian Conference dedicated to the 80th Anniversary of KamchatNIRO*, 176–183 (2012) [In Russian].

Katugin, O. N., and V. V. Kulik Forecasting catch per unit effort for the commander squid (*Berryteuthis magister*) near the Kuril Islands in relation to the Aleutian Low. Tr. VNIRO (in press). [In Russian].

Katugin, O. N., V. V. Kulik, and A. I. Mikhaylov. Validation of statistical significance for the influence of climatic factors on the schoolmaster gonate squid (*Berryteuthis magister*) fishery capacity off the Kuril Islands. *Trudi VNIRO*, **151**: 81–86 (2014) [In Russian with English abstract].

Katugin, O. N., G. A. Shevtsov, M. A. Zuev, V. D. Didenko, V. V. Kulik, and N. S. Vanin. *Berryteuthis magister* (Berry, 1913), schoolmaster gonate squid. **In**: *Advances in Squid Biology, Ecology and Fisheries. Part II – Oegopsid Squids*, pp. 1–48 (R. Rosa, G. Pierce and R. O'Dor, Eds.). Nova Science Publishers (2013).

Kawano, M. Distribution of swordtip squid and its hydrographic condition. *Bull. Jpn. Soc. Fish. Oceanog.*, **51**: 244–249 (1987) [in Japanese].

Kawano, M. Characteristics of swordtip squid caught by offshore trawls. *Report of Seikai Bock Council on bottom fish*, **1**: 37–46 (1991) [in Japanese].

Kawano, M. Study on ecology of *Photololigo edulis* resources in the southwestern Sea of Japan. *Bull. Yamaguchi Pref. Gaikai Fish. Exp. Stn.*, **26**: 1–25 (1997) [in Japanese with English abstract].

Kawano, M. An egg mass of *Photololigo edulis* found in coastal waters off Yamaguchi Prefecture, southwestern Japan Sea. *Bull. Yamaguchi Pref. Fish. Res. Ctr.*, **4**: 69–72 (2006) [in Japanese with English abstract].

Kawano, M. Changes in the distribution and abundance of firefly squid, *Watasenia scintillans*, eggs in the southwestern Japan Sea. *Bull. Yamaguchi Pref. Fish. Res. Ctr.*, **5**: 29–34 (2007).

Kawano, M. Fishing condition of squid angling in waters off Yamaguchi Prefecture in the southwestern Sea of Japan. *Report of Surumeika Shigen Hyoka Kyogikai* : 30–36 (2013) [in Japanese].

Kawano, M., Y. Ogawa, R. Takeda, H. Yamada, and S. Moriwaki. The management of the fisheries resources of *Loligo edulis* in coastal waters of the western Japan Sea. *Report on Cooperative Investigations of "Shiroika", Loligo edulis, inhabiting western Japan Sea*, **2**: 124–133 (1986). [in Japanese with English abstract]

Kawano, M., and H. Saitoh. Characteristic changes in fishery biology and fishing situation of *Photololigo edulis* in coastal waters off Yamaguchi Prefecture, southwestern Sea of Japan in recent years. *Bull. Yamaguchi Pref. Fish. Res. Ctr.*, **2**: 77–85 (2004) [in Japanese with English abstract].

Kawano, M., M. Tashiro, A. Kobayakawa, and S. Akimoto. Swordtip squid in waters off Yamaguchi Prefecture to northwestern Kyushu. *Suisan Gijyutsu and Keiei*, **36**: 18–33 (1990) [in Japanese].

Kawasaki, K., and S. Kakuma. Biology and fishery of *Thysanoteuthis rhombus* in the waters around Okinawa, southwestern Japan. **In**: *Contributed Papers to International Symposium on Large Pelagic Squids*, pp. 183–189 (T. Okutani, Ed.). Tokyo, Japan: Japan Marine Fishery Resources Research Center (1998).

Keyl, F., J. Arguelles, and R. Tafur. Interannual variability in size structure, age, and growth of jumbo squid (*Dosidicus gigas*) assessed by modal progression analysis. *ICES J. Mar. Sci.*, **68**: 507–518 (2011).

Keyl, F., M. Wolff, J. Arguelles, L. Mariategui, R. Tafur, and C. Yamashiro. A hypothesis on range expansion and spatio-temporal shifts in size-at-maturity of jumbo squid (*Dosidicus gigas*) in the Eastern Pacific ocean. *Cal. Coop. Ocean. Fish. Inv. Rep.*, **49**: 119–128 (2008).

Khrueniam, U., and N. Suksamrarn. Status of squid trap fishery in the eastern Gulf of Thailand. *Tech. Pap., Mar. Fish. Res. Dev. Bur., Dept. Fish.* (2012).

Kidokoro, H. Impact of climatic changes on the distribution, migration pattern and stock abundance of the Japanese common squid, *Todarodes pacificus* in the Sea of Japan. *Bull. Fish. Res. Agen.*, **27**: 95–189 (2009).

Kidokoro, H., K. Mori, T. Goto, and T. Kinoshita. Stock assessment and management method for the Japanese common squid in Japan. *Suisankanri Danwakaiho*, **30**: 18–35 (2003).

Kidokoro, H., T. Goto, and R. Matsukura. Stock assessment and evaluation for autumn spawning stock of Japanese common squid (fiscal year 2012). **In**: *Marine fisheries stock assessment and evaluation for Japanese waters (fiscal year 2012)*, pp. 605–635. Tokyo: Fishery Agency and Fisheries Research Agency of Japan (2013).

Kidokoro, H., T. Goto, T. Nagasawa, H. Nishida, T. Akamine, and Y. Sakurai. Impacts of a climate regime shift on the migration of Japanese common squid (*Todarodes pacificus*). *ICES J. Mar. Sci.* **67**: 1314–1322 (2010).

Kinoshita, T. Age and growth of loliginid squid, *Heterololigo bleekeri*. *Bull. Sekai Reg. Fish. Res. Lab.*, **67**: 59–68 (1989) [in Japanese, with English abstract].

Kitahara, T., and N. Hara. An abundance index of immigrants in exploited migratory populations. *Nippon Suisan Gakkaishi*, **56**: 1927–1931 (1990). [in Japanese with English abstract]

Kitaura, J., G. Yamamoto, and M. Nishida. Genetic variation in populations of the diamond-shaped squid *Thysanoteuthis rhombus* as examined by mitochondrial DNA sequence analysis. *Fish. Sci.*, **64**: 538–542 (1998).

Kitazawa, H. Study on the fisheries biology of *Loligo bleekeri* in the southwestern Japan Sea (part 1). *Rep. Shimane Pref. Fish. Exp. Sta.*, **4**: 67–82 (1986) [in Japanese].

Kittivorachate, R. Study on catch and size composition of the economically important invertebrates in the Gulf of Thailand from research vessel "*Pramong 2 and 9*". *Tech. Pap., Invertebr. Sect., Mar. Fish. Div., Dept. Fish.* (1980).

Klett, A. Pesquería de calamar gigante *Dosidicus gigas*. **In**: *Estudio del potencial pesquero y acuícola de Baja California Sur*. (M. Casas-Valdez, and G. Ponce-Díaz, Eds.). Vol. **I**, pp: 127–149 (1996).

Koganezaki, E. Foreign fishing fleets for neon flying squid and the states in the North Pacific. Heisei 12 nendo ikarui shigen kenkyuu kaigi houkoku [Report of the 2000 Meeting on Squid Resources]. National Research Institute of Far Seas Fisheries, Shimizu, pp. 88–91 (2002) [in Japanese].

Kolator, D. J., and D. P. Long. The foreign squid fishery off the northeast United States coast. *Mar. Fish. Rev.*, **41** (7): 1–15 (1979).

Kongprom, A., N. Kulanujaree, U. Augsornpa-ob, and K. Thongsila. Stock assessment of mitre squid (*Photololigo chinensis*) and Indian squid (*P. duvaucelii*) in the Gulf of Thailand. *Tech. Pap., Mar. Fish. Res. Dev. Bur., Dept. Fish.* (2010).

Koslow, J. A., and C. Allen. The influence of the ocean environemtn on the abundance of market squid, *Doryteuthis* (*Loligo*) *opalescens*, paralarvae in the Southern California bight. *Calif. Coop. Ocean. Fish. Inv. Rep.*, **52**: 205–213 (2011).

Krebs, C. J. Ecological methodology, 2nd edition. Benjamin Cummins, Menlo Park, 624 pp (1999).

Krstulović Šifner, S., E. Lefkaditou, N. Ungaro, L. Ceriola, K. Osmani, S. Kavadas, and N. Vrgoč, Composition and distribution of the cephalopod fauna in the eastern Adriatic and eastern Ionian Sea. *Isr. J. Zool.*, **51**: 315–330 (2005).

Krstulović Šifner, S., M. Peharda, N. Vrgoč, I. Isajlović, V. Dadić, and M. Petrić. Biodiversity and distribution of cephalopods caught by trawling along the northern and central Adriatic Sea. *Cah. Biol. Mar.*, **52**: 291–302 (2011).

Krstulović Šifner, S., and N. Vrgoč. Population structure, maturation and reproduction of the European squid, *Loligo vulgaris*, in the central Adriatic Sea. *Fish. Res.*, **69**: 239–249 (2004).

Kubodera, T. Ecological studies of pelagic squids in the Subarctic Pacific region. D. Fish. Sci. Thesis. Hokkaido Univ., Hakodate, Japan (1982) [In Japanese].

Kuroiwa, M. Explorations of the Jumbo squid, *Dosidicus gigas*. Resources in the Southeastern Pacific Ocean with notes on the history of jigging surveys by the Japan Marine Fishery Resources Center, pp. 89–105. **In**: Contributed papers to international symposium on large pelagic squid (T. Okutani Ed.). Japan Marine Fishery Resources Research Center, Tokyo. (1998).

Kurosaka, K., T. Yanagimoto, T. Wakabayashi, Y. Shigenobu, Y. Ochi, and H. Inada, Population genetic structure of the neon flying squid *Ommastrephes bartramii* inferred from mitochondrial DNA sequence analysis. *Nippon Suisan Gakkaishi*, **78**: 212–219 (2012) [in Japanese].

Lamarck, J.-B. Histoire Naturelle des Animaux sans Vertebres. . .Vol. **1–7**. Paris (1815–1822).

Lange, A. M. T. Historical trends and current status of the squid fisheries off the Northeastern United States. **In**: *Proceedings of the workshop on the squid Illex illecebrosus*. (N. Balch, T. Amaratunga, and R. K. O'Dor, Eds.). Halifax, Nova Scotia: Dalhousie University (1978).

Lange, A. M. T., and M. Sissenwine. Biological considerations relevant to the management of squid *Loligo pealeii* and *Illex illecebrosus* of the Northwest Atlantic. *Mar. Fish. Rev.*, **42**: 23–38 (1980).

Lange, A. M. T., and M. Sissenwine. Squid resources of the Northwest Atlantic. **In**: *Advances in assessment of world cephalopod resources*, pp. 21–54. (J. F. Caddy, Ed.). FAO Fisheries Tech. Paper No. **231**. Rome, Italy (1983).

Lange, A. M. T., and G. Waring. Fishery interactions between long-finned squid (*Loligo pealei*) and butterfish (*Peprilus triacanthus*) off the northeast USA. *J. Northw. Atl. Fish. Sci.*, **12**: 49–62 (1992).

Lapko, V. V., M. A. Stepanenko, G. M. Gavrilov, V. V. Napazakov, A. M. Slabinskyi, O. N. Katugin, and M. M. Raklistova. Composition and biomass of nekton in near–bottom layers in the northwestern Bering Sea in autumn 1998. *Izvestiya TINRO (TINRO Proceedings)* **126**: 145–154 (1999) [In Russian, English summary].

Laptikhovsky, V. V. Diurnal vertical migrations of squid *Todarodes angolensis* Adam (Cephalopoda, Ommastrephidae) off Namibia. *Okeanologiya*, **29**: 836–839 (1989) [In Russian].

Laptikhovsky, V., J. Pompert, and P. Brickle. Fishery discards, management and environmental impact in Falkland Islands fisheries. *ICES CM 2006/ K* (2006).

Laptikhovsky, V. V., A. Salman, B. Önsoy, and T. Katağan, T. Systematic position and reproduction of squid of the genus *Alloteuthis* (Cephalopoda: Loliginidae) in the eastern Mediterranean. *J. Mar. Biol. Ass. UK*, **82**: 983–985 (2002).

Larcombe, J., and G. Begg. Fisheries Status Reports 2007 - Status of fish stocks managed by the Australian Government. *Australian Government Department of Agriculture, Fisheries and Forestry, Bureau of Rural Sciences* (2008).

Larkin, P. A. Concepts and issues in marine ecosystem management. *Rev. Fish Biol. Fisher.*, **6**: 139–164 (1996).

Lefkaditou, E. Review of Cephalopod fauna in Hellenic waters. **In**: State of Hellenic Fisheries, pp. 62–69. Ed. by C. Papaconstantinou, A. Zenetos, V. Vassilopoulou, and G. Tserpes. Athens. HCMR Publications. 466 pp (2007).

Lefkaditou, E., and A. Adamidou. Beach-seine fisheries in the Thracian Sea. Preliminary results. In: Proceedings of the 5th Pan-Hellenic Symposium of Oceanography and Fisheries, Kavala, Greece, 15–18 April 1997, Vol. **II**, pp. 21–24 (1997) [in Greek, abstract in English].

Lefkaditou, E., N. Bailey, I. Bruno, A. Guerra, L. C. Hastie, P. Jereb, N. Koueta, J. Pereira, G. J. Pierce, J.-P. Robin, P. Sánchez, I. Sobrino, R. Villanueva, and I. G. Young. European cephalopod fisheries and aquaculture. **In**: Cephalopod biology and fisheries in Europe, pp. 43–70 (G. J. Pierce, L. Allcock, I. Bruno, P. Bustamante, Á. González, Á. Guerra, P. Jereb, et al., Eds.) *ICES Coop. Res. Rep.*, 303. 175 pp. (2010).

Lefkaditou, E., C. Mitilineou, P. Maiorano, and G. D'Onghia. Cephalopod species captured by deep-water exploratory trawling in the eastern Ionian Sea. *J. Northw. Atl. Fish. Sci.*, **31**: 431–440 (2003a).

Lefkaditou, E., P. Peristeraki, P. Bekas, G. Tserpes, C.-Y. Politou, and G. Petrakis. Cephalopod distribution in the southern Aegean Sea. *Medit. Mar. Sci.*, **4**: 79–86 (2003b).

Lefkaditou, E., P. Sanchez, A. Tsangidis, and A. Adamidou. A preliminary investigation on how meteorological changes may affect beach-seine catches of *Loligo vulgaris* in the Thracian Sea (Eastern Mediterranean). *S. Afr. J. Marine Sci.*, **20**: 453–461 (1998).

Lefkaditou, E., C. S. Tsigenopoulos, C. Alidromiti, and J. Haralabous. On the occurrence of *Alloteuthis subulata* in the eastern Ionian Sea and its distinction from the sympatric *Alloteuthis media*. *J. Biol. Res., Thessaloniki*, **17**: 169–175 (2012).

Leiva, B., D. Oliva, and R. Bahamondes. Pesca de Investigación de Calamar en el Mar territorial y Zona Económica Exclusiva de las Islas Oceánicas de Chile. Instituto de Fomento Pesquero, Chile. 55 pp. (1993).

Lelli, S., A. Belluscio, P. Carpentieri, and F. Colloca. Ecologia trofica di *Illex coindetii* e *Todaropsis eblanae* (Cephalopoda: Ommastrephidae) nel Mar Tirreno centrale. *Biol. Mar. Mediter.*, **12**: 531–534 (2005).

Leos, R. R. The biological characteristics of the Monterey Bay squid catch and the effect of a two-day-per-week fishing closure. *Calif. Coop. Ocean. Fish. Inv. Rep.*, **39**: 204–211 (1998).

Leta, H. R. Descripción de los huevos, larvas y juveniles de *Illex argentinus* (Ommastrephidae) y juveniles de *Loligo brasiliensis* (Loliginidae) en la zona comun de pesca Argentino-Urugauya. *Publ. Cient. INAPE*, **1**: 1–8 (1987).

Li, J. Z., P. M. Chen, X. P. Jia, and S. H. Xu. Resource status and conservation Strategy of *Loligo edulis* Hoyle in the northern South China Sea. *J. Fish. Sci. Chin.*, **17**: 1309–1318 (2010).

Li, Y., and D. R. Sun. Biological Characteristics and stock changes of *Loligo chinensis* Gray in Beibu Gulf, South China Sea. *Hubei Agric. Sci.*, **50**: 2716–2735 (2011).

Liao, C. H., M. A. Lee, Y. C. Lan, and K. T. Lee. The temporal and spatial change in position of squid fishing ground in relation to oceanic features in the northeastern waters of Taiwan. *J. Fish. Soc. Taiwan*, **33**: 99–113 (2006).

Link, J. S. Ecological considerations in fisheries management: when does it matter? *Fisheries*, **27**: 10–17 (2002).

Link, J. S. *Ecosystem-based fisheries management: confronting tradeoffs*. Cambridge Univ. Press, Cambridge (2010).

Lipinski, M. R. Food, and feeding of *Loligo vulgaris reynaudii* from St Francis Bay, South Africa. *S. Afr. J. mar. Sci.*, **5**: 557–564 (1987).

Lipinski, M. R. Cephalopods and the Benguela ecosystem: trophic relationships and impact. **In**: *Benguela Trophic Functioning*, pp. 791–802 (A. I. L. Payne, K. H. Brink, K. H. Mann and R. Hilborn, Eds). *S. Afr. J. mar. Sci.*, **12** (1992).

Lipiński, M. R., and S. Jackson, S. Surface-feeding on cephalopods by procellariiform seabirds in the Benguela region, South Africa. *J. Zool., Lond.*, **218**: 549–563 (1989).

Lipinski, M. R., M. A. C. Roeleveld, and L. G. Underhill. Comparison of the statoliths of *Todaropsis eblanae* and *Todarodes angolensis* (Cephalopoda: Ommastrephidae) in South African waters. **In**: *Recent Advances in Cephalopod Fisheries Biology*, pp 263–273 (T. Okutani, R. K. O'Dor and T. Kubodera, Eds). Tokyo: Tokai University Press (1993).

Lipinski, M. R., and M. A. Soule. A new direct method of stock assessment of the loliginid squid. *Rev. Fish Biol. Fish.*, **17**: 437–453 (2007).

Liu, B., X. Chen, X. Chen, S. Tian, J. Li, Z. Fang, and M. Yang. Age, maturation, and population structure of the Humboldt squid *Dosidicus gigas* off the Peruvian Exclusive Economic Zones. *Chinese J. Oceanol. Limnol.*, **31**: 81–91 (2013).

Liu, B. L., X. J. Chen, H. J. Lu, Y. Chen, and W. G. Qian. Fishery biology of the jumbo flying squid *Dosidicus gigas* off the Exclusive Economic Zone of Chilean waters. *Sci. Mar.*, **74**: 687–695 (2010).

Lleonart J., J. Lloret, S. Touzeau, J. Salat, L. Recasens, F. Sardà (J. M. Fromentin, D. Levi, K. I. Stergiou, and S. Tudela Revisors). Mediterranean fisheries, an overview, II SAP meeting, Barcelona, 13–17/10/98 (1998).

Lloret, J., and J. Lleonart. Recruitment dynamics of eight fishery species in the northwestern Mediterranean Sea. *Sci. Mar.*, **66**(1): 77–82 (2002).

Lo Bianco, S. Notizie biologiche riguardanti specialmente il periodo di maturità sessuale degli animali del Golfo di Napoli. *Mittheilungen aus der Zoologischen Station zu Neapel*, **19**: 513–761 (1909).

Loder, J. W., B. Petrie, and G. Gawarkiewicz. The coastal ocean off northwestern North America: a large-scale view. **In**: *The Sea*, Vol 11: *The Global Coastal Ocean: Regional Studies and Syntheses*, pp. 105–133 (A. R. Robinson and K. H. Brink, Eds). New York: John Wiley and Sons (1998).

Løkkeberg, S. Impacts of trawling and scallop dredging on benthic communities. *FAO Fish. Tech. Pap.* No. 472 (2005).

Lordan, C., and J. Casey. The first evidence of offshore spawning in the squid species Loligo forbesi. *J. Mar. Biol. Assoc. U.K.*, **79**: 379–381 (1999).

Lordan, C., M. A. Collins, L. N. Key, and E. D. Browne. The biology of the ommastrephid squid, *Todarodes sagittatus*, in the north-east Atlantic. *J. Mar. Biol. Assoc. U.K.*, **81**: 299–306 (2001b).

Lowry, M. S., and J. V. Carretta. Market squid (*Loligo opalescens*) in the diet of the California sea lions (Zalophus californianus) in souther California (1981–1995). *Calif. Coop. Ocean. Fish. Inv. Rep.*, **40**: 196–207 (1999).

Lumare, F. Nota sulla distribuzione di alcuni cefalopodi del mar Tirreno. *Boll. Pesca, Piscic. Idrobiol.*, **25**: 313–344 (1970).

Lum-Kong, A., G. J. Pierce, and C. Yau. Timing of spawning and recruitment in *Loligo forbesi* Steenstrup (Cephalopoda: Loliginidae) in Scottish waters. *J. Mar. Biol. Assoc. U.K.*, **72**: 301–311 (1992).

Lyle, J., C. Green, K. Rowling, and M. Steer. Southern calamari Sepioteuthis australis. **In**: *Status of key Australian fish stocks reports 2012*, pp. 109–113 (M. Flood, I. Stobutzki, J. Andrews, G. Begg, W. Fletcher, C. Gardner, J. Kemp, A. Moore, A. O'brien, R. Quinn, J. Roach, K. Rowling, K. Sainsbury, T. Saunders, T. Ward and M. Winning, Eds.). Canberra, Australia: Fisheries Research and Development Corporation (2012).

Macewicz, B. J., J. R. Hunter, N. C. H. Lo, and E. L. LaCasella. Fecundity, egg deposition, and mortality of market squid (*Loligo opalescens*). *Fish. Bull.*, **102**: 306–327 (2004).

Machias, A., V. Vassilopoulou, D. Vatsos, P. Bekas, A. Kallianiotis, C. Papaconstantinou, and N. Tsimenides. Bottom trawl discards in the northeastern Mediterranean Sea. *Fish. Res.*, **53**: 181–195 (2001).

Machida, S. Report of the squid survey by the FV Hoyo Maru No.67 in south eastern Australian waters 1979/80. *Japan Marine Fishery Resource Center, JAMARC*, **22**: 1–43 (1979).

Macy, W. K., and J. K. T. Brodziak. Seasonal maturity and size at age of *Loligo pealeii* in waters of southern New England. *ICES J. Mar. Sci.*, **58**(4): 852–864 (2001).

Macy, W. K. The application of digital image processing to the aging of long-finned squid, *Loligo pealei*, using the statolith. **In**: *Recent developments in fish otolith research*, p. 283–302 (D. H. Secor, J.

M. Dean, and S. E. Campana, Eds.), Columbia, S. C: University of South Carolina Press (1995).

Malyshev, A. A., and P. P. Railko. Oceanologic features associated with formation of commander squid aggregations near the Simushir Island. *Abstracts of Communications on Commercial Invertebrates*. Moscow, VNIRO: 153–159 (1986). [In Russian].

Mangold-Wirz, K. Biologie des Céphalopodes benthiques et nectoniques de la Mer Catalane. *Vie et Milieu*, Suppl. **13**. 285 pp. (1963).

Mangold, K., and S. v. Boletzky. Céphalopodes. **In**: Fiches FAO d'identification des espèces pour les besoins de la pêche (Révision 1). Méditerranée et mer Noire. Zone de pêche 37, Volume 1, Végétaux et Invertébrés, pp. 633–714. Ed. by W. Fischer, M.-L. Bauchot, and M. Schneider. 760 pp. (1987).

Mannini, P., and C. Volpi. Nota sulla presenza e distribuzione di alcuni cefalopodi del Tirreno Settentrionale. *Oebalia*, **15**: 693–701 (1989).

Maragliano, M., and M. T. Spedicato. Osservazioni sulla riproduzione e l'accrescimento di *Illex coindetii* (Cephalopoda: Teuthoidea) nel Tirreno meridionale. *Biol. Mar., Suppl. Notiz. SIBM*, **1**: 299–300 (1993).

Margalef, R. El Mediterráneo occidental. Omega Edit., Barcelona, 374 pp. (1989).

Mariátegui, L. Pesquería sostenible del calamar gigante *Dosidicus gigas* (Orbigny, 1835) en el mar peruano. Tesis para optar el Grado Académico de Doctor en Medio Ambiente y Desarrollo Sostenible, Univ. Nac. Federico Villarreal, Lima-Perú, p. 195 (2009).

Mariátegui, L., R. Tafur, O. Morón, and P. Ayon. Distribución y captura del calamar gigante *Dosidicus gigas* a bordo de buques calamareros en aguas del Pacífico Centro Oriental y en aguas nacionales y adyacentes. *Inf. Progr. Inst. Mar Perú*, **63**: 3–36 (1997).

Mariátegui, L., and A. Taipe. Distribución y abundancia relativa del calamar gigante (*Dosidicus gigas*) en el Perú. Informe Progresivo Inst. *Mar Perú*, **34**: 3–27 (1996).

Marinovic, B. B., D. A. Croll, N. Gong, S. R. Benson, and F. P. Chavez. Effects of the 1997–1999 El Nino and La Nina events on zooplankton abundance and euphausiids community composition within the Monterey Bay coastal upwelling system. *Progr. Oceanogr.*, **54**: 265–277 (2002).

Markaida, U. Food and feeding of jumbo squid *Dosidicus gigas* in the GC and adjacent waters after the 1997–98 El Niño event. *Fish. Res.*, **79**: 16–27 (2006).

Markaida, U., J. J. C. Rosenthal, and W. F. Gilly. Tagging studies on the jumbo squid (*Dosidicus gigas*) in the Gulf of California, Mexico. *Fish. Bull.*, **103**: 219–226 (2005).

Martínez, P., M. Perez-Losada, A. Guerra, and A. Sanjuan. First genetic validation and diagnosis of the short-finned squid species of the genus *Illex* (Cephalopoda: Ommastrephidae). *Mar. Biol.*, **148**: 97–108 (2005a).

Martínez, P., P. Belcari, A. Sanjuan, and Á. Guerra. Allozyme analysis of geographical and seasonal variation of *Illex coindetii* (Cephalopoda: Ommastrephidae) from central Mediterranean and Iberian Atlantic. *J. Mar. Biol. Assoc. U.K.*, **85**: 177–184 (2005b).

Martins, H. R. Biological studies of the exploited stock of *Loligo forbesi* (Cephalopoda) in the Azores. *J. Mar. Biol. Assoc. U.K.*, **62**: 799–808 (1982).

Martins, M. C. Biology of pre-and post-hatching stages of *Loligo vulgaris* Lamarck, 1798 and *Loligo forbesi* Steenstrup, 1856 (Mollusca, Cephalopoda). PhD thesis. Aberdeen: University of Aberdeen (1997).

Martins, R. S., R. de Camargo, and M. A. Gasalla. The São Paulo shelf (SE Brazil) as a nursery ground for *Doryteuthis plei* (Blainville, 1823) (Cephalopoda, Loliginidae) paralarvae: a Lagrangian particle-tracking Individual-Based Model approach. *Hydrobiologia*, **725**: 57–68 (2014).

Martins, R. S., and J. A. A. Perez. Artisanal fish-trap fishery around Santa Catarina Island. During spring/summer: characteristics, species interactions and the influence of the winds on the catches. *B. Inst. Pesca, São Paulo*, **34**: 413–423 (2008).

Martins, R. S., and J. A. A. Perez. The ecology of Loliginid squid in shallow waters around Santa Catarina Island, Southern Brazil. *Bull. Mar. Sci.*, **80**: 125–146 (2007).

Martins, R. S., J. A. A. Perez, and C. A. F. Schetini. The squid *Loligo plei* around Santa Catarina Island, Southern Brazil: Ecology and Interactions with Coastal Oceanographic environment. *J. Coast. Res.*, **38**: 1285–1290 (2004).

Martins, R. S., and J. A. A. Perez. Occurrence of Loliginid paralarvae around Santa Catarina Island, Southern Brazil. Pan-Am. *J. Aquat. Sci.*, **1**: 24–27 (2006).

Massutí, E., and O. Reñones. Demersal resource assemblages in the trawl fishing grounds off the Balearic Islands (western Mediterranean). *Sci. Mar.*, **69**: 167–181 (2005).

Matsuura, Y. Exploração pesqueira. **In**: *Os ecossistemas brasileiros e os principais macrovetores de desenvolvimento: subsídios ao planejamento da gestão ambiental*. *Programa nacional do meio ambiente, Brasília*, pp. 77–89. Brasília, Brazil: Ministério do Meio Ambiente, dos Recursos Hídricos e da Amazônia Legal (1995).

May, R. M., J. R. Beddington, C. W. Clark, S. J. Holt, and R. M. Laws. *Science*, **205** (4403): 267–277 (1979).

McCoy, F. Prodromus of the zoology of Victoria, or figures and descriptions of the living species of all classes of 1888 the Victorian indigenous animals. *Decade*, **17**: 255–257 (1888).

McGrath Steer, B. L., and G. D. Jackson. Temporal shifts in the allocation of energy in the arrow squid, *Nototodarus gouldi*: Sex-specific responses. *Mar. Biol.*, **144**: 1141–1149 (2004).

McGrath, B. L., and G. D. Jackson. Egg production in the arrow squid *Nototodarus gouldi* (Cephalopoda: Ommastrephidae), fast and furious or slow and steady? *Mar. Biol.*, **141**: 699–706 (2002).

McKinna, D., C. Wall, R. Brown, K. Lonie, and J. M. Improving efficiency of Southern Squid Jig Fisheries. *Fisheries Research and Development Corporation*. (2011).

McMahon, J. J., and W. C. Summers. Temperature effects on the developmental rate of squid (*Loligo pealei*) embryos. *Biol. Bull., (Woods Hole)*, **141**: 561–567 (1971).

Medeiros, R. P., M. Polette, S. C. Vizinho, C. X. Macedo, and J. C. Borges. Diagnóstico sócio-econômico e cultural nas comunidades pesqueiras artesanais do litoral centro-norte do estado de Santa Catarina. *Not. Téc. FACIMAR*, **1**: 33–42 (1997).

Medeiros, R. P. Estratégias de pesca e usos dos recursos em uma comunidade de pescadores artesanais da praia do Pântano do Sul (Florianópolis, SC). MSc. Thesis, Universidade Estadual de Campinas, Campinas, Brazil (2001).

Meiyappan, M. M., and K. S. Mohamed. Cephalopods. **In**: *Status of Exploited Marine Fishery Resources of India*, pp. 221–227 (M. Mohan Joseph and A. A. Jayaprakash, Eds.) CMFRI, Cochin (2003).

Meiyappan, M. M., K. S. Mohamed, K. Vidyasagar, K. P. Nair, N. Ramachandran, A. P. Lipton, G. S. Rao, V. Kripa, K. K. Joshi, E. M. Abdussamad, R. Sarvesan, and G. P. K. Achari. A review on cephalopod resources, biology and stock assessment in Indian seas. **In**: *Marine Fisheries Research and Management*, pp 546–562 (V. N. Pillai and N. G. Menon, Eds.). Kochi, CMFRI (2000).

Meiyappan, M. M., M. Srinath, K. P. Nair, K. S. Rao, R. Sarvesan, G. S. Rao, K. S. Mohamed, K. Vidyasagar, K. S. Sundaram, A. P. Lipton, P. Natarajan, G. Radhakrishnan, K. A. Narasimham, K. Balan, V. Kripa, and T. V. Sathianandan. Stock assessment of the Indian squid *Loligo duvauceli* Orbigny. *Indian J. Fish.*, **40**: 74–84 (1993).

Melo, Y. C., and W. H. H. Sauer. Determining the daily spawning cycle of the chokka squid *Loligo vulgaris reynaudii* off the South African Coast. *Rev. Fish Biol. Fish.*, **17**: 247–257 (2007).

Mercer, M. C. Distribution and biological characteristics of the ommastrephid squid *Illex illecebrosus* (LeSueur) on the Grand Bank, St. Pierre Bank and Nova Scotian Shelf (Subareas 3 and 4) as determined by otter-trawl surveys 1970 to 1972. *Int. Comm. N. W. Atl. Fish. Res. Doc. 73/79. Ser. No. 3031* (1973a).

Mercer, M. C. Nominal catch of squid in Canadian Atlantic waters Subareas 2–4, 1920–1968. *Int. Comm. N.W. Atl. Fish. Res. Doc. 73/73* (1973c).

Mercer, M. C. Sexual maturity and sex ratios of the ommastrephid squid *Illex illecebrosus* (LeSueur) at Newfoundland (Subarea 3). *Int. Comm. N.W. Atl. Fish. Res. Doc. 73/71. Ser. No. 3023* (1973b).

Mhitu, H. A., Y. D. Mgaya, and M. A. K. Ngoile. Growth and reproduction of the big fin squid, *Sepioteuthis lessoniana*, in the coastal waters of Zanzibar. Marine science development in Tanzania and Eastern Africa, Zanzibar, Tanzania, **1**, 289–300 (2001).

Mikami, T. Labor-saving, automatization and optimization on board work. **In**: *Surumeika no sekai – Shigenm, gyogyou, riyou* [World of Japanese common squid – Resource, fisheries and utilization], (T. Arimoto and H. Inada, Eds.). Tokyo: Seizando Shoten. (2003) [in Japanese].

Miki, K. Development of squid jigging fisheries and squid processing industry. **In**: *Surumeika no sekai (World of Japanese common squid)*. pp. 1–91 (T. Arimoto and H. Inada, Eds.). Tokyo: Seizando Shoten. (2003) [in Japanese].

Miki, K., and M. Sakai. Amerikaooakaika no ryutu – Peru wo cyuushin ni shite. [Marketing of jumbo flying squid *Dosidicus gigas* – In case of Peru]. [Report of the 2007 Meeting on Squid Resources]. Hokkaido National Fish. Res. Inst. pp. 1–12 (2008) [in Japanese].

Miki, K., and T. Wakabayashi. Shigen riyou kouzou [Utilization structure of *Dosidicus gigas* stock], **In**: *Amerika-ooakaika no riyou kakudai ni kannsuru teiann [A proposal for expansion of the utilization]*. pp. 39–42 (M. Sakai, T. Wakabayashi and N. Hamaji, Eds.), Fish. Res. Agency (2010).

Miki, K., M. Sakai, and T. Wakabayashi. Mexico to Chile niokeru amerikaooakaika no kakou ryutu [Processing and Distribution of Jumbo Flying Squid in Mexico and Chile]. Report of the 2010 Meeting on Squid Resources. Japan Sea National Fish. Res. Inst., pp. 57–64 (2010) [in Japanese].

Miyahara, K., N. Hirose, G. Onitsuka, and S. Gorie. Catch distribution of diamond squid (*Thysanoteuthis rhombus*) off Hyogo Prefecture in the western Sea of Japan and its relationship with seawater temperature, *Bull. Jap. Soc. Fish. Oceanogr.*, **71**: 106–111 (2007a).

Miyahara, K., K. Fukui, T. Ota, and T. Minami. Laboratory observations on the early life stages of the diamond squid *Thysanoteuthis rhombus*. *J. Mollus Stud.*, **72**: 199–205 (2006b).

Miyahara, K., K. Fukui, T. Nagahama, and T. Ohtani. First record of planktonic egg masses of the diamond squid, *Thysanoteuthis rhombus* Troschel, in the Sea of Japan. *Plankton Benthos Res.*, **1**: 59–63 (2006a).

Miyahara, K., T. Ota, J. Hatayama, Y. Mitsunaga, T. Goto, and G. Onitsuka. Tagging studies on the diamond squid (*Thysanoteuthis rhombus*) in the western Sea of Japan, *Bull. Jap. Soc. Fish. Oceanogr.*, **72**: 30–36 (2008).

Miyahara, K., T. Ota, N. Kohno, Y. Ueta, and J. R. Bower. Catch fluctuations of the diamond squid *Thysanoteuthis rhombus* in the Sea of Japan and models to forecast CPUE based on analysis of environmental factors. *Fish. Res.*, **72**: 71–79 (2005).

Miyahara, K., T. Ota, S. Gorie, and T. Goto. The diamond-squid stock in the Sea of Japan: its status and effective utilization. **In**: *Heisei 18 nendo ikarui shigen kenkyuu kaigi houkoku* [*Report of the 2006 Meeting on Squid Resources*], pp. 119–121. Niigata, Japan: Japan Sea National Fisheries Research Institute (2007b).

Miyahara, K., T. Ota, T. Goto, and S. Gorie. Age, growth and hatching season of the diamond squid *Thysanoteuthis rhombus* estimated from statolith analysis and catch data in the western Sea of Japan. *Fish. Res.*, **80**: 211–220 (2006c).

Mohamed, K. S. Estimates of growth, mortality and stock of the Indian squid *Loligo duvauceli* orbigny, exploited off Mangalore Southwest coast of India. *B. Mar. Sci.*, **58**: 393–403 (1996).

Mohamed, K. S., and G. S. Rao. Seasonal growth, stock-recruitment relationship and predictive yield of the Indian squid *Loligo duvauceli* (Orbigny) exploited off Karnataka coast. *Indian J. Fish.*, **44**: 319–329 (1997).

Mohamed, K. S., G. Sasikumar, K. P. S. Koya, V. Venkatesan, V. Kripa, R. Durgekar, M. Joseph, P. S. Alloycious, R. Mani, and D. Vijay. Know… The Master of the Arabian Sea - Purple-Back Flying *Squid Sthenoteuthis* oualaniensis. NAIP Booklet. Project Report. CMFRI, COCHIN, Cochin (2011).

Mohamed, K. S., M. Joseph, and P. S. Alloycious. Population characteristics and some aspects of the biology of oceanic squid *Sthenoteuthis oualaniensis* (Lesson, 1830). J. Mar. Biol. Assoc. India, **48**: 256–259 (2006).

Mohan, J. Studies on some aspects of landings utilization and export of commercially important Cephalopods. PhD Thesis, Cochin University of Science and Technology, Kochi, India (2007).

Moltschaniwskyj, N. A., and G. T. Pecl. Small-scale spatial and temporal patterns of egg production by the temperate loliginid squid *Sepioteuthis australis*. *Mar. Biol.*, **142**: 509–516 (2003).

Moltschaniwskyj, N., G. Pecl, and J. Lyle. An assessment of the use of short-term closures to protect spawning southern calamary aggregations from fishing pressure in Tasmania, Australia. *Bull. Mar. Sci.*, **71**: 501–514 (2002).

Moltschaniwskyj, N., G. Pecl, J. Lyle, M. Haddon, and M. Steer. Population dynamics and reproductive ecology of the southern calamary (*Sepioteuthis australis*) in Tasmania. *Tasmanian Aquaculture and Fisheries Institute* (2003).

Moltschaniwskyj, N. A., and M. A. Steer. Spatial and seasonal variation in reproductive characteristics and spawning of southern calamary (*Sepioteuthis australis*): Spreading the mortality risk. *ICES J. Mar. Sci.*, **61**: 921–927 (2004).

Morales, E. Cefalopodos de Cataluna. *I. Invest. Pesq.*, **11**: 3–32 (1958).

Morales-Nin, B., J. Moranta, C. García, M. P. Tugores, A. M. Grau, F. Riera, and M. Cerdà. The recreational fishery off Majorca Island (western Mediterranean): some implications for coastal resource management. *ICES J. Mar. Sci.*, **62**: 727–739 (2005).

Moreno, A. *Alloteuthis spp*. (Cephalopoda: Loliginidae), um recurso natural subexplorado. Aspectos da sua biologia. Diploma thesis. Lisbon: University of Lisbon (1990).

Moreno, A. Aspectos da biologia de *Alloteuthis subulata* e distribução de *Alloteuthis* spp. Relatorios Cientificos e Técnicos do Instituto Português de Investigação Marítima, **8**. Lisbon: Instituto Português de Investigação Marítima (1995).

Moreno, A., M. Azevedo, J. M. F. Pereira, and G. J. Pierce. Growth strategies in the European squid *Loligo vulgaris* from Portuguese waters. *Mar. Biol. Res.*, **3**: 49–59 (2007).

Mori, J., Geographical differences between the parasites' infection levels of the neon flying squid (*Ommastrephes bartrami*) from the North Pacific Ocean (Abstract). Heisei 7 nendo ikarui shigen kenkyuu kaigi houkoku [Report of the 1995 Meeting on Squid Resources]. Contributions to the Fisheries Researches in the Japan Sea Block, No. 36. Japan Sea National Fisheries Research Institute, Niigata, pp. 85–86 (1997) [in Japanese].

Moriwaki, S. Annual fluctuations of areas of distribution of *Loligo edulis* in the western Japan Sea. *Report on Cooperative Investigations of "Shiroika", Loligo edulis, inhabiting western Japan Sea*, (2): 12–187 (1986) [in Japanese with English abstract].

Moriwaki, S., and Y. Ogawa. Influences of pelagic fishes as prey on the formation of fishing grounds and aatch fluctuations of *Loligo edulis*. *Jpn. Soc. Fish. Oceanog.*, **50**: 114–120 (1986) [in Japanese with English abstract].

Moustahfid, H., M. C. Tyrrell, and J. S. Link. Accounting explicitly for predation mortality in surplus production models: an approach to longfin inshore squid (*Loligo pealeii*). *North Amer. J. Fish. Manage.*, **29**: 1555–1566 (2009a).

Moustahfid, H., W. J. Overholtz, J. S. Link, and M. C. Tyrrell. The advantage of explicitly incorporating predation mortality into age-structured stock assessment models: an application for Northwest Atlantic mackerel. *ICES J. Mar. Sci.*, **66**: 445–454 (2009b).

Munekiyo, M., and M. Kawagishi. Diurnal behaviors of the oval squid, *Sepioteuthis lessoniana* and fishing strategy of a small-sized set net (Preliminary report). **In**: Recent Advances in Cephalopod Fisheries Biology, pp. 283–291 (T. Okutani, R. K. O'dor, and T. Kubodera, Eds.). Tokyo, Japan: Tokai University Press (1993).

Munprasit, A. Squid fishing by luring light. *SEAFDEC Pap, Mar. Fish. Seminar, Dept. Fish.* (1984).

Murata, M. Population assessment, management and fishery forecasting for the Japanese common squid, Todarodes pacificus. **In**: *Marine Invertebrate Fisheries: their Assessment and Management*, pp. 613–636 (J. F. Caddy, Ed.). New York: John Wiley (1989).

Murata, M. Oceanographic environment and distribution and migration of neon flying squid in driftnet ground in the North Pacific. *Japan Sea Block Exp. Res.* **17**: 144–148 (1990) [in Japanese].

Murata, M. Oceanic resources of squids. *Mar. Behav. Physiol.*, **18**: 19–71 (1990).

Murata, M., T. Ishii, and H. Araya. The distribution of the oceanic squids, *Ommastrephes bartramii* (Lesueur), *Onychoteuthis borealijaponicus* Okada, *Gonatopsis borealis* Sasaki and *Todarodes pacificus* Steenstrup in the Pacific Ocean off north-eastern Japan. *Bull. Hokkaido Reg. Fish. Res. Lab.*, **41**: 1–29 (1976) [In Japanese with English abstract].

Murata, M., and Y. Nakamura. Seasonal migration and diel vertical migration of the neon flying squid, *Ommastrephes bartramii*, in the North Pacific. **In**: *Contributed Papers to International Symposium on Large Pelagic Squids*, pp. 13–30 (T. Okutani, Ed.), Japan Marine Fishery Resources Research Center: Tokyo (1998).

Murayama, T., and H. Kitazawa. The growth and maturation of *Loligo bleekeri* in the Japan Sea. **In**: Report of the 2004 Meeting on Squid Resources, pp.133–144 (Japan Sea National Fishery Research Institute (JSNFRI), Eds.) Niigata, Japan, JSNFRI (2004) [in Japanese].

Nabhitabhata, J. Life cycle of cultured bigfin squid, *Sepioteuthis lessoniana* Lesson. *Phuket Mar. Biol. Cent. Spec. Pub.*, **16**: 83–95 (1996).

Nabhitabhata, J., A. Nateewathana, and C. Sukhsangchan. Cephalopods. **In**: *Checklist of Mollusca Fauna in Thailand*, pp. 256–277 (J. Nabhitabhata, Compl.). Bangkok, Thailand: Office of Natural Resources and Environmental Policy and Planning (2009).

Nabhitabhata, J., and A. Nateewathana. Past and present of records of cephalopod fauna in Thai Waters with species checklist. *Trop. Natur. Hist. Suppl.*, **3**: 264 (2010).

Nabhitabhata, J., P. Nilaphat, P. Promboon, C. Jaroongpattananon, G. Nilaphat, and A. Reunreng. Performance of simple large-scale cephalopod culture system in Thailand. *Phuket Mar. Biol. Cent. Res. Bull.*, **66**: 337–350 (2005).

Naef, A. Cephalopoda. Fauna and Flora of the Bay of Naples. Monograph No. 35. Part I, Vol. I (1–2): 1–917. Translated by A. Mercado. Ed. by O. Theodor. Israel Program for Scientific Translations Ltd, 1972. IPST Cat. No. 5110/1,2 (1921/1923).

Nagasawa, K., J. Mori, and H. Okamura. Parasites as biological tags of stocks of neon flying squid (*Ommastrephes bartramii*) in the North Pacific Ocean. **In**: *Contributed Papers to International Symposium on Large Pelagic Squids*,. pp. 49–64 (T. Okutani, Ed.), Japan Marine Fishery Resources Research Center: Tokyo (1998).

Nagasawa, K., S. Takayanagi, and T. Takami. Cephalopod tagging and marking in Japan, a review. In T. Okutani, R.K. O'Dor and T. Kubodera (eds) *Recent Advances in Cephalopod Fisheries Biology*, 313–330, Tokyo, Tokai University Press. (1993).

Naito, M., K. Murakami, T. Kobayashi, N. Nakayama, and J. Ogasawara. Distribution and migration of oceanic squids (*Ommastrephes bartrami, Onychoteuthis borealijaponicus, Berryteuthis magister* and *Gonatopsis borealis*) in the Western Subarctic Pacific region. *Res. Inst. Nor. Pac. Fish., Fac. Fish., Hokkaido Univ.,* **spec. vol.**: 321–337 (1977).

Nakata, I. Squid driftnet fishery. **In**: *Comprehensive report on research on marine mammals in the North Pacific Ocean, relating to Japanese salmon driftnet fisheries, 1984–1986*, p. 1–112 (K. Takagi, ed.). (Document submitted to the International North Pacific Fisheries Commission.), Natl. Res. Inst. Far Sea Fish., Fish. Agency of Japan, Shimizu 424, Japan (1987).

Nakata, J. Long-term changes in catch and biological features of Japanese common squid (*Todarodes pacificus*) in waters off the east coast of Hokkaido. **In**: *Recent Advances in Cephalopod Fisheries Biology*, pp. 343–350 (T. Okutani, R. K. O'Dor, and T. Kubodera, Eds.). Tokyo: Tokai University Press (1993).

Nakaya, H., H. Miyaki, and S. Ishikawa. Strange taste component of purpleback flying squid. **In**: *Report on 1995 Research Cruise of the R/V Shoyo-Maru. Distribution of Purpleback Flying Squid and Tunas in the Indian Ocean, October 1995-January 1996*, pp. 209–212. Fishery Agency of Japan (1998).

Narasimha-Murthy, L., K. P. Satyen, V. R. Madhu, P. K. Asokan, G. Shubhadeep, D. Shibsankar, and B. Rajendra. Cadmium in the purpleback flying squid *Sthenoteuthis oualaniensis* (Lesson, 1830) along northwest coast of India. *J. Mar. Biol. Ass. India.*, **50**: 191–195 (2008).

Nashida, K., and H. Sakaji. 2012 stock assessment and evaluation for Pacific stock of spear squid (fiscal year 2011). **In**: Marine Fisheries Stock Assessment and Evaluation for Japanese Waters (fiscal year 2011/2012), pp. 1720–1731 (Fisheries Agency and Fisheries Research Agency of Japan (FA&FRA), Eds.). Tokyo, FA&FRA (2012) [in Japanese].

National Marine Fisheries Service [NMFS], Office of Science and Technology, U.S. Foreign Trade Statistics. Fishery product export data downloaded Oct. 31, 2013 from: http://www.st.nmfs.noaa.gov/commercial-fisheries/foreign-trade/applications/annual-trade-through-specific-us-customs-districts (2013).

Natsukari, Y. SCUBA diving observations on the spawning ground of the squid, *Doryteuthis kensaki* (WAKIYA et ISHIKAWA, 1921) (Cephalopoda: Loliginidae). *Venus*, **35**: 206–208 (1976) [in Japanese with English abstract].

Natsukari, Y., and N. Komine. Age and growth estimation of the European squid Loligo vulgaris, based on statolith microstructure. *J. mar. biol. Ass. U.K.*, **72**: 271–280 (1992).

Natsukari, Y., T. Nakanose, and K. Oda. Age and growth of loliginid squid *Photololigo eudlis* (Hoyle, 1885). *J. Exp. Mar. Biol. Ecol.*, **116**: 177–190 (1988).

Natsukari, Y., Y. Nishiyama, and Y. Nakanishi. A preliminary study on the isozymes of the loliginid squid, *Photololigo edulis* (Houle, 1885). *Report on Cooperative Investigations of "Shiroika"*, *Loligo edulis, inhabiting western Japan Sea*, **2**: 14–151 (1986) [in Japanese with English abstract].

Natsukari, Y., and M. Tashiro. Neritic squid resources and cuttlefish resources in Japan. *Mar. Behav. Physiol.*, **18**: 149–226 (1991).

Nazumi, T. Notes on the fishery and the ecology of the squid, *Thysanoteuthis rhombus* Troschel in the east San'in water. *Bull. Hyogo Pref. Fish. Exp. Stat.*, **15**: 15–34 (1975) [in Japanese].

Nesis, K. N. Population structure in the squid, *Sthenoteuthis oualaniensis* (Lesson, 1830) (Ommastrephidae), in the western tropical Pacific. *Trudy Institute of Oceanology of the Academy of Sciences USSR*, **107**: 15–29 [In Russian with English abstract] (1977).

Nesis, K. N. Short Guide to the Cephalopod Mollusks of the World Ocean. Moscow: Izdatelstvo Legkaya i Pischevaya Promyshlennost (Light and Food Industry Press) (1982) [In Russian].

Nesis, K. N. *Dosidicus gigas*. **In**: *Cephalopod life cycles*, Vol. **1**, pp. 215–231 (P. R. Boyle, Ed.). London, Academic Press (1983).

Nesis, K. N. Oceanic cephalopods: distribution, life forms, evolution. Moscow, Nauka Press (1985) [In Russian].

Nesis, K. N. Population structure of oceanic ommastrephids, with particular reference to *Sthenoteuthis oualaniensis*. **In**: *Recent Advances in Cephalopod Fisheries Biology*, pp. 375–383 (T. Okutani, R. K. O'Dor and T. Kubodera, Eds.). Tokyo: Tokai University Press (1993).

Nesis, K. N. Cephalopods of the world. Squids, cuttlefishes, octopuses and allies. TFH Publications, Neptune City, NJ and London (1987).

Nesis, K. N. The gonatid squid *Berryteuthis magister* (Berry, 1913): distribution, biology, ecological connections, and fisheries, **In**: *Contributed Papers to International Symposium on Large Pelagic squids, JAMARC*, pp. 233–249 (T. Okutani, Ed.). Tokyo (1998).

Nevárez-Martínez, M., A. Hernández-Herrera, E. Morales-Bojórquez, A. Balmori Ramírez, M. A. Cisneros-Mata, and R. Morales Azpeitia. Biomass and distribution of the jumbo squid (*Dosidicus gigas* d'Orbigny, 1835) in the Gulf of California, Mexico. *Fish. Res.*, **49**: 129–140 (2000).

Nevárez-Martínez, M., O. Morales-Bojorquez, E. Cervantes-Valle, C. Santos-Molina, and J. P. Lopez-Martinez. Population dynamics of the jumbo squid (*Dosidicus gigas*) in the 2002–2008 fishing seasons off Guaymas, Mexico. *Fish. Res.*, **106**: 132–140 (2010).

Nigmatullin, Ch. M. Biomass, production, role in the World Ocean ecosystem, and fishery potential of squids family Ommastrephidae. **In**: *VI All-Russian Conference on Commercial Invertebrates, Kaliningrad (Lesnoye), Sept. 3–6, 2002, Abstracts of Reports*, pp. 155–157 (G. I. Ivanov, and Ch. M. Nigmatullin, eds). Moscow: VNIRO Publishing (1989) [In Russian, with English title].

Nigmatullin, Ch. M. Resources and perspectives of the fisheries of nektonic epipelagic squids in the World Ocean. Abstr. Commun. All-USSR Conf. on reserve food biological resources of the open ocean and the USSR seas, Kaliningrad, March, 1990. Moscow. p. 11–13 (1990) [in Russian, English abstract].

Nigmatullin, Ch. M. Estimation of biomass, production and fishery potential of ommastrephid ssquids in theWorld Ocean and problems of their fishery forecasting. ICES Theme Session on Cephalopod Stocks: Review, Analyses, Assessment, and Sustainable Management. [Abstract]. Available at www.ices.dk (2004).

Nigmatullin, Ch. M. Paradoxical situation on the Argentine squid fishery in 2007: large catch is not always good. **In**: *Collected papers on memory of famous Russian hydrobiologist B.G. Ivanov "Marine commercial invertebrates and algae (biology and fishery)". Trudy VNIRO*, **147**: 284–298 (2007) (In Russian with English abstract).

Nigmatullin, C. M., and A. Arkhipkin. A review of the biology of the diamondback squid, *Thysanoteuthis rhombus* (Oegopsida: Thysanoteuthidae). **In**: *Contributed Papers to International Symposium on Large Pelagic Squids*, pp. 155–181 (T. Okutani, Ed.). Tokyo, Japan: Japan Marine Fishery Resources Research Center (1998).

Nigmatullin Ch. M., P. Fedulov, and A. Z. Sundakov. Review of USSR/Russia cephalopod fishery in 1980–1994. **In**: *The 3rd International Cephalopod Trade conference "Squid 94 Venice"* (15–17 November 1994, Venice), pp. 1–16. Agra Europe (London) Ltd. (1995).

Nigmatullin, Ch. M., V. V. Laptikhovsky, and H. Moustahfid. H. Population biology and fishery of squid *Todarodes sagittatus* (Lamarck) (Cephalopoda: Ommastrephidae) off North-Western Africa. **In**: F*ishery Biological Researches by AtlantNIRO in 1996–1997*, pp. 72–95 (P. P. Chernyshkov, ed). Kalingrad: Trudy AtlantNIRO Publishing (1998) [In Russian, with English abstract].

Nigmatullin, C. M., K. N. Nesis, and A. I. Arkhipkin. A review of the biology of the jumbo squid *Dosidicus gigas* (Cephalopoda: Ommastrephidae). *Fish. Res.*, **54**: 9–19 (2001).

Nigmatullin, Ch. M., V. Laptikhovsky, and H. Moustahfid. Brief review on the ecology in the North African population of arrow squid *Todarodes sagittatus* (*Cephalopoda, Ommastrephidae*). *Bull. Mar. Sci.*, **71**: 581–590 (2002).

Nihonkai Hotaruika Shigen Kenkyu Team. Nihonkai ni okeru Hotaruika no Shigenriyoukenkyu. Suisangyou Kankeitiiki Zyuyoushingizyutsu Kaihatsusokushin Zigyou Sougou Houkokusyo. (1991).

Nishida, H., I. Uchiyama, and K. Hirakawa. Possibility of forecasting the abundance of the firefly squid *Watasenia scintillans* immigrating into Toyama bay, southern Japan sea. *Bull. Japan Sea Natl. Fish. Res. Inst.*, **48**: 37–49 (1998).

Nishimura, S. Notes on the occurrence and biology of the oceanic squid, *Thysanoteuthis rhombus* Troschel, in Japan. *Publ. Seto Mar. Biol. Lab.*, **14**: 327–349 (1966).

NOAA, NMFS, and PIRO. Diamondback Squid (*Thysanoteuthis rhombus*) **In**: P*elagic squid fishery management under the fishery management plan for the pelagic fisheries of the western Pacific region and the high seas fishing compliance act*. pp. 470–477. Honolulu, USA: National Oceanic and Atmospheric Administration, National Marine Fisheries Service and Pacific Island Regional Office (2005).

Norman, M., and A. Reid. Guide to squid, cuttlefish and octopuses of Australasia. Collingwood, Vic: CSIRO Publishing (2000).

Northeast Fisheries Science Center [NEFSC]. Report of the 29th Northeast Regional Stock Assessment Workshop (29th SAW): Stock Assessment Review Committee SARC) Consensus Summary of Assessments. *Northeast Fish. Sci. Cent. Ref. Doc. 99–14* (1999).

Northeast Fisheries Science Center [NEFSC]. Report of the 37th Northeast Regional Stock Assessment Workshop (37th SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments. *Northeast Fish. Sci. Cent. Ref. Doc. 03–16* (2003).

Northeast Fisheries Science Center [NEFSC]. 42nd Northeast Regional Stock Assessment Workshop (42nd SAW) Stock Assessment Report Part A: Silver Hake, Mackerel, & Northern Shortfin Squid. *Northeast Fish. Sci. Cent. Ref. Doc.* 06–09a (2006).

Northeast Fisheries Science Center [NEFSC]. 51st Northeast Regional Stock Assessment Workshop (51st SAW) Assessment Report. Northeast Fish. Sci. Center Ref Doc. 11–02, 856 p. Available at: http://nefsc.noaa.gov/publications/crd/crd1102/loligo.pdf (2011).

Northridge, S. P. Driftnet fisheries and their impacts on non-target species: a worldwide review. *FAO Fisheries Technical Paper* No. 320. FAO, Rome, p. 115. (1991).

Nowara, G. B., and T. I. Walker. Effects of time of solar day, jigging method and jigging depth on catch rates and size of Gould's squid, *Nototodarus gouldi* (McCoy), in southeastern Australian waters. *Fish. Res.*, **34**: 279–288 (1998).

O'Dor, R. K., N. Balch, E. A. Foy, R. W. M. Hirtle, D. A. Johnston, and T. Amaratunga. Embryonic development of the squid, *Illex illecebrosus*, and effect of temperature on developmental rates. *J. Northwest Atl. Fish. Sci.*, **3**: 41–45 (1982).

O'Dor, R. K., and E. G. Dawe. Chapter 4. *Illex illecebrosus*. **In**: *Squid recruitment dynamics: the genus Illex as a model, the commercial Illex species and influences of variability*, pp. (P. G. Rodhouse, E. G. Dawe, and R. K. O'Dor, Eds.). *FAO Fish. Tech. Paper 376* (1998).

O'Dor, R. K., and E. G. Dawe, 2013. Chapter III. *Illex illecebrosus*. **In**: Advances in squid biology, ecology and fisheries. Part II Oegopsid squids pp. 73–108 (R. Rosa, G. J. Pierce, and R. O'Dor, eds). New York: Nova Science Publishers (2013).

O'Dor, R. K., and M. L. Coelho. Big squid, big currents, and big fisheries. **In**: *Recent Advances in cephalopod fisheries biology*, p. 385–396 (T. Okutani, R. K. O'Dor and T. Kubodera, Eds.). Tokyo, Japan: Tokai University Press (1993).

Oesterwind, D., R. ter Hofstede, B. Harley, H. Brendelberger, and U. Piatkowski. Biology and meso-scale distribution patterns of North Sea Cephalopods. *Fish. Res.*, **106**: 141–150 (2010).

Ogawa, Y. Evaluation of the influence of changes in prey abundance on catch fluctuations of "Shiroika", *Loligo edulis*, in coastal waters of the Southwestern Japan Sea. *Bull. Jpn. Soc. Fish. Oceanog.*, **41**: 11–16 (1982) [in Japanese with English abstract].

Ogawa, Y., S. Moriwaki, H. Yamada, and Y. Okajima. Seasonal changes in locations of fishing grounds for *Loligo edulis* anglers in coastal waters of the southwestern Japan Sea (preliminary report). *Report on Cooperative Investigations of "Shiroika", Loligo edulis, inhabiting western Japan Sea*, **1**: 124–133 (1983) [in Japanese with English abstract].

Ogawa, Y., and H. Yamada. Distribution of *Loligo edulis* in a shelf region of the southwestern Japan Sea. *Bull. Jpn. Soc. Fish. Oceanog.*, **44**: 1–8 (1983) [in Japanese with English abstract].

Ogawara, M., P. Masthawee, A. Munprasit, B. Chokesangaun, and Y. Theparunrat. Fishing gear of Thailand. Samut Prakan: Training Department, Southeast Asian Fisheries Development Center (SEAFDEC) (1986).

Okada, Y. Lures for squids and cuttlefish in Kagoshima Prefecture, Japan. Tokyo: Uchida Rokakuho Shinsha (1978).

Okiyama, M. Nihonkai ni okeru chushinsousei gyorui ikarui maikuronekuton no seibutsugaku. *Marine Science Monthly*, **10**: 895–890 (1978).

Okutani, T. Guide and keys to squids in Japan. *Bull. Tokai Reg. Fish. Res. Lab.*, **74**: 83–111 (1973) [in Japanese with English abstract].

Okutani, T. Stock assessment of cephalopod resource fished by Japan. *FAO Fish. Tech. Paper* No. **173** (1977).

Okutani, T. Calamares de las aguas mexicanas. Breve descripción de los calamares existentes en aguas mexicanas. PESCA. Mexico (1980).

Okutani, T. *Todarodes pacificus*. **In**: *Cephalopod Life Cycles. 1. Species Accounts*, pp. 201–214 (P. R. Boyle, Ed.). London: Academic Press (1983).

Okutani, T. Evidence of spawning of *Berryteuthis magister* in the northeastern Pacific. *Bull. Ocean Res. Inst., Univ. Tokyo*, **26**: 193–200 (1988).

Okutani, T. Cuttlefish and squids of the world in colour. National Cooperative Association of Squid Processors. Japan (1995a).

Okutani, T. Oceanic big squids – Introduction. *Aquabiol.*, **17**: 437–470 (1995b) [in Japanese].

Okutani, T. Stock assessment of cephalopod resources fished by Japan. *FAO Fish. Tech. Pap.*, **173**. 62 pp (1997).

Okutani, T. Biological significance and fisheries potential of large pelagic squids. **In**: *Contributed Papers to International Symposium on Large Pelagic Squids*, pp. 7–12 (T. Okutani, Ed.). Tokyo, Japan: Japan Marine Fishery Resources Research Center (1998).

Okutani, T. Cuttlefishes and squids of the world. Tokyo: Seizando-Shoten Co. Ltd. (2005).

Okutani T., and J. A. McGowan. Systematics, distribution and abundance of the epiplanktonic squid (Cephalopoda, Decapoda) larvae of the California Current April, 1954−March, 1957. *Bull. Scripps Inst. Oceanogr.*, **14**: 1–90 (1969).

Okutani T., and T. Watanabe. Stock assessment by larval surveys of the winter population of *Todarodes pacificus* Steenstrup (Cephalopoda: Ommastrephidae), with a review of early works. *Biol. Oceanog.* **2**: 401–431 (1983).

Olyott, L. J. H., W. H. H. Sauer, and A. J. Booth. Spatio-temporal patterns in maturation of the chokka squid (*Loligo vulgaris reynaudii*) off the coast of South Africa. *ICES J. Mar. Sci.*, **63**: 1649–1664 (2006).

Olyott, L. J. H., W. H. H. Sauer, and A. J. Booth. Spatial patterns in the biology of the chokka squid, *Loligo vulgaris reynaudii* on the Agulhas Bank, South Africa. *Rev. Fish Biol. Fish.*, **17**: 159–172 (2007).

Onitsuka, G., N. Hirose, K. Miyahara, T. Ota, J. Hatayama, Y. Mitsunaga, and T. Goto. Numerical simulation of the migration and distribution of diamond squid (*Thysanoteuthis rhombus*) in the southwest Sea of Japan. *Fish. Oceanogr.*, **19**: 63–75 (2010).

Oppian Colluthus Tryphiodorus. Halieuthica. W. Heinemann London, and G. P. Putnam's Sons, New York (1928).

Ormseth, O. A. Assessment of the squid stock complex in the Bering Sea and Aleutian Islands. *NPMFC Bering Sea and Aleutian Islands SAFE*: 1849–1886 (2012).

Orsi Relini, L. Field observations of young *Ommastrephes bartrami* in offshore waters in the Ligurian Sea. Rapports et procès-verbaux des réunions de la Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée, **32**(1): 243 (1990).

Orsi Relini, L., A. Mannini, L. Lanteri, and E. Beccornia. First record of an egg mass of *Loligo forbesi* (Cephalopoda: Loliginidae) in the Ligurian Sea, with notes about egg laying patterns in southern populations. *Boll. Malacol.*, **45**(Suppl. 2009): 27–33 (2009).

Osako, M., and M. Murata. Stock assessment of cephalopod resources in the northwestern Pacific. **In**: *Advances in Assessment of World Cephalopod Resources*, pp. 55–144 (J. F. Caddy, Ed.), *FAO Fish. Tech. Paper* No. **231** (1983).

O'Shea, S., K. S. Bolstad, and P. A. Ritchie. First records of egg masses of *Nototodarus gouldi* McCoy, 1888 (Mollusca: Cephalopoda: Ommastrephidae), with comments on egg-mass susceptibility to damage by fisheries trawl. *N. Z. J. Zool.*, **31**: 161–166 (2004).

O'Sullivan, D., and J. M. Cullen. Food of the squid *Nototodarus gouldi* in Bass Strait. *Aust. J. Mar. Freshwater Res.*, **34**: 261–285 (1983).

Otero, H. O., S. I. Bezzi, R. Perrotta, J. A. Perez Comas, M. A. Simonazzi, and M. A. Renzi. Los recursos pesqueros demersales del mar argentino. Parte 3 - Distribución, estructura de la población, biomassa y rendimiento potencial de la polaca, el bacalao austral, la merluza de cola y del calamar. *Contrib. Inst. Nac. Invest. Desarrollo Pesq.* **383**: 28–41 (1981).

Overholtz, W. J., L. D. Jacobson, and J. S. Link. An ecosystem approach for assessment advice and biological reference points for the Gulf of Maine–Georges Bank herring complex. *North Amer. J. Fish. Manage.*, **28**: 247–257 (2008).

Packard, A. Cephalopods and fish, the limits of convergence. *Biol. Rev.*, **47**: 241–307 (1972).

Panjarat, S. Sustainable Fisheries in the Andaman Sea Coast of Thailand. Division for Ocean Affairs and the Law of the Sea Office of Legal Affairs. The United Nations, New York (2008).

Papaconstantinou, C., and H. Farrugio. Fisheries in the Mediterranean. *Medit. Mar. Sci.*, **1**: 5–18 (2000).

Parfeniuk, A. V., Yu. M. Froerman, and A. N. Golub. Particularidades de la distribucion de los juveniles de *lllex argentinus* en el area de la Depresion Argentina. *Frente Maritimo*, **12**: 105–111 (1992).

Patterson, K. R. Life history of Patagonian squid *Loligo gahi* and growth parameter estimates using least square fits to linear and von Bertalanffy models. *Mar. Ecol. Progr. Ser.*, **47**: 65–74 (1988).

Pauly, D. Why squids, though not fish, may be better understood by pretending they are. *S. Afr. J. Marine Sci.*, **20**: 47–58 (1998).

Pauly, D., V. Christensen, J. Dalsgaard, R. Froese, and F. Torres. Fishing down marine food webs. *Science*, **279**(5352): 860–863 (1998).

Pauly, D., R. Hilborn, and T. A. Branch T. A. Does catch reflect abundance? *Nature*, **494**: 303–306 (2013).

Pauly, D., R. Watson, and J. Alder. Global trends in world fisheries: impacts on marine ecosystems and food security. *Philos. Trans. R. Soc. Lond. B Biol Sci.*, **360**: 5–12 (2005).

Pecl, G. T. Flexible spawning strategies in tropical and temperate *Sepioteuthis* squids. *Mar. Biol.*, **138**: 93–101 (2001).

Pecl, G. T. The *in situ* relationships between season of hatching, growth and condition of southern calamary, *Sepioteuthis australis*. *Mar. Freshwater Res.*, **55**: 429–438 (2004).

Pecl, G. T., and G. D. Jackson. The potential impacts of climate change on inshore squid: biology, ecology and fisheries. *Rev. Fish Biol. Fisher.*, **18**: 373–385 (2008).

Pecl, G. T., and N. A. Moltschaniwskyj. Life history of a short-lived squid (*Sepioteuthis australis*): resource allocation as a function of size, growth, maturation, and hatching season. *ICES J. Mar. Sci.*, **63**: 995–1004 (2006).

Pecl, G. T., N. A. Moltschaniwskyj, S. R. Tracey, and A. R. Jordan. Inter-annual plasticity of squid life history and population structure: Ecological and management implications. *Oecologia*, **139**: 515–524 (2004a).

Pecl, G. T., M. A. Steer, and K. E. Hodgson. The role of hatchling size in generating the intrinsic size-at-age variability of cephalopods: extending the Forsythe Hypothesis. *Mar. Freshwater Res.*, **55**: 387–394 (2004b).

Pecl, G. T., S. R. Tracey, J. M. Semmens, and G. D. Jackson. Use of acoustic telemetry for spatial management of southern calamary *Sepioteuthis australis*, a highly mobile inshore squid species. *Mar. Ecol. Prog. Ser.*, **328**: 1–15 (2006).

Pecl, G. T., S. R. Tracey, L. Danyushevsky, S. Wotherspoon, and N. A. Moltschaniwskyj. Elemental fingerprints of southern calamary (*Sepioteuthis australis*) reveal local recruitment sources and allow assessment of the importance of closed areas. *Can. J. Fish. Aquat. Sci.*, **68:** 1351–1360 (2011).

Pecl, G. T., T. Ward, Z. Doubleday, S. Clarke, J. Day, C. Dixon, S. Frusher, P. Gibbs, A. Hobday, N. Hutchinson, S. Jennings, K. Jones, X. Li, D. Spooner, and R. Stoklosa. Rapid assessment of fisheries species sensitivity to climate change in south east Australia. *Climatic Change*. DOI 10.1007/s10584–014–1284-z (2014).

Peng, Z., Y. Lin, Z. Xufeng, and T. Yongguang. The present status and prospect on exploitotion of tuna and squid fishery resources in South China Sea. *South China Fish. Sci.*, **6**: 68–74 (2010).

Perdichizzi, A., L. Pirrera, D. Giordano, F. Perdichizzi, B. Busalacchi, A. Profeta, T. Bottari, and P. Rinelli. Distribution patterns and population structure of *Illex coindetii* (Cephalopoda: Ommastrephidae) in the southern Tyrrhenian Sea: historical series of 14 years trawl survey. *Fish. Res.*, **109**: 342–350 (2011).

Pereira, J. M. F., A. Moreno, and M. M. Cunha. Western European squid distribution: a review. ICES Document CM 1998/M: 29. Copenhagen: International Council for the Exploration of the Sea (1998).

Perez, J. A. A. Biomass dynamics of the squid *Loligo plei* and the development of a small-scale seasonal fishery off southern Brazil. *Bull. Mar. Sci.*, **71**(2): 633–651 (2002a).

Perez, J. A. A. Padronização do esforço da pesca de arrasto em Santa Catarina e análise da variação da abundância da lula *Loligo plei* através da aplicação de modelo linear generalizado. *Not. Téc. FACIMAR*, **6**: 19–31 (2002b).

Perez, J. A. A., D. C. Aguiar, and U. C. Oliveira. Biology and population dynamics of the long-finned squid *Loligo plei* (Cephalopoda: Loliginidae) in southern Brazilian waters. *Fish. Res.*, **58**: 267–279 (2001a).

Perez, J. A. A., D. C. de Aguiar, and J. A. T. Santos. Gladius and statoliths as tools for age and growth studies of the squid *Loligo plei* (Teuthida: Loliginidae) off southern Brazil. *Braz. Arch. Biol. Technol.*, **49**(5): 747–755 (2006).

Perez, J. A. A., M. A. Gasalla, D. C de Aguiar, U. C. Oliveira, C. A. Marques, and A. R. G. Tomás. *Loligo plei*. **In**: *Análise das Principais Pescarias Comerciais da Região Sudeste-Sul do Brasil. Dinâmica Populacional das Espécies em Explotação*, pp. 62–68 (M. C. Cergole, A. O. Ávila-da-Silva and C. L. D. B. Rossi-Wongtschowski, Eds.). São Paulo. Brazil: Série Documentos REVIZEE - SCORE SUL: Ed. Ulhoa Cintra (2005).

Perez, J. A. A., R. S. Martins, and J. R. Buratto, J. R. Estrutura e dinâmica a pesca artesanal de lulas (Mollusca: Cephalopoda) em Santa Catarina. **In**: *Proceedings of XII CONBEP*, 954–967. Olinda, Brazil: Sociedade Brasileira de Engenharia de Pesca (1999).

Perez, J. A. A., and R. K. O'Dor. 1998. The impact of environmental gradients on the early life inshore migration of the short-finned squid *Illex illecebrosus*. *S. Afr. J. Mar. Sci.*, **20**: 293–303 (1998).

Perez, J. A. A., and P. R. Pezzuto. Pesca de arrasto de talude do Sudeste e Sul do Brasil: Tendências da Frota Nacional entre 2001 e 2003. *Bol. Inst. Pesca. São Paulo*, **32**: 127–150 (2006).

Perez, J. A. A., and P. R. Pezzuto. Valuable shellfish species in the bycatch of shrimp fishery in southern Brazil: spatial and temporal patterns. *J. Shellfish Res.* **17**(1): 303–309 (1998).

Perez, J. A. A., P. R. Pezzuto, S. H. B. Lucato, and W. G. Vale. Frota de arrasto de Santa Catarina. **In**: *Dinâmica das frotas pesqueiras comerciais da região Sudeste-Sul do Brasil*, pp. 104–164 (C. L. D. B. Rossi-Wongtschowski, R. A. Bernardes and M. C. Cergole, Eds.). São Paulo, Brazil: Série Documentos REVIZEE – SCORE Sul. São Paulo, Instituto Oceanográfico, USP (2007).

Perez, J. A. A., P. R. Pezzuto, L. F. Rodrigues, H. Valentini, and C. M. Vooren. Relatório da reunião técnica de ordenamento da pesca de arrasto nas regiões sudeste e sul do Brasil. *Not. Téc. FACIMAR*, **5**: 1–34 (2001b).

Perez, J. A. A., T. N. Silva, R. Schroeder, R. Schwartz, and R. S. Martins. Biological patterns of the Argentine shortfin squid *Illex argentinus* in the slope trawl fishery off Brazil. *Lat. Am. J. Aquat. Res.*, **37**: 409–428 (2009).

Petsalapsri, O., W. Panthakit, S. Boonsuk, and C. Sa-nga-ngam. Small-scale fisheries in the closed area during spawning and breeding season in the Andaman Sea. *Tech. Pap. 18/2013, Andaman Sea Fish. Res. Dev. Cent., Mar. Fish. Res. Dev. Bur., Dept. Fish.* (2013).

Pham, C. K., G. P. Carreira, F. M. Porteiro, J. M. Gonçalves, F. Cardigos, and H. R. Martins. First description of spawning in a deep-water loliginid squid, *Loligo forbesi* (Cephalopoda: Myopsida). *J. Mar. Biol. Assoc. U. K.*, **89**(1): 171–177 (2009).

Piatkowski, U., V. Hernández-García, and M. R. Clarke. On the biology of the European flying squid *Todarodes sagittatus* (Lamarck, 1798) (Cephalopoda, Ommastrephidae) in the central eastern Atlantic. *S. Afr. J. Marine Sci.*, **20**: 375–383 (1998).

Pierce, G. J., L. Allcock, I. Bruno, P. Bustamante, Á. F. González, Á. Guerra, P. Jereb, E. Lefkaditou, S. Malham, A. Moreno, J. Pereira, U. Piatkowski, M. Rasero, P. Sánchez, M. B. Santos, M. Santurtún, S. Seixas, I. Sobrino, and R. Villanueva. Cephalopod biology and fisheries in Europe. ICES Cooperative Research Report No. 303. Copenhagen: International Council for the Exploration of the Sea (2010).

Pierce, G. J., N. Bailey, Y. Stradoudakis, and A. Newton. Distribution and abundance of the fished population of *Loligo forbesi* in Scottish waters: analysis of research cruise data. *ICES J. Mar. Sci.*, **55**: 14–33 (1998).

Pierce, G. J., and P. R. Boyle. Empirical modelling of interannual trends in abundance of squid (*Loligo forbesi*) in Scottish waters. *Fish. Res.*, **59**: 305–326 (2003).

Pierce, G. J., P. R. Boyle, L. C. Hastie, and L. Key. The life history of *Loligo forbesi* (Cephalopoda: Loliginidae) in Scottish waters. *Fish. Res.*, **21**: 17–41 (1994c).

Pierce, G. J., P. R. Boyle, L. C. Hastie, and M. B. Santos. Diets of squid *Loligo forbesi* and Loligo vulgaris in the northeast Atlantic. *Fish. Res.*, **21**: 149–164 (1994a).

Pierce, G. J., P. R. Boyle, L. C. Hastie, and A. M. Shanks. Distribution and abundance of the fished population of *Loligo forbesi* in UK waters: analysis of fishery data. *Fish. Res.*, **21**: 193–216 (1994b).

Pierce G. J., and A. Guerra. Stock assessment methods used for cephalopod fisheries. *Fish. Res.*, **21**: 255–285 (1994).

Pierce, G. J., L. C. Hastie, Á. Guerra, R. S. Thorpe, F. G. Howard, and P. R. Boyle. Morphometric variation in *Loligo forbesi* and *Loligo vulgaris*: regional, seasonal, maturity and worker differences. *Fish. Res.*, **21**: 127–148 (1994e).

Pierce, G. J., and J. M. Portela. Fisheries production and market demand. **In**: *Cephalopod Culture* pp. 41–58 (J. Iglesias, L. Fuentes, and R. Villanueva, Ed). Dordrecht: Springer (2014).

Pierce, G. J., R. S. Thorpe, L. C. Hastie, A. S. Brierley, Á. Guerra, P. R. Boyle, R. Jamieson, and P. Avila. Geographic variation in *Loligo forbesi* in the Northeast Atlantic Ocean: analysis of morphometric data and tests of casual hypotheses. *Mar. Biol.*, **119**: 541–547 (1994d).

Pierce, G. J., V. D. Valavanis, A. Guerra, P. Jereb, L. Orsi-Relini, J. M. Bellido, I. Katara, U. Piatkowski, J. Pereira, E. Balguerias, I. Sobrino, E. Lefkaditou, J. Wang, M. Santurtun, P. R. Boyle, L. C. Hastie, C. D. MacLeod, J. M. Smith, M. Viana, A. F. González, and A. F. Zuur. A review of cephalopod-environment interactions in European Seas and other world areas. *Hydrobiologia*, **612**: 49–70 (2008).

Pierce, G. J., A. F. Zuur, J. M. Smith, M. B. Santos, N. Bailey, C.-S. Chen, and P. R. Boyle. Interannual variation in life-cycle characteristics of the veined squid (*Loligo forbesi*) in Scottish (UK) waters. *Aquat. Living Resour.*, **18**: 327–340 (2005).

Pinchukov, M. A. Oceanic Squids. **In**: Parin, N. V. and N. P. Novikov. (eds.). Biological Resources of the Indian Ocean. Nauka. Moscow. p. 186–194. [in Russian, English abstract] (1989).

PINRO. Polar Research Institute of Fisheries. Underexploited species of fish, invertebrates and algae. http://www.pinro.ru/labs/indexaqua.htm?top=aqua/bio2.htm Accessed on 11.08.2014 (2011)

Pliny the Elder. Natural History. Vol. III, books 8–11. Loeb Classical Library 353. Harvard University Press, Cambridge (1940).

Porteiro, F. M., and H. R. Martins. First finding of natural laid eggs from *Loligo forbesi* Steenstrup, 1856 (Mollusca: Cephalopoda) in the Azores. *Arquipelago*, **10**: 119–120 (1992).

Porteiro, F. M. The present status of squid fishery (*Loligo forbesi*) in the Azores archipelago. *Fish. Res.*, **21**: 243–253 (1994).

Porzio, D., J. Phillips, K. Loke, T. Tanaka, C. McKnight, D. Neilson, C. Juhasz, T. Mason, and Wilkins, E. Review of selected California fisheries for 2011: ocean salmon, California sheephead, California halibut, longnose skate, petrale sole, California spiny lobster, dungeness crab, garibaldi, white shark, and algal blooms. *Calif. Coop. Ocean. Fish. Inv. Rep.*, **53**: 15–40 (2012).

Postuma, F. A., and M. A. Gasalla. On the relationship between squid and the environment: artisanal jigging for *Loligo plei* at São Sebastião Island (24°S), southeastern Brazil. *ICES J. Mar. Sci.*, **67**: 1353–1362 (2010).

Potoschi, A., and F. Longo. Descrizione della pesca ai molluschi cefalopodi teutoidei nell'arcipelago delle Eolie. *Biol. Mar. Medit.*, **16**: 356–357 (2009).

Powell, E. N., A. J. Bonner, B. Muller, and E. A. Bochenek. Assessment of the effectiveness of scup bycatch-reduction regulations in the *Loligo* squid fishery. *J. Environ. Manage.*, **71**: 155–167 (2004).

Profeta, A., B. Busalacchi, A. Perdichizzi, and D. Giordano. Distribuzione e biologia del cefalopode *Illex coindetii* (Verany, 1839) nel mar Tirreno meridionale. *Biol. Mar. Mediterr.*, **15**: 348–349 (2008).

Prosvirov, E. S., and G. D. Vasiliev. New fishing grounds in the South-Western Atlantic. AtlantNIRO Publ., Kaliningrad, Russia (1969) [In Russian].

Quetglas, A., F. Alemany, A. Carbonell, P. Merella, and P. Sánchez. Some aspects of the biology of *Todarodes sagittatus* (Cephalopoda: Ommastrephidae) from the Balearic Sea (western Mediterranean). *Sci. Mar.*, **62**: 73–82 (1998).

Quetglas, A., F. Alemany, A. Carbonell, P. Merella, and P. Sánchez, P. Diet of the European flying squid *Todarodes sagittatus* (Cephalopoda: Ommastrephidae) in the Balearic Sea (western Mediterranean). *J. Mar. Biol. Ass. U. K.*, **79**: 479–486 (1999).

Quetglas, A., A. Carbonell, and P. Sánchez. Demersal continental shelf and upper slope cephalopods assemblages from the Balearic Sea (North-western Mediterranean). Biological aspects of some deep sea species *Est. Coast. Shelf Sci.*, **50**: 739–749 (2000).

Ragonese, S., and M. L. Bianchini. Sulla fattibilità della pesca dei totani tramite "jigging" nel canale di Sicilia (Cephalopoda: Oegopsida). *Quad. Istit. Idrobiol. Acquac. Brunelli*, **10**: 65–79 (1990).

Ragonese, S., and P. Jereb. *Loligo forbesi* Steenstrup 1856 (Cephalopoda: Loliginidae) nel Versante Siciliano del *Mare Pelagico* (Canale di Sicilia): Nota Preliminare sulla Distribuzione, Composizione per Taglia e Biologia Riproduttiva. *Nova Thalassia*, **8**: 529–555 (1986).

Ragonese, S., and P. Jereb. A large specimen of *Ommastrephes bartramii* (Lesueur, 1821) caught in the southern Tyrrhenian Sea. *Oebalia*, **16**: 741–744 (1990a).

Ragonese, S., and P. Jereb. Sulla teutofauna di interesse commerciale nel Canale di Sicilia. *Oebalia*, **16**: 745–748 (1990b).

Railko, P. P. Distribution and some features of biology of the commander squid *Berryteuthis magister* in the Japan Sea. **In**: *Mollusks. Main Results of their Investigations. Abstracts of Communications*, pp. 128–129. Leningrad: Nauka (1979) [In Russian].

Railko, P. P. Biology and distribution of the commander squid *Berryteuthis magister* in the area off Kurile Islands. **In**: *Taxonomy and Ecology of Cephalopods*, pp. 97–98 (Ya. I. Starobogatov) Leningrad: Zoological Institute of the USSR Academy of Sciences (1983) [In Russian].

Railko, P. P. Methods of distribution density and biomass estimation for commander squid. **In**: *Planning, Organization and Ensuring Fishery Research in the Russian Far Eastern Seas and Northwestern Pacific Ocean*, pp. 59–60. Vladivostok: TINRO–Centre (2005) [In Russian].

Ramirez, M., and A. Klett. Composición de tallas de la captura de calamar gigante en el Golfo de California durante 1981. *Transactions CIBCASIO*, **X**: 124–137 (1985).

Rao, G. S. Biology of inshore squid *Loligo duvaucelli* Orbigny, with a note on its fishery off Mangalore. *Indian J. Fish.*, **35**: 121–130 (1988).

Rasero, M., A. F. González, B. G. Castro, and Á. Guerra. Predatory relationships of two sympatric squid, *Todaropsis eblanae and Illex coindetii* (Cephalopoda: Ommastrephidae) in Galician waters. *J. Mar. Biol. Ass. U. K.*, **76**: 73–87 (1996).

Rathjen, W. F. Exploratory squid catches along the continental slope of the Eastern United States. *J. Shellfish Res.*, **1**: 153–159 (1981).

Rathjen, W. F. Cephalopod capture methods, an overview. *Bull. Mar. Sci.*, **49**: 494–505 (1991).

Rattana-anant, T. Biological studies on *Sepioteuthis lessoniana* Lesson (Cephalopoda; Loliginidae) in the Gulf of Thailand. *Invertebr. Sect., Mar. Fish. Div., Dept. Fish.* (1978).

Rattana-anant, T. Biological studies on *Sepioteuthis lessoniana* Lesson (Cephalopoda; Loliginidae) in the Gulf of Thailand. *Invertebr. Sect., Mar. Fish. Div., Dept. Fish.* (1979).

Rattana-anant, T. Biological studies on *Sepioteuthis lessoniana* Lesson (Cephalopoda; Loliginidae) in the Gulf of Thailand. *Invertebr. Sect., Mar. Fish. Div., Dept. Fish.* (1980).

Raya, C. P. Determinación de la edad y estudio del crecimiento del choco (*Sepia hierredda* Rang, 1837), el calamar (*Loligo vulgaris* Lamarck, 1798) y el pulpo (*Octopus vulgaris* Cuvier, 1797) de la costa Noroccidental Africana. PhD thesis, University of La Laguna, Spain. 192 pp. (2001).

Raya, C. P., Balguerias, E., Fernández-Núñez M. M., and Pierce, G. J. 1999. On the reproduction and age of the squid *Loligo vulgaris* from the Saharan Bank (north-west African coast). *J. Mar.Biol. Ass. UK*, **79**: 111–120.

Reichow, D., and M. Smith. Microsatellites reveal high levels of gene flow among populations of the California squid *Loligo opalescens*. *Mol. Ecol.*, **10**: 1101–1109 (2001).

Reiss C. S., M. R. Maxwell, J. R. Hunter, and A. Henry. Investigating environmental effects on population dynamics of *Loligo opalescens* in the Southern California Bight. *Calif. Coop. Ocean. Fish. Inv. Rep.*, **45**: 87–97 (2004).

Relini, G., C. De Rossi, T. Piano, and A. Zamboni. Osservazioni sui cefalopodi dei fondi strascicabili liguri. *Biol. Mar. Medit.*, **9**: 792–795 (2002).

Reshef, D. N., Y. A. Reshef, H. K. Finucane, S. R. Grossman, G. McVean, P. J. Turnbaugh, E. S. Lander, M. Mitzenmacher, and P.

C. Sabeti. Detecting novel associations in large data sets. *Science*, **334**: 1518–1524 (2011).

Restrepo, V. R., G. G. Thompson, P. M. Mace, W. L. Gabriel, L. L. Low, A. D. MacCall, R. D. Methot, J. E. Powers, B. L. Taylor, P. R. Wade, and J. F. Witzig. Technical guidance on the use of precautionary approaches to implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. *NOAA Tech. Memo. NMFS-F/SPO-31* (1998).

Ria, M., Rustighi, C., Casotti, M., Silvestri, R., and Baino, R. Note sulla distribuzione e biologia di Loligo vulgaris e Loligo forbesi nelle acque toscane. *Biol. Mar. Medit.*, **12**: 575–579 (2005).

Riad, R., and H. A. Al Werfaly. Reproductive biology of the squid *Loligo forbesi* (Cephalopoda: Loliginidae) in the Egyptian Mediterranean waters. *Egypt. J. Aquat. Biol. & Fish.*, **18**: 75–87 (2014).

Rice, J. Food web theory, marine food webs, and what climate change may do to northern marine fish populations. **In**: *Climate change and northern fish populations*. (R. J. Beamish, Ed.), *Can. Spec. Publ. Fish. Aquat. Sci.*, **121**: 561–568 (1995).

Rivard, D., L. C. Hendrickson, and F. M. Serchuk. Yield estimates for short-finned squid (*Illex illecebrosus*) in SA 3–4 from research vessel survey relative biomass indices. *NAFO SCR Doc. 98/75, Ser. No. N3068* (1998).

Roa-Ureta, R., and A. I. Arkhipkin. Short-term stock assessment of *Loligo gahi* at the Falkland Islands: sequential use of stochastic biomass projection and stock depletion models. *ICES J. Mar. Sci.*, **64**: 3–17 (2007).

Roberge, M., and T. Amaratunga. Review of the *Illex* Fisheries in Subareas 3 and 4 with special reference to 1978 and 1979 FLASH data. *NAFO SCR Doc. 80/II/32. Ser. No. N064* (1980).

Roberts, M. J. Chokka squid (*Loligo vulgaris reynaudii*) abundance linked to changes in South Africa's Agulhas Bank ecosystem during spawning and the early life cycle. *ICES J. Mar. Sci.*, **62**: 33–55 (2005).

Roberts, M. J. The influence of the environment on chokka squid *Loligo vulgaris reynaudii* spawning aggregations: Steps towards a quantified model. *S. Afr. J. mar. Sci.*, **20**: 267–284 (1998).

Roberts, M. J., M. Barange, M. R. Lipinski, and M. R. Prowse. Direct hydroacoustic observations of chokka squid *Loligo vulgaris reynaudii* spawning activity in deep water. *S. Afr. J. mar. Sci.*, **24**: 387–393 (2002).

Roberts, M. J., N. J. Downey, and W. H. H. Sauer. The relative importance of shallow and deep shelf spawning habitats for the South African chokka squid (*Loligo reynaudi*). *ICES J. Mar. Sci.*, **69**: 563–571 (2012).

Roberts, M. J., and W. H. H. Sauer. Environment: the key to understanding the South African chokka squid (*Loligo vulgaris reynaudii*) life cycle and fishery? *Antarct. Sci.*, **6**: 249–258 (1994).

Robin, J.-P., and E. Boucaud-Camou. Squid catch composition in the English Channel bottom trawl fishery: proportion of *Loligo forbesi* and *Loligo vulgaris* in the landings and length-frequencies of both species during the 1993–1994 period. ICES Document CM 1995/K: 36. Copenhagen: International Council for the Exploration of the Sea (1995).

Robin, J.-P., and V. Denis. Squid stock fluctuations and water temperature: temporal analysis of English Channel Loliginidae. *J. Appl. Ecol.*, **36**: 101–110 (1999).

Robin, J-P., V. Denis, J. Royer, and L. Challier. Recruitment, growth and reproduction in *Todaropsis eblanae* (Ball, 1841), in the area fished by French Atlantic trawlers. *Bull. Mar. Sci.*, **71**: 711–724 (2002).

Rocha, F., B. G. Castro, M. S. Gil, and Á. Guerra. The diets of *Loligo vulgaris* and *Loligo forbesi* (Cephalopoda: Loliginidae) in Northwestern Spanish Atlantic waters. *Sarsia*, **79**: 119–126 (1994).

Rocha, F., and Á. Guerra. Age and growth of two sympatric squid *Loligo vulgaris* and *Loligo forbesi*, in Galician waters (north-west Spain). *J. Mar. Biol. Assoc. U. K.*, **79**: 697–707 (1999).

Rocha, F., Á. Guerra, and A. F. González. A review of reproductive strategies in cephalopods. *Biol. Rev.*, **76**: 291–304 (2001).

Rocha F. M., and M. Vega. Overview of cephalopod fisheries in Chilean waters. *Fish. Res.*, **60**: 151–159 (2003).

Rodhouse, P. G. Managing and forecasting squid fisheries in variable environments. *Fish. Res.*, **54**: 3–8 (2001).

Rodhouse, P. G. Population structure of *Martialia hyadesi* (Cephalopoda: Ommastrephidae) at the Antarctic Polar Front and the Patagonian Shelf, South Atlantic. *Bull. Mar. Sci.*, **49**: 404–418 (1991).

Rodhouse, P. G. Precautionary measures for a new *Martialia hyadesi* (Cephalopoda, Ommastrephidae) fishery in the Scotia Sea: an ecological approach. *CCAMLR Sci.*, **4**: 125–139 (1997).

Rodhouse, P. G. K. Role of squid in the Southern Ocean pelagic ecosystem and the possible consequences of climate change. *Deep-Sea Res. Pt. II:* **95**: 129–138 (2013).

Rodhouse, P. G. K., A. I. Arkhipkin, V. Laptikhovsky, Ch. Nigmatullin, and C. M. Waluda. *Illex argentinus*, Argentine shortfin squid. **In**: Rosa, Rui; Pierce, Graham; O'Dor, Ron, (eds.) *Advances in Squid Biology, Ecology and Fisheries. Part II - Oegopsid squids.* New York, Nova Science Publishers, 109–148 (2013).

Rodhouse, P. G., C. D. Elvidge, and P. N. Trathan. Remote sensing of the global light fishing fleet: an analysis of interactions with oceanography, other fisheries and predators. *Adv. Mar. Biol.*, **39**: 261–303 (2001).

Rodhouse, P. G., and E. M. C. Hatfield. Dynamics of growth and and maturation in the cephalopod *Illex argentinus* de Castellanos, 1960 (Teuthoidea: Ommastrephidae). *Phil. Trans. Roy. Soc. Lond. B*, **329**: 229–241 (1990).

Rodhouse, P. G., and Ch. M. Nigmatullin. Role as consumers. *Phil. Trans. R. Soc. Lond. B.*, **351**: 1003–1022 (1996).

Rodhouse, P. G. K., G. J. Pierce, O. C. Nichols, W. H. H. Sauer, A. I. Arkhipkin, V. V. Laptikhovsky, M. R. Lipinski, J. Ramos, M. Gras, H. Kidokoro, K. Sadayasu, J. Pereira, E. Lefkaditou, C. Pita, M. Gasalla, M. Haimovici, M. Sakai, and N. Downey. Environmental effects on cephalopod population dynamics: implications for management of fisheries. *Adv. Mar. Biol.*, **67**: 99–223. (2014).

Rodhouse, P. G., R. C. Swinfen, and A. W. A. Murray. Life cycle, demography and reproductive investment in the myopsid squid *Alloteuthis subulata. Mar. Ecol. Progr. Ser.*, **45**: 245–253 (1988).

Rodrigues, A. R., and M. A. Gasalla. Spatial and temporal patterns in size and maturation of *Loligo plei* and *Loligo sanpaulensis* (Cephalopoda: Loliginidae) in southeastern Brazilian waters, between 23°S and 27°S. *Sci. Mar.*, **72**(4): 631–643 (2008).

Roel, B. Stock assessment of the chokka squid *Loligo vulgaris reynaudii*. Ph.D. thesis, University of Cape Town, Cape Town, South Africa (1998).

Roel, B., K. Cochrane, and G. Field. Investigation into the declining trend in chokka squid *Loligo vulgaris reynaudii* catches made by South African trawlers. *S. Afr. J. mar. Sci.*, **22**: 121–135 (2000).

Roeleveld, M. A. C., M. R. Lipinski, C. J. Augustyn, and B. A. Stewart. The distribution and abundance of cephalopods on the continental slope of the eastern south Atlantic. **In**: *Benguela Trophic Functioning*, pp. 739–752 (A. I. L. Payne, K. H. Brink, K. H. Mann and R. Hilborn, Eds). *S. Afr. J. mar. Sci.*, **12** (1992).

Rondelet, G. Libri de Piscibus Marinis. . .. Lugdunum (= Lyon), typo Mathias Bonhomme (1556).

Roongratri, M. Biology of bigfin reef squid (*Sepioteuthis lessoniana*) in the eastern coast of the Gulf of Thailand. *Tech. Pap. 65, East. Mar. Fish. Dev. Cent., Mar. Fish. Div., Dept. Fish.* (1997).

Roper, C. F. E., and C. C. Lu. Rhynchoteuthion larvae of ommastrephid squids of the western North Atlantic, with the first description of larvae and juveniles of *Illex illecebrosus*. *Proc. Bio. Soc. Washington*, **91**(4): 1039–1059 (1979).

Roper, C. F. E., C. Nigmatullin, and P. Jereb. Family Ommastrephidae. **In**: *Cephalopods of the world. An annotated and illustrated catalogue of species known to date. Vol. 2. Myopsid and Oegopsid Squids. FAO Species Catalogue for Fishery Purposes. No. 4, Vol. 2*, pp. 269–347 (P. Jereb and C. F. E. Roper, Eds.). Rome, Italy: FAO (2010).

Roper, C. F. E., and M. J. Sweeney. Techniques for fixation, preservation, and curation of cephalopods. *Memories of the National Museum of Victoria*, **44**: 28–47 (1983).

Roper, C. F. E., M. J. Sweeney, and F. G. Hochberg. Cephalopodos. **In**: *Guía FAO para la identificación de especies para los fines de la pesca. Pacífico centro-oriental. Volumen I. Plantas e invertebrados* (W. Fisher, F. Krupp, W. Schneider, C. Sommer, K. E. Carperter and V. H. Niem, Eds.). FAO, Rome. (1995).

Roper, C. F. E., M. J. Sweeney, and C. E. Nauen. FAO species Catalogue, vol. 3. Cephalopods of the world. An annotated and illustrated catalogue of species of interest to fisheries.—FAO Fisheries Synopsis **125**: 277 pp (1984).

Rosa, R., R. O'Dor, and G. J. Pierce (Eds). Advances in squid biology, ecology and fisheries. Part I. Myopsid squids. New York: Nova Science Publishers, Inc. (2013a).

Rosa, R., G. J. Pierce, and R. O'Dor (Eds). Advances in squid biology, ecology and fisheries. Part II. Oegopsid squids. New York: Nova Science Publishers, Inc. (2013b).

Rosa, R., C. Yamashiro, M. Markaida, P. Rodhouse, C. Waluda, C. Salinas-Zavala, F. Keyl, R. O´Dor, J. Stewart, and W. Gilly. *Dosidicus gigas*, Humboldt Squid. **In**: Advances in Squid Biology, Ecology and Fisheries Part II Oegopsid Squids, pp. 169–206 (R. Rosa, R. O'Dor and G. J. Pierce Eds.), New York: Nova Science Publishers, Inc. (2013c).

Rosenberg, A. A., G. P. Kirkwood, J. A. Crombie, and J. R. Beddington. The assessment of stocks of annual squid species. *Fish. Res.*, **8**: 335–350 (1990).

Rowell, T. W., and F. G. Scattolon. The 1985 fishery and biological characteristics of *Illex illecebrosus* in Subarea 4. *NAFO SCR Doc. 86/26, Ser. No. N1140* (1986).

Rowell, T. W., and R. W. Trites. Distribution of larval and juvenile *Illex* (Mollusca, Cephalopoda) in the Blake Plateau region (northwest Atlantic). *Vie Milieu*, **35**: 139–147 (1985).

Rowell, T. W., R. W. Trites, and E. G. Dawe. Distribution of shortfinned squid (*Illex illecebrosus*) larvae and juveniles in relation to the Gulf Stream frontal zone between Florida and Cape Hatteras. *NAFO Sci. Coun. Studies*, **9**: 77–92 (1985b).

Rowell, T. W., J. H. Young, J. C. Poulard, and J. P. Robin. Changes in distribution and biological characteristics of *Illex illecebrosus* on the Scotian shelf, 1980–83. *NAFO Sci. Coun. Studies*, **9**: 11–26 (1985a).

Royer, J., P. Peries, and J.-P. Robin. Stock assessments of English Channel loliginid squids: updated depletion methods and new analytical methods. *ICES J. Mar. Sci.*, **59**: 445–457 (2002).

Rubio, J., and C. Salazar. Prospección pesquera del calamar gigante *(Dosidicus gigas)* a bordo del buque japonés Shinko Maru 2. *Inf. Inst. Mar Perú.*, **103**: 3–32 (1992).

Sabirov, R. M., A. V. Golikov, Ch. M. Nigmatullin, and P. A. Lubin. Structure of the reproductive system and hectocotylus in males of lesser flying squid *Todaropsis eblanae* (Cephalopoda: Ommastrephidae), J. *Nat. Hist.*, **46**: 1761–1778 (2012).

Sacchi, J. Analysis of economic activities in the Mediterranean: Fishery and aquaculture sectors. Plan Bleu, Valbonne (2011).

Sahlqvist, P. Southern Squid Jig Fishery. *Fishery Status Reports 2006: Status of Fish Stocks Managed by the Australian Government*, *Bureau of Rural Sciences*, 187–194 (2007).

Sakai, M. The Southeastern Atlantic Ocean sea area. **In**: *Ika—sono seibutsu kara shouhi made [Squids—From the Animal to Consumption] 3rd ed.*, pp. 168–184, (K. Nasu, T. Okutani and M. Ogura, Eds.), Seizando Shoten: Tokyo (2002) [in Japanese].

Sakai, M., and T. Wakabayashi. The geographical distribution of the fishing grounds of pelagic squid jigging in 2007/2008. National Research Institute of Far Seas Fisheries, No.22. 19 pp. (2010) [in Japanese].

Sakai, M., T. Wakabayashi, and N. Hamaji. Amerika-ooakaika no riyou kakudai ni kansuru teian [A proposal for expansion of the utilization of the jumbo flying squid (*Dosidicus gigas*)], Fisheries Research Agency, 50 p. (2010) [in Japanese].

Sakai, M., C. Yamashiro, L. Mariátegui, T. Wakabayashi, E. Tello, Y. Kato, R. Tafur, V. Blascovic, E. Torres, M. Sanjinez, P. Ayón, M. Romero, K. Suda, and T. Dioses. Crucero de investigación conjunta del calamar gigante *Dosidicus gigas* BIC Kaiyo Maru 2011–2012 (16 de diciembre del 2011 al 19 de enero de 2012). **In**: Informe Final Instituto del Mar del Perú/Fisheries Research Agency (FRA) National Research Institute of Far Seas Fisheries/Fisheries Agency of Japan (M. Sakai and C. Yamashiro Eds.). (2013).

Sakurai, Y., H. Kiyofuji, S. Saitoh, T. Goto, and Y. Hiyama. Changes in inferred spawning areas of the *Todarodes pacificus* (Cephalopoda: Ommastrephidae) due to changing environmental conditions. *ICES J. Mar. Sci.*, **57**: 24–30 (2000).

Salman, A., T., Katağan, and H. A. Benli. Bottom trawl teuthofauna of the Aegean Sea. *Arch. Fish. Mar. Res.*, **45**: 183–196 (1997).

Sánchez, P. Determinacíon de la edad y de los parámetros del crescimento de *Illex coindetii* (Vérany, 1837) en la mar Catalán (Mediterráneo occidental). *Inv. Pesq.*, **48**: 59–70 (1984).

Sanchez, P. Cephalopods from off the Pacific coast of México: biological aspects of the most abundant species. *Sci. Mar.*, **67**: 81–90 (2003).

Sánchez, P., Á. González, P. Jereb, V. Laptikhovsky, K. Mangold, Ch.M. Nigmatullin, and S. Ragonese. *Illex coindetii*. **In**: Squid Recruitment Dynamics: the Genus *Illex* as a Model, the Commercial *Illex* Species and Influences on Variability, pp. 54–76. Ed. by P. G. Rodhouse, E. G. Dawe, and R. K. O'Dor. *FAO Fish. Tech. Pap.*, **376**, 273 pp. (1998).

Sánchez, P., and Á. Guerra. Bathymetric distribution and aspects of the life history of the loliginid squid *Loligo vulgaris* (Mollusca: Cephalopoda) in the Catalan sea (NW Mediterranean). *Iberus*, **12** (2): 1–12 (1994).

Sandoval-Castellanos, E., M. Uribe-Alcoce, and P. Diaz-Jaimes. Population genetic structure of jumbo squid (*Dosidicus gigas*) evaluated by RAPD analysis. *Fish. Res.*, **83**: 113–118 (2007).

Sandoval-Castellanos, E., M. Uribe-Alcocer, and P. Diaz-Jaimes. Population genetic structure of the Humboldt squid (*Dosidicus gigas*) inferred by mitochondrial DNA analysis. *J. Exp. Mar. Biol. Ecol.*, **385**: 73–78 (2010).

Santora, J. A., J. C. Field, I. D. Schroeder, K. M. Sakuma, B. K. Wells, and W. J. Sydeman. Spatial ecology of krill, micronekton and top predators in the central California Current: implications for defining ecologically important areas. *Progr. Oceanogr.*, **106**: 154–174 (2012).

Santos, R. A., and M. Haimovici. Food and feeding of the short-finned squid *Illex argentinus* (Cephalopoda: Ommastrephidae) off southern Brazil. *Fish. Res.*, **33**: 139–147 (1997).

Sartor, P., P. Belcari, A. Carbonell, M. González, A. Quetglas, and P. Sánchez. The importance of cephalopods to trawl fisheries in the western Mediterranean. *S. Afr. J. Mar. Sci.*, **20**: 67–72 (1998).

Sarvesan, R. V Cephalopods. **In**: The Commercial molluscs of India, pp. 63–83 (R. V. Nair, and Rao, K. Satyanarayana, Eds.). Mandapam Camp, CMFRI Bulletin 25 (1974).

Sasaki, M. A monograph of the dibranchiate cephalopods of Japanese and adjacent waters. *Jour. Fac. Agric. Hokkaido Imp. Univ.*, **20**, suppl. 10: 1–357 (1929).

Sasikumar, G., and K. S. Mohamed. Temporal patterns in cephalopod catches and application of non-equilibrium production model to the cephalopod fishery of Karnataka. *Indian J. Mar. Sci.*, **41**: 134–140 (2012).

Sato, M. The movement and migration of *Loligo bleekeri* in the northern Japan Sea. **In**: Report of the 1990 Meeting on Squid Resources and Oceanographic Conditions, pp.49–57 (Tohoku National Fisheries Research Institute (TNFRI), Eds.). Hachinohe, Japan, TNFRI (1990) [in Japanese].

Sato, T., and H. Hatanaka. A review of assessment of Japanese distant-water fisheries for cephalopods. **In**: *Advances in assessment of world cephalopod resources* (J. F. Caddy, Ed.). *FAO Fish. Tech. Pap.*, **231**: 145–180 (1983).

Sauer, W. H. H. The impact of fishing on chokka squid *Loligo vulgaris reynaudii* concentrations on inshore spawning grounds in the South-Eastern Cape, South Africa. *S. Afr. J. mar. Sci.*, **16**: 185–193 (1995).

Sauer, W. H. H., N. J. Downey, M. R. Lipinski, M. J. Roberts, M. J. Smale, J. Glazer, and Y. Melo. *Loligo reynaudi*. **In**: *Advances in Squid Biology, Ecology and Fisheries*, pp. 33–72 (R. Rosa, G. Pierce, and R. O'Dor, Eds.). New York, United States of America: Nova Science Publishers, Inc. (2013).

Sauer, W. H. H., W. S. Goschen, and A. S. Koorts. A preliminary investigation of the effect of sea temperature fluctuations and wind direction on catches of chokka squid *Loligo vulgaris reynaudii* off the Eastern Cape, South Africa. *S. Afr. J. Mar. Sci.*, **11**: 467–473 (1991).

Sauer, W. H. H., and M. R. Lipinski. Histological validation of morphological stages of sexual maturation in chokker squid *Loligo vulgaris reynaudii* D'Orb (Cephalopoda: Loliginidae). *S. Afr. J. mar. Sci.*, **9**: 189–200 (1990).

Sauer, W., M. Lipinski, and J. Augustyn. Tag recapture studies of the chokka squid *Loligo vulgaris reynaudii* D′ Orbigny, 1845 on inshore spawning grounds on the south-east coast of South Africa. *Fish. Res.*, **45**: 283–289 (2000).

Sauer, W. H. H., M. J. Smale, and M. R. Lipinski. The location of the spawning grounds, spawning and schooling behaviour of the squid *Loligo vulgaris reynaudii* (Cephalopoda: Myopsida) off the eastern Cape coast, South Africa. *Mar. Biol.*, **114**: 97–107 (1992).

Schön, P. An investigation into the influence of the environment on spawning aggregations and jig catches of chokka squid *Loligo vulgaris reynaudii* off the coast of South Africa. PhD Thesis, University of Port Elizabeth, Port Elizabeth, South Africa (2000).

Scofield, W. L. Squid at Monterey. *Calif. Dept. Fish Game*, **10**: 176–182 (1924).

Scovazzi, T. Fisheries in the Mediterranean Sea: the relevant international law provisions. **In**: *The state of Italian marine fisheries and aquaculture*, pp. 329–344 (S. Cataudella and M. Spagnolo, Eds.). *Ministero delle Politiche Agricole, Alimentari e Forestali (MiPAAF)*, Italy (2011).

Segawa, S. Life history of the oval squid *Sepioteuthis lessoniana* in Kominato and adjacent waters central Honsyu, Japan. *J. Tokyo Univ. Fish.*, **74**: 67–105 (1987).

Segawa, S., S. Hirayama, and T. Okutani. Is *Sepioteuthis lessoniana* in Okinawa a single species?. **In**: Recent Advances in Cephalopod Fisheries Biology, pp. 513–521 (T. Okutani, R. K. O'dor, and T. Kubodera, Eds.). Tokyo, Japan: Tokai University Press (1993a).

Segawa, S., T. Izuka, T. Tamashiro, and T. Okutani. A note on mating and egg deposition by *Sepioteuthis lessoniana* in Ishigaki Island, Okinawa, Southwestern Japan. *Venus*, **52**: 91–106 (1993b).

Senjyu, T. The Japan Sea Intermediate Water; Its Characteristics and Circulation. *J. Oceanogr.*, **55**: 111–122 (1999).

Serchuk, F. M., and W. F. Rathjen. Aspects of the distribution and abundance of the long-finned squid, *Loligo pealei*, between Cape Hatteras and Georges Bank. *Mar. Fish. Rev.*, **36**: 10–17 (1974).

Shaw, P. W., A. I. Arkhipkin, G. J. Adcock, W. J. Burnett, G. R. Carvalho, J. N. Scherbich, and P. Villegas. DNA markers indicate that distinct spawning cohorts and aggregations of Patagonian squid, *Loligo gahi*, do not represent genetically discrete subpopulations. *Mar. Biol.*, **144**: 961–970 (2004).

Shaw, P. W., G. J. Pierce, and P. R. Boyle. Subtle population structuring within a highly vagile marine invertebrate, the veined squid *Loligo forbesi*, demonstrated with microsatellite DNA markers. *Mol. Ecol.*, **8**: 407–417 (1999).

Shaw, P. W., L. Hendrickson, N. J. McKeown, T. Stonier, M.-J. Naud, and W. H. H. Sauer. Discrete spawning aggregations of loliginid squid do not represent genetically distinct populations. *Mar. Ecol. Prog. Ser.*, **408**: 117–127 (2010).

Shaw, P. W., L. Hendrickson, N. J. McKeown, T. Stonier, M.-J. Naud, and W. H. H. Sauer. Population structure of the squid *Doryteuthis* (*Loligo*) *pealeii* on the eastern coast of the USA: Reply to Gerlach et al. (2012). *Mar. Ecol. Prog. Ser.*, **450**: 285–287 (2012).

Shaw, R. An economic description and assessment of the squid catching industry in Great Britain, Portugal and Spain. *Fish. Res.*, **21**: 287–303 (1994).

Silas, E. G., M. M. Meiyappan, R. Sarvesan, K. P. Nair, M. Srinath, and K. S. Rao. Stock assessment: squids and cuttlefishes at selected centres. *CMFRI Bull.*, **37**: 71–79 (1985a).

Silas, E. G., K. S. Rao, R. Sarvesan, K. P. Nair, and M. M. Meiyappan. The exploited squid and cuttlefish resources of India: A review. Marine Fisheries Information Service, Technical and Extension Series, **34**: 1–16 (1982).

Silas, E. G., R. Sarvesan, M. M. Meiyappan, K. P. Nair, K. S. Rao, K. Vidyasagar, Y. Appanasastry, P. V. Sreenivasan, and B. N. Rao. Cephalopod fisheries at selected centres in India. *CMFRI Bull.*, **37**: 116–128 (1985b).

Sims, D. W., M. J. Genner, A. J. Southward, and S. J. Hawkins. Timing of squid migration reflects North Atlantic climate variability. *P. Roy. Soc. Lond. B Bio.*, **268**: 2607–2611 (2001).

Siriraksophon, S. The 1st Workshop on the Assessment of Fishery Stock Status in South and Southeast Asia. Bangkok, Thailand (2009).

Sissenwine, M. P., and E. W. Bowman. An analysis of some factors affecting the catchability of fish by bottom trawls. *ICNAF Res. Bull.*, **13**: 81–87 (1978).

Sivashanthini, K., G. A. Charles, and W. S. Thulasitha. Length-weight relationship and growth pattern of *Sepioteuthis lessoniana* lesson 1830 (Cephalopoda: Teuthida) from the Jaffna Lagoon, Sri Lanka. *J. Biol. Sci.*, **9**: 357–361 (2009).

Smith, A. D. M., D. C. Smith, G. N. Tuck, N. Klaer, A. E. Punt, I. Knuckey, J. Prince, A. Morison, R. Kloser, M. Haddon, S. Wayte, J. Day, G. Fay, F. Pribac, M. Fuller, B. Taylor, and L. R. Little. Experience in implementing harvest strategies in Australia's south-eastern fisheries. *Fish. Res.*, **94**: 373–379 (2008).

Smith, A. D. M., E. J. Fulton, A. J. Hobday, D. C. Smith, and P. Shoulder. Scientific tools to support the practical implementation of ecosystem-based fisheries management. *ICES J. Mar. Sci.*, **64**: 633–639 (2007).

Smith, J. M. Growth investment and distribution of the squid *Loligo forbesi* (Cephalopoda: Loliginidae) in northeast Atlantic waters. PhD thesis. Aberdeen: University of Aberdeen (2011).

Smith, J. M., C. D. MacLeod, V. Valavanis, L. C. Hastie, T. Valinassab, N. Bailey, M. B. Santos, and G. J. Pierce. Habitat and distribution of post-recruit life stages of the squid *Loligo forbesii*. *Deep-Sea Res. Pt. II*, **95**: 145–159 (2013).

Smith, P. J., P. E. Roberts, and R. J. Hurst. Evidence for Two Species of Arrow Squid in the New Zealand Fishery. *N. Z. J. Mar. Freshwater. Res.*, **15**: 247–253 (1981).

Smith, P. J., R. H. Mattlin, M. A. Roeleveld, and T. Okutani. Arrow squids of the genus Nototodarus in New Zealand waters: Systematics, biology, and fisheries. *N. Z. J. Mar. Freshwater. Res.*, **21**: 315–326 (1987).

Smith, T. M., C. P. Green, and C. D. H. Sherman. Patterns of connectivity and population structure of the southern calamary *Sepioteuthis australis* in southern Australia. *Mar. Freshw. Res.* (2015, In press).

Snyder, R. Aspects of the biology of the giant form of *Sthenoteuthis oualaniensis* (Cephalopoda: Ommastrephidae) from the Arabian Sea. *J. Moll. Std.*, **64**: 21–34 (1998).

So.Ge.Mi. SpA, Ente Gestore dei Mercati Agroalimentari all'Ingrosso di Milano, 2013. *www.mercatimilano.it*.

Soeda, J. The migration of the squid; Surume-ika; *Ommastrephes sloani pacificus* (Steenstrup) in the coastal waters of Japan. *Scientific Report of Hokkaido Fisheries experimental station*, **4**: 1–30 (1950).

Sokimi, W. Giant squid trials in the Cook Islands. *SPC Fisheries Newsletter*, **141**: 9 (2013).

Song, H. T., T. M. Ding, and K. D. Xu. The quantity distribution and growth characteristics of Loligo edulis in the East China Sea. *J. Zhejiang Oce. Univ.*, **27**: 115–118 (2008).

Songjitsawat, A., and S. Sookbuntoeng. Catch composition of marine fauna from light luring squid fishing. *Tech. Pap. 10, East. Mar. Fish. Dev. Cent., Mar. Fish. Div., Dept. Fish.* (1988).

Songjitsawat, A., and S. Sookbuntoeng. Experiment on optimal light intensity in squid light luring castnet. *Tech. Pap. 6/2001, East. Mar. Fish. Dev. Cent., Mar. Fish. Div., Dept. Fish.* (2001).

Soro, S., and M. Paolini. *Illex coindetii* (Verany, 1839): aspetti biologici ed evoluzione della popolazione in alto e medio Adriatico. *Biol. Mar. Mediter.*, **1**: 213–218 (1994).

Southeast Asian Fisheries Development Center (SEAFDEC). *Proceedings of the Third Technical Seminar on Marine Fishery Resources Survey in the South Chine Sea, Area III: Western Philipines. Special*, paper No. SEC/SP/41. Bangkok: Southeast Asian Fisheries Development Center (2000).

Southeast Asian Fisheries Development Center (SEAFDEC). Southeast Asian fishery statistics. www.fishstat.seafdec.org. Access 15 February 2013 (2013).

SPC (Secretariat of the Pacific Community) Coastal Fisheries Programme. Exploratory squid fishing in Fiji waters, a success. Accessed August 1, 2014. http://www.spc.int/coastfish/en/component/content/article/429-fiji-giant-squid.html

Speed, T. Mathematics. A correlation for the 21st century. *Science*, **334**: 1502–1503 (2011).

Squires, H. J. Growth and hypothetical age of the Newfoundland bait squid *Illex illecebrosus illecebrosus*. *J. Fish. Res. Board. Canada*, **24**: 1209–1217 (1967).

Squires, H. J. Squid *Illex illecebrosus* (Lesueur), in the Newfoundland fishing area. *J. Fish. Res. Board Canada*, **14**: 693–728 (1957).

Srichanngam, S. Age and growth determination and stock identification using statolith microstructure of Indian squid, *Loligo duvauceli*. MSc Thesis, University of Bergen, Bergen, Norway (2010).

Srikum, T., and P. Binraman. Collapsible squid trap fisheries in Ban Jao-lhao, Chantaburi Province. *Tech. Pap., Mar. Fish. Res. Dev. Bur., Dept. Fish.* (2008).

Staaf, D. J., S. Camarillo-Coop, S. H. D. Haddock, A. C. Nyack, J. Payne, C. A. Salinas-Zavala, B. A. Seibel, L. Trueblood, C. Widmer, and W. F. Gilly. Natural egg mass deposition by the Humboldt squid (*Dosidicus gigas*) in the Gulf of California, and characteristics of hatchlings and paralarvae. *J. Mar. Biol. Assoc. U.K.*, **88**: 759–770 (2008).

Staaf, D. J., R. I. Ruiz-Cooley, C. Elliger, Z. Lebaric, B. Campos, U. Markaida, and W. Gilly. Ommastrephid squids *Sthenoteuthis oualaniensis* and *Dosidicus gigas* in the eastern Pacific show convergent biogeographic breaks but contrasting population structures. *Mar. Ecol. Prog. Ser.*, **418**: 165–178 (2010).

Stark, K. E., G. D. Jackson, and J. M. Lyle. Tracking arrow squid movements with an automated acoustic telemetry system. *Mar. Ecol. Prog. Ser.*, **299**: 167–177 (2005).

Starr, R. M., and R. E. Thorne. Acoustic assessment of squid stocks. In: Rodhouse, P. G., Dawe, E. G., O'Dor, R. K. (Eds.), Squid Recruitment Dynamics: the Genus *Illex* as a Model, the Commercial *Illex* Species and Influences on Variability, FAO Fisheries Technical Paper No. 376. FAO, Rome, pp. 181–198 (1998).

Staudinger, M. D. Seasonal and size-based predation on two species of squid by four fish predators on the Northwest Atlantic continental shelf. *Fish. Bull.*, **104**: 605–615 (2006).

Staudinger, M. D., and F. Juanes. A size-based approach to quantifying predation on longfin inshore squid (*Loligo pealeii*) in the northwest Atlantic. *Mar. Ecol. Progr. Ser.*, **399**: 225–241 (2010).

Steer, M. A., M. T. Lloyd, and W. B. Jackson. Assessing the feasibility of using 'by-product' data as a pre-recruit index in South Australia's southern calamary (*Sepioteuthis australis*) fishery. *Fish. Res.*, **88**: 42–50 (2007).

Steer, M. A., N. A. Moltschaniwskyj, and F. C. Gowland. Temporal variability in embryonic development and mortality in the southern calamary *Sepioteuthis australis*: a field assessment. *Mar. Ecol. Prog. Ser.*, **243**: 143–150 (2002).

Steer, M. A., G. T. Pecl, and N. A. Moltschaniwskyj. Are bigger calamary *Sepioteuthis australis* hatchlings more likely to survive? A study based on statolith dimensions. *Mar. Ecol. Prog. Ser.*, **261**: 175–182 (2003).

Stevenson, J. A. On the behavior of the long-finned squid (*Loligo pealei* (LeSueur)). *Can. Field Nat.*, **48**: 4–7 (1934).

Stewart, J. S., E. L. Hazen, D. G. Foley, S. J. Bograd, and W. F. Gilly. Marine predator migration range expansion: Humboldt squid *Dosidicus gigas* in the northern California Current System. *Mar. Ecol. Progr. Ser.*, **471**: 135–150 (2012).

Stroud, G. D. Squid. Torry Advisory Note No. 77. Aberdeen: Torry Research Station, Ministry of Agriculture, Fisheries and Food (1978).

Sukramongkol, N., S. Promjinda, and R. Prommas, Age and Reproduction of *Sthenoteuthis oualaniensis* in the Bay of Bengal. **In**: *The Ecosystem Based Fishery Management in the Bay of Bengal*. Department of Fisheries. 195–205. Thailand (2008).

Sukramongkol, N., K. Tsuchiya, and S. Segawa. Age and maturation of *Loligo duvauceli* and *L. chinensis* from Andaman Sea of Thailand. *Rev. Fish Biol. Fish.*, **17**: 237–246 (2007).

Sukramongkol, N., K. Tsuchiya, and S. Segawa. Age and maturation of *Loligo duvauceli* and *L. chinensis* from Andaman Sea of Thailand. *Rev fish Biol. Fish.*, **17**: 237–246 (2007).

Summers, W. C. Winter population of *Loligo pealei* in the Mid-Atlantic Bight. *Biol. Bull.*, **137**: 202–216 (1969).

Summers, W. C. (*Loligo pealei*), **In**: *Cephalopod Life Cycles, Vol. I: Species Accounts*. P. 115–142 (P. R. Boyle, Ed.). New York, NY: Academic Press, Inc. (1983).

Sun, D. R., Y. Li, X. H. Wang, Y. Z. Wang, and Q. E. Wu. Biological characteristics and stock changes of *Loligo edulis* in Beibu Gulf, South China Sea. *S. Chin. Fish. Sci.*, **7**: 8–13 (2011).

Sundaram, S., and V. D. Deshmukh. Emergence of squid jigging in India. *Fish. Chimes*, **30**: 18–20 (2011).

Sundet, J. A short review on the biology and fishery of the squid *Todarodes sagittatus*. ICES Document CM 1985/K: 44. Copenhagen: International Council for the Exploration of the Sea (1985).

Supongpan, M. Cephalopod resources in the Gulf of Thailand. **In**: *Biology and Culture of Cephalopods*, pp. 191–220 (J. Nabhitabhata, Ed.). Rayong, Thailand: Rayong Coastal Aquaculture Station (1995).

Supongpan, M. The fisheries biology of Indian squid (*Loligo duvauceli*) in west coast of the Gulf of Thailand. PhD Dissertation, Nagasaki University, Nagasaki, Japan (1996).

Supongpan, M., C. Chotiyaputta, and M. Sinoda. Maturity and length frequency distribution of the Indian squid *Loligo duvauceli* caught in the Gulf of Thailand. *Nippon Suisan Gakk.*, **59**: 1963–1969 (1993).

Supongpan, M., K. Kongmuag, and S. Jittrapong. Bigfin reef squid fisheries in the Gulf of Thailand. *Tech. Pap. 1/1988, Mar. Fish. Div., Dept. Fish.* (1988).

Supongpan, M., and Y. Natsukari. Age and growth determination using statolith increments of *Loligo duvauceli* in the Gulf of Thailand. *Tech. Pap. Bangkok Mar. Fish. Dev. Mar. Fish. Div.*, **38**: 1–14 (1996).

Suppanirun, T., N. Songkeaw, U. Khrueniam, and C. Pinputtasin. Reproductive biology of Indian squid, *Photololigo duvaucelii* (d'Orbigny, 1835) and mitre squid, *P. chinensis* (Gray, 1849) in the Gulf of Thailand. *Tech. Pap., Mar. Fish. Res. Dev. Bur., Dept. Fish.* (2011).

Suppapreuk, T., S. Sangchan, K. Loychuen, S. Boonsuk, and C. Sanga-ngam. Squid trap fishery in the Andaman Sea of Thailand. *Tech. Pap., Andaman Sea Fish. Res. Dev. Cent., Mar. Fish. Res. Dev. Bur., Dept. Fish.* (2013).

Suzuki, T. Japanese common squid – *Todarodes pacificus* Steenstrup. *Mar. Behav. Physiol.*, **18**: 73–109 (1990).

Tafur, R., and M. Rabí. Reproduction of the jumbo flying squid, *Dosidicus gigas* (Orbigny, 1835) (Cephalopoda: Ommastrephidae) off Peruvian coasts. *Sci. Mar.*, **61**: 33–37 (1997).

Tafur, R., P. Villegas, M. Rabi, and C. Yamashiro. Dynamics of maturation, seasonality of reproduction and spawning grounds of the jumbo squid *Dosidicus gigas* (Cephalopoda: Ommastrephidae) in Peruvian waters. *Fish. Res.*, **54**: 33–50 (2001).

Taipe, A, C. Yamashiro, L. Mariategui, P. Rojas, and C. Roque. Distribution and concentration of jumbo flying squid (*Dosidicus gigas*) off the Peruvian coast between 1991 and 1999. *Fish. Res.*, **54**: 21–32 (2001).

Takahashi, M., and H. Furuta. Relationship between fishing grounds and oceanographic structure of *Loligo edulis* and *Loligo edulis budo* in angling fishery of Chikuzenkai, north coastal waters off Fukuoka. *Bull. Fukuoka Fish. Exp. Stn.*, **14**: 13–21 (1988) [in Japanese].

Takayanagi, S. Changes in growth and maturity of Japanese common squid (*Todarodes pacificus*) related to differences in stock size in the Tsugaru Strait, Northern Japan. **In**: *Recent Advances in Cephalopod Fisheries Biology*, pp. 545–553 (T. Okutani, R. K. O'Dor, and T. Kubodera, Eds.). Tokyo: Tokai University Press (1993).

Takeda, R., and M. Tanda. *Thysanoteuthis rhombus* Troschel caught in Tajima region of the Japan Sea. **In**: *Heisei 7 nendo ikarui shigen kenkyuu kaigi houkoku [Report of the 1995 Meeting on Squid Resources]*. pp. 1–7. Niigata, Japan: Japan Sea National Fisheries Research Institute (1997).

Takeda, R., and M. Tanda. Fishing and migration of *Thysanoteuthis rhombus* Troschel in the Japan Sea. **In**: *Contributed Papers to International Symposium on Large Pelagic Squids*, pp. 191–198 (T. Okutani, Ed.). Tokyo, Japan: Japan Marine Fishery Resources Research Center (1998).

Tashiro, M. Swordtip squid and its fishery in coastal waters of northwestern Kyushu. *Nihonkai Block Shigen Kenkyu Shuroku*, **1**: 81–96 (1977) [in Japanese].

Tashiro, M. Broods. *Report on a Survey of the Ecology and Stock of Swordtip Squid in the Western Japanese Waters*: 22–26 (1978) [in Japanese].

Thapanand, T., and W. Phetchsuthti. Stock assessment of bigfin reef squid (*Sepioteuthis lessoniana* Lesson) caught by squid trap at Sikao bay, Trang province. *Warasan Kan Pramong*, **53** (2000).

Thomas, H. J. Some observations on the exploitation and distribution of squid around Scotland. ICES Document CM 1969/K: 29. Copenhagen: International Council for the Exploration of the Sea (1969).

Thomas, H. J. Squid. *Scottish Fishery Bulletin*, **39**: 35–39 (1973).

Ti, Z., X. Ma, Z. Wang, G. Lin, F. Xu, Z. Dong, F. Li, and D. Lv. Mollusca of Huanghai and Bohai Seas. Beijing: Agricultural Publishing House (1987) [In Chinese].

Tian, S., X. Chen, Y. Chen, L. Xu, and X. Dai. Standardizing CPUE of *Ommastrephes bartramii* for Chinese squid-jigging fishery in Northwest Pacific Ocean. *Chinese J. Oceanog. Limnol.* **27**: 729–739 (2009).

Tian, Y. Long-term changes in the relative abundance and distribution of spear squid, *Loligo bleekeri*, in relation to sea water temperature in the south-western Japan Sea during the last three decades. *GIS/Spatial Analyses in Fishery and Aquatic Sciences*, **3**: 27–46 (2007).

Tian, Y. Interannual-interdecadal variations of spear squid *Loligo bleekeri* abundance in the southwestern Japan Sea during 1975–2006: impacts of the trawl fishing and recommendations for management under the different climate regimes. *Fish. Res.*, **100**: 78–85 (2009).

Tian, Y. Stock assessment and evaluation for Tsushima Warm Current stock of spear squid (fiscal year 2011). **In**: Marine Fisheries Stock Assessment and Evaluation for Japanese Waters (fiscal year 2011/2012), pp. 1732–1743 (Fisheries Agency and Fisheries Research Agency of Japan (FA&FRA), Eds.). Tokyo, FA&FRA (2012) [in Japanese].

Tian, Y., H. Kidokoro, and T. Fujino. Interannual-decadal variability of demersal fish community in the Japan Sea: Impacts of climate regime shifts and trawl fishing with implications for ecosystem-based management. *Fish. Res.*, **112**: 140–153 (2011).

Tian, Y., K. Nashida, and H. Sakaji. Synchrony in abundance trend of spear squid *Loligo bleekeri* in the Japan Sea and the Pacific Ocean with special reference to the latitudinal differences in response to the climate regime shift. *ICES J. Mar. Sci.*, **70**: 968–979 (2013).

Tokai, T., and Y. Ueta. Estimation of size selectivity for oval squid Sepioteuthis lessoniana in the squid jigging fishery of Tokushima Prefecture, *Fish. Sci.*, **65**: 448–454 (1999).

Tokimura, M. Distribution of demersal fish in winter, 1991 (report of the results by Kaiho Maru surveys). *Report of Seikai Block Council on Demersal Fish*, **3**: 15–39 (1992) [in Japanese].

Tomás, A. R. G., M. A. Gasalla, and M. H. Carneiro. Dinâmica da frota de arrasto-de-portas do Estado de São Paulo. **In**: *Dinâmica das frotas pesqueiras comerciais da região Sudeste-Sul do Brasil*, pp. 41–59 (C. L. D. B. Rossi-Wongtschowski, R. A. Bernardes and M. C. Cergole, Eds.). São Paulo, Brazil: Série Documentos REVIZEE – SCORE Sul. São Paulo, Instituto Oceanográfico, USP (2007).

Toriyama, M., H. Sakamoto, and H. Horikawa. Relationship between the distribution of spear squid and the environment in Tosa Bay. *Fisheries Biology and Oceanography in the South-Western Waters of Japan*, **3**: 27–36 (1987) [in Japanese].

Triantafillos, L. Population biology of southern calamary, *Sepioteuthis australis*, in Gulf St. Vincent, South Australia. PhD Dissertation, Northern Territory University (2001).

Triantafillos, L. Use of depetion analysis in the Southern Squid Jig Fishery of Australia. *Internal report submitted to the Australian Fisheries Management Authority*, (2008).

Triantafillos, L., and M. Adams. Allozyme analysis reveals a complex population structure in the southern calamary *Sepioteuthis australis* from Australia and New Zealand. *Mar. Ecol. Progr. Ser.* **212**: 193–209 (2001).

Triantafillos, L., and M. Adams. Genetic evidence that the northern calamary, *Sepioteuthis lessoniana*, is a species complex in Australian waters. *ICES J. Mar. Sci.*, **62**: 1665–1670 (2005).

Triantafillos, L., G. D. Jackson, M. Adams, and B. L. McGrath Steer. An allozyme investigation of the stock structure of arrow squid *Nototodarus gouldi* (Cephalopoda: Ommastrephidae) from Australia. *ICES J. Mar. Sci.*, **61**: 829–835 (2004).

Trites, R. W. Physical oceanographic features and processes relevant to *Illex illecebrosus* spawning in the western North Atlantic and subsequent larval distribution. *NAFO Sci. Coun. Stud.*, **6**: 39–55 (1983).

Tryon G. W. Manual of Conchology. Vol. 1: Cephalopoda. Philadelphia (1879).

Tsou, T. S., and J. S. Collie. Predation-mediated recruitment in the Georges Bank fish community. *ICES J. Mar. Sci.*, **58**: 994–1001 (2001).

Tung, I. On the reproduction of common squid, *Symplectoteuthis oualaniensis* (Lesson). *Rep. Inst. Fish. Biol. Taipei.*, **3**: 26–48 (1976).

Tursi, A., and G., D'Onghia. Cephalopods of the Ionian Sea (Mediterranean Sea). *Oebalia*, **18**: 25–43 (1992).

Uchino, K., A. Yamasaki, S. Fujita, and T. Tojima. Food Habits of the Flatfish, *Hippoglossoides dubius* (Schmidt), in the Sea off Kyoto Prefecture. *Bull. Kyoto Inst. Ocean. Fish. Sci.*, **17**: 41–45 (1994).

Uchiyama, I., S. Hayashi, and Y. Ogawa. Catch fluctuation patterns of firefly squid (*Watasenia scintillans*) in Toyama Bay. *Bull. Jpn. Soc. Fish. Oceanogr.*, **69**: 271–283 (2005).

Uda, M. Nihonkai oyobi sono rinsetsukaiku no kaikyou. *J. Imp. Fish. Exp. Sta.*, **5**: 57–190 (1934).

Ueda, T. Relationship between spawning sites and its water temperatures. *Bull. Fukuoka Fisheries Mar. Techno. Res. Cent.*, **19**: 61–67 (2009) [in Japanese].

Ueno, Y., and M. Sakai. Fish stocks expected to be expanded to the utilization, Pacific saury and neon flying squid, In: *A design to rebuild Japanese fisheries; Issues and improvements to the offshore fisheries industry*, p.42–64 (Y. Ueno, Y. Kumazawa and H. Inada, Eds), Koseisha Koseikaku (2010) [in Japanese].

Ueta, Y., T. Tokai and S. Segawa. Relationship between year-class Abundance of oval squid *Sepioteuthis lessoniana* and environmetal factors off Tokushima Prefecture. *Japan. Fish. Sci*. **65**: 424–431 (1999).

Ueta, Y. Fisheries biological studies of the oval squid, *Sepioteuthis lessoniana* around Tokushima Prefecture. *Bull. Tokushima Pref. Fish. Exp. Stn.* **1**: 1–79 (2000) [in Japanese with English abstract].

Ueta, Y. Ecology and stock management of oval squid, *Sepioteuthis lessoniana*. Tokyo: Japan Fisheries Resource Conservation Association (2003) [in Japanese].

Ueta, Y., and T. Umino. Challenge to the clarification of secret on oval squid. Tokyo: Seizandou (2013) [in Japanese].

Ungaro, N., C. A. Marano, R. Marsan, M. Martino, M. C. Marzano, G. Strippoli, and A. Vlora. Analysis of demersal species assemblages from trawl surveys in the South Adriatic sea. *Aquat. Living Resour.*, **12**: 177–185 (1999).

Ünsal, İ., N. Ünsal, M. H. Erk, and H. Kabasakal. Demersal cephalopods from the Sea of Marmara, with remarks on some ecological characteristics. *Acta Adriat.*, **40**: 105–110 (1999).

Uozumi, Y. Fishery biology of arrow squids, *Nototodarus gouldi* and N. *sloanii*, in New Zealand waters. *Bull. Nat. Res. Inst. Far Seas Fish.* **35**: 1–111 (1998).

Uozumi, T., and C. Shiba. Growth and age composition of *Illex argentinus* (Cephalopoda: Oegopsida) based on daily increment counts in statoliths. **In**: *Recent advances in cephalopod fisheries biology*, pp. 591–605 (T. Okutani, R. K. O'Dor and T. Kubodera, Eds.). Tokai University Press, Tokyo (1993).

Valavanis, V. D., S. Georgakarakos, D. Koutsoubas, C. Arvanitidis, and J. Haralabous. Development of a marine information system for cephalopod fisheries in eastern Mediterranean. *Bull. Mar. Sci.*, **71**: 867–882 (2002).

Valinassab, T., G. J. Pierce, and K. Johannesson, K. Lantern fish (*Benthosema pterotum*) resources as a target for commercial exploitation in the Oman Sea. *J. Appl. Ichthyol.*, **23**: 573–577 (2007).

van Camp, L. M., K. M. Saint, S. C. Donnellan, J. N. Havenhand, and P. G. Fairweather. Polymorphic microsatellite markers for paternity assessment in southern calamari *Sepioteuthis australis* (Cephalopoda: Loliginidae). *Mol. Ecol. Notes*, **3**: 654–655 (2003).

van Camp, L., S. C. Donnellan, A. R. Dyer, and P. Fairweather. Multiple paternity in field-and captive-laid egg strands of *Sepioteuthis australis* (Cephalopoda: Loliginidae). *Mar. Freshwater Res.*, **55**: 819–823 (2004).

van der Elst, R., B. Everett, N. Jiddawi, G. Mwatha, P. S. Afonso, and D. Boulle. Fish, fishers and fisheries of the Western Indian Ocean: their diversity and status. A preliminary assessment. *Philosophical Transactions of the Royal Society. A*. **363**: 263–284 (2005).

Vaughn, D. L., and C. W. Recksiek. Detection of market squid, *Loligo opalescens*, with echo sounders. *Calif. Coop. Ocean. Fish. Inv. Rep.*, **20**: 40–50 (1979).

Vaz, S., A. Carpentier, and F. Coppin. Eastern English Channel fish assemblages: measuring the structuring effect of habitats on distinct subcommunities. *ICES J. Mar. Sci.*, **64**: 271–287 (2007).

Vecchione, M. Aspects of the early life history of *Loligo pealei* (Cephalopoda: Myopsida). *J. Shellfish Res.*, **1**: 171–180 (1981).

Vecchione, M. *In-situ* observations on a large squid spawning bed in the eastern Gulf of Mexico. *Malacologia*, **29**: 135–141 (1988).

Vecchione, M., R. E. Young, and U. Piatkowski. Cephalopods of the northern Mid-Atlantic Ridge. *Mar. Biol. Res.*, **6**: 25–52 (2010).

Vega, M. A., F. J. Rocha, A. Guerra, and C. Osorio. Morphological differences between the Patagonian squid *Loligo gahi* populations from the Pacific and Atlantic Oceans. *Bull. Mar. Sci.*, **71**: 903–913 (2002).

Vega, M. A., F. Rocha, and C. Osorio. Morfometría comparada de los estatolitos del calamar *Loligo gahi* d'Orbigny, 1835 (Cephalopoda: Loliginidae) del norte de Perú e islas Falkland. *Invest. Mar.*, **29**: 3–9 (2001).

Venter, J. D., S. van Wyngaardt, M. R. Lipinski, H. M. Verheye, and J. A. Verschoor. Detection of zooplankton prey in squid paralarvae with immunoassay. *J. Immunoassay*, **20**: 127–149 (1999).

Verrill, A. E. http://archive.org/search.php?query=creator%3A%22Verrill. (1879–1882).

Viana, M., G. J. Pierce, J. Illian, C. D. MacLeod, N. Bailey, J. Wang, and L. C. Hastie. Seasonal movements of veined squid *Loligo forbesii* in Scottish (UK) waters. *Aquat. Living Resour.*, **22**: 1–15 (2009).

Vibhasiri, A. Present status of squid fisheries of Thailand. *Ann. Rep. 1980, Invertebr. Sect., Mar. Fish. Div., Dept. Fish.* (1980).

Vibhasiri, A., S. Hayase, and S. Shindo. Changes in the stock of invertebrates in the Gulf of Thailand 1972–1981. *Res. Pap. Ser. 5, Train. Dept., SEAFDEC* (1985).

Villa, H., J. Quintela, M. L. Coelho, J. D. Icely, and J. P. Andrade. Phytoplankton biomass and zooplankton abundance on the south coast of Portugal (Sagres), with special reference to spawning of Loligo vulgaris. *Sci. Mar.*, **61**(2): 123–129 (1997).

Villanueva, R. Cephalopods of Namibia: three life strategies in the Benguela system. PhD Thesis, University of Barcelona, Barcelona, Spain (1992).

Villegas, P. Growth, life cycle and fishery biology of *Loligo gahi* (d'Orbigny, 1835) off the Peruvian coast. *Fish. Res.*, **54**: 123–131 (2001).

Vojkovich, M. The California fishery for market squid (*Loligo opalescens*). *Calif. Coop. Ocean. Fish. Inv. Rep.*, **39**: 55–60 (1998)

Voss, G. L. Cephalopod resources of the world. FAO Fisheries Circular, No. 49, 75 pp (1973).

Vovk, A. N., and Ch. M. Nigmatullin. On biology and fishery of mass abundant Atlantic cephalopods. *Trudy AtlantNIRO*, **42**: 22–56 (1972) [In Russian].

Wada, Y., and T. Kobayashi. On an iteroparity of the oval squid *Sepioteuthis lessoniana*. *Nippon Suisan Gakkaishi*, **61**: 151–158 (1995) [in Japanese with English abstract].

Wada, Y. On the multiple copulations of the oval squid *Sepioteuthis lessoniana*. *Bull. Kyoto Inst. Ocean. Fish. Sci.*, **61**: 151–158 (1993) [in Japanese with English abstract].

Wakabayashi, T., S. Wada, Y. Ochi, T. Ichii, and M. Sakai, M. Genetic differentiation of the neon flying squid *Ommastrephes bartramii* between North Pacific and South Atlantic populations. *Nippon Suisan Gakkaishi*, **78**: 198–210 (2012) [in Japanese].

Wakabayashi, T., T. Yanagimoto, and T. Kobayashi. Kokunai de no riyou jittai [Actual condition on the utilization of jumbo flying squid in Japan]. **In**: *Amerika-ooakaika no riyou kakudai ni kannsuru teiann [A proposal for expansion of the utilization]*. pp. 36–37 (M. Sakai, T. Wakabayashi and N. Hamaji, Eds.), Fish. Res. Agency (2010).

Wakabayashi T., T. Yanagimoto, M. Sakai, T. Ichii, and K. Miki. Identification of squid species for processed foods using mtDNA COI analyses. *DNA Polymorphism*, **21**: 144–146 (2009).

Waldron, D. Distribution of *Illex illecebrosus* during the 1977 international fishery on the Scotian Shelf. **In**: Proceedings of the workshop on the squid *Illex illecebrosus*, pp. 4.1–4.26 (N. Balch, T. Amaratunga, and R. K. O'Dor, Eds.). Halifax, Nova Scotia: Dalhousie University (1978).

Waluda, C. M., and G. J. Pierce. Temporal and spatial patterns in the distribution of squid *Loligo* spp. in United Kingdom waters. *S. Afr. J. Mar. Sci.*, **20**: 323–336 (1998).

Waluda C. M., P. G. Rodhouse, G. P. Podesta, and P. N. Trathan. Surface oceanography of the inferred hatching grounds of *Illex argentinus* (Cephalopoda: Ommastreshidae) and influences on recruitment variability. *Mar. Biol.* **139**: 671–679 (2001).

Wang, K. Y., K. Y. Chang, C. H. Liao, M. A. Lee, and K. T. Lee. Growth strategies of the swordtip squid, *Photololigo edulis*, in response to environmental changes in the Southern East China Sea — a cohort analysis. *Bull. Mar. Sci.*, **89**: 677–698 (2013).

Wang, K. Y., R. G. Chen, C. H. Liao, K. T. Lee, C. L. Wu, M. A. Lee, and K. Y. Chang. Seasonal growth differences of *Uroteuthis edulis* in the southern East China Sea, based on statolith analysis. *J. Taiwan Fish. Res.*, **19**: 1–13 (2011) [In Chinese with English abstract].

Wang, K. Y., K. T. Lee, and C. H. Liao. Age, growth and maturation of swordtip squid (*Photololigo edulis*) in the southern East China Sea. *J. Mar. Sci. Technol. Taiwan*, **18**: 99–105 (2010).

Wang, K. Y., C. H. Liao, and K. T. Lee. Population and maturation dynamics of the swordtip squid (*Photololigo edulis*) in the southern East China Sea. *Fish. Res.*, **90**: 178–186 (2008).

Wang, Y. G. and X. J. Chen. The resource and biology of economic oceanic squid in the world. Ocean Press, Beijing, pp.79–295 (2005) [In Chinese].

Wang, Y. X. Fishery biological characteristics of swordtip squid *Loligo edulis* in the southern part of the East China Sea. *Mar. Fish.*, **4**: 169–172 (2002).

Wangvoralak, S. Life history and ecological importance of the veined squid *Loligo forbesii* in Scottish waters. PhD thesis. Aberdeen: University of Aberdeen (2011).

Wangvoralak, S., L. C. Hastie, and G. J. Pierce. Temporal and ontogenetic variation in the diet of squid (*Loligo forbesii* Streenstrup) in Scottish waters. *Hydrobiologia*, **670**: 223–240 (2011).

Waring, G. T., P. Gerrior, P. M. Payne, B. I. Barry, and J. R. Nicolas. Incidental take of marine mammals in foreign fishery activities off the Northeast United States, 1977–1988. *Fish. Bull. U.S.*, **88**: 347–360 (1990).

Warner, R. R., S. L. Hamilton, M. S. Sheehy, L. D. Zeidberg, B. C. Brady, and J. E. Caselle. Geographic variation in natal and early larval trace-elemental signatures in the statoliths of the market squid *Doryteuthis* (formerly *Loligo*) opalescens. *Mar. Ecol. Progr. Ser.*, **379**: 109–121 (2009).

Watters G. M., R. J. Olson, R. C. Francis, P. C. Fiedler, J. J. Polovina, S. B. Reilly, K. Y. Aydin, C. H. Boggs, T. E. Essington, C. J. Walters, and J. F. Kitchell. Physical forcing and the dynamics of the pelagic ecosystem in the eastern tropical Pacific: simulations with ENSO-scale and global-warming climate drivers. *Can. J. Fish. Aquat. Sci.*, **60**: 1161–1175 (2003).

Watters, G. M., R. J. Olson, J. C. Field, and T. E. Essington. Range expansion of the Humboldt squid was not caused by tuna fishing. *Proc. Nat. Acad. Sci. U. S. A.* **105**: E5 (2008).

Whitaker, J. D. A contribution to the biology of *Loligo pealei* and *Loligo plei* (Cephalopoda, Myopsida) off the southeastern coast of the United States, M.Sc. Thesis, College of Charleston. USA (1978).

Wiborg, K. F. The squid *Todarodes sagittatus* (Lamarck) in the Norwegian coastal waters during the autumn 1977 and spring 1978. ICES C. M. K:16. Copenhagen: International Council for the Exploration of the Sea (1978).

Wiborg, K. F. Investigations on the squid, *Todarodes sagittatus* (Lamarck) in Norwegian coastal and bank waters in September-December 1984, April and August-September 1985, at Shetland in July 1984, and at the Faroes in August 1985. *Fisken Havunders* **2**: 1–8 (1987).

Wiborg, K. F., and I. M. Beck. The squid *Todarodes sagittatus* (Lamarck). Distribution and biology in Norwegian waters, August 1982 – June 1983. ICES Document CM 1983/K: 7. Copenhagen: International Council for the Exploration of the Sea (1983).

Wiborg, K. F., and I. M. Beck. The squid *Todarodes sagittatus* (Lamarck). Investigations in Norwegian coastal and bank waters, July 1983–January 1984, and west of the British Isles, March-April 1984. ICES Document CM 1984/K: 20. Copenhagen: International Council for the Exploration of the Sea (1984).

Wiborg, K. F., J. Gjøsæter, I. M. Beck, and P. Fossum. Squid *Todarodes sagittatus* (Lamarck) distribution and biology in northern waters, April 1981–April 1982. ICES Document CM 1982/K: 30. Copenhagen: International Council for the Exploration of the Sea (1982).

Willcox, S., J. Lyle, and M. Steer. Tasmanian arrow squid fishery—status report 2001. *Tasmanian Aquaculture and Fisheries Institute, Hobart* (2001).

Wilson, D., R. Curtotti, G. Begg, and K. Phillips. Fishery status reports 2008: status of fish stocks and fisheries managed by the Australian Government. *Bureau of Rural Sciences & Australian Bureau of Agricultural and Resource Economics, Canberra* (2009).

Wilson, T. D., R. Curtotti, and G. Begg. Fishery status reports 2009: status of fish stocks and fisheries managed by the Australian Government. *Australian Bureau of Agricultural and Resource Economics – Bureau of Rural Sciences, Canberra* (2010).

Wing, B. L., and R. W. Mercer. Temporary northern range extension of the squid *Loligo opalescens* in southeast Alaska. *Veliger*, **33**: 238–240 (1990).

Winstanley R. H., M. A. Potter, and A. E. Caton. Australian cephalopod resources. *Mem. Natl. Mus. Victoria, Melbourne*, **44**: 243–253 (1983).

Wolf, D. C. Tasmanian Surveys put to good use. *Aust. Fish.*, **32**: 6–9 (1973).

Woodhams, J., S. Vieira, and I. Stobutzki. Fishery status reports 2011. *Australian Bureau of Agricultural and Resource Economics and Sciences*. (2012).

Worms, J. Aspects de la biologie de *Loligo vulgaris* Lam. liés á la reproduction. *Vie Milieu*, **30**: 263–267 (1980).

Worms, J. L'utilisation des prises commercialesen biologie des pêches. Application à l'étude d'une population de *Loligo vulgaris* (Cephalopoda, Teuthoidea) du Golfe du Lion. Thése, 3ème cycle, USTL Montpellier, France, 119 pp., 71 figs. (1979).

Wormuth, J. H. The biogeography and numerical taxonomy of the Oegopsid squid family Ommastrephidae in Pacific Ocean. *Bull. Scripps Inst. Oceanogr.*, **23**: 1–90 (1976).

Wormuth, J. H. Workshop deliberations on the Ommastrephidae: a brief history of their systematics and a review of the systematics, distribution, and biology of the genera *Martialia* Rochebrune and Mabille, 1889, Todaropsis Girard, 1890, *Dosidicus* Streenstrup,1857, *Hyaloteuthis* Gray,1849, and *Eucleoteuthis* Berry, 1916. *Smith. Contr. Zool.*, **586**: 373–381 (1998).

Xavier, J. C., A. L. Allcock, Y. Cherel, M. R. Lipinski, G. J. Pierce, P. G. K. Rodhouse, R. Rosa, E. K. Shea, J. M. Strugnell, E. A. G. Vidal, R. Villanueva, and A. Ziegler. Future challenges in cephalopod research. *J. Mar. Biol. Ass. U. K.*, doi:10.1017/S0025315414000782 (2014).

Yakoh, A., P. Kaewmanee, T. Leartkaitratchtna, K. Tes-a-sen, and T. Intharasuwan. Reproductive biology of bigfin reef squid (*Sepioteuthis lessoniana* Lesson, 1830) in the Andaman Sea coast of Thailand. *Tech. Pap., Mar. Fish. Res. Dev. Bur., Dept. Fish.* (2013).

Yamada, H., M. Kawano, M. Moriwaki, Y. Hori, and R. Takeda. Some different types of "Shiroika", *Loligo edulis*, in the coastal waters of the western Japan Sea. *Report on Cooperative Investigations of "Shiroika", Loligo edulis, inhabiting western Japan Sea*, **2**: 1–18 (1986) [in Japanese with English abstract].

Yamada, H., Y. Ogawa, M. Moriwaki, and Y. Okajima. Some biological characteristics in groups of Loligo edulis in the western coastal waters of the Japan Sea. *Report on Cooperative Investigations of "Shiroika", Loligo edulis, inhabiting western Japan Sea*, **1**: 29–50 (1983) [in Japanese with English abstract].

Yamada, H., and M. Tokimura. States of fishery and research of swordtip squid resources in the East China Sea. *Report of Ikarui Shigen Gyokaikyo Kento Kaigi*: 163–181 (1994) [in Japanese].

Yamanaka, H., M. Matsumoto, K. Hatae, and H. Nakaya. Studies on components of off-flavor in the muscle of American jumbo squid. *Nippon Suisan Gakkaishi*, **61**: 612–618 (1995).

Yamasaki, S., G. Adachi, N. Tanaka, Y. Yuuki, and K. Ishida. Chusou Toro-ru Ami Gyogu Kaihatsu Kenkyu. *Rep. Shimane Pref. Fish. Exp. Sta.*, **3**: 67–119 (1981).

Yamashita, N., and T. Kaga. Stock assessment and evaluation for winter spawning stock of Japanese common squid (fiscal year 2012), **In**: *Marine fisheries stock assessment and evaluation for Japanese waters (fiscal year 2012)*, pp. 571–604. Tokyo: Fishery Agency and Fisheries Research Agency of Japan (2013).

Yamashiro, C., L. Mariátegui, J. Rubio, J. Argüelles, R. Tafur, A. Taipe, and M. Rabí. Jumbo flying squid fishery in Peru, pp. 119–125. **In**: Contributed Papers to International Symposium on Large Pelagic Squids (T. Okutani, Ed.) Japan Marine Fishery Resources Research Center, Tokyo (1998).

Yamashiro, C., L. Mariátegui, and A. Taipe. Cambios en la distribución y concentración del calamar gigante (*Dosidicus gigas*) frente a la costa peruana durante 1991–1995. *Informe Progresivo Inst. Mar Perú.*, **52**: 3–40 (1997).

Yamashita, N., and K. Mori. Changes in the fishing conditions of Japanese common squid in the coastal area of the Pacific Ocean, *Report of the 2008 Annual Meeting on Squid Resources*. 11–21 (2009).

Yamrungrueng, A., and C. Chotiyaputta. Survey on squid resources from squid traps. *Tech. Pap., Mar. Fish. Res. Dev. Bur., Dept. Fish.* (2005).

Yatsu, A. The biology of *Sthenoteuthis oualaniensis* and exploitation of the new squid resources. *Bull. Far Sea Fishery.*, **101**: 6–9 (1997).

Yatsu, A., K. Hiramatsu, and S. Hayase. Outline of the Japanese squid driftnet fishery with notes on the by-catch. *Bull. Int. N. Pac. Fish. Comm. Bull.*, **53**: 5–24 (1993).

Yatsu, A., F. Kato, F. Kakizoe, K. Yamanaka, and K. Mizuno. Distribution and biology of *Sthenoteuthis oualaniensis* in the Indian Ocean-Preliminary results from the research cruise of the R/V Shoyo-Maru in 1995, **In**: Contributed Papers to the International Symposium on Large Pelagic Squids, pp. 145–153 (T. Okutani, Ed.). Tokyo: Japan Marine Fishery Resources Research Center (1998a).

Yatsu, A., S. Midorikawa, T. Shimada, and Y. Uozumi. Age and growth of the neon flying squid, *Ommastrephes bartrami*, in the North Pacific Ocean. *Fish. Res.*, **29**: 257–270 (1997).

Yatsu, A., H. Tanaka, and J. Mori. Population structure of the neon flying squid, *Ommastrephes bartramii*, in the North Pacific. **In**: *Contributed Papers to International Symposium on Large Pelagic Squids*, pp. 31–48 (T. Okutani, Ed.), Japan Marine Fishery Resources Research Center: Tokyo (1998b)

Yeh, S., and I. Tung. Review of Taiwanese pelagic squid fisheries in the North Pacific. *Bull. Int. North Pacific Fish. Comm.*, **53**: 71–76 (1993).

Yoda, M., and M. Fukuwaka. Stock assessment and evaluation for swordtip squid (fiscal year 2012). **In**: *Marine fisheries stock assessment and evaluation for Japanese waters* (fiscal year 2012/2013), pp.1697–1708. Fisheries Agency and Fisheries Research Agency of Japan (2013) [in Japanese].

Yoshikawa, N. Fisheries in Japan. Squid and Cuttlefish. Japan Marine Products Photo Materials Association, Tokyo: 162 pp (1978).

Young, I. A. G., G. J. Pierce, H. I. Daly, M. B. Santos, L. N. Key, N. Bailey, J.-P. Robin, A. J. Bishop, G. Stowasser, M. Nyegaard, S. K. Cho, M. Rasero, and J. M. F. Pereira. Application of depletion methods to estimate stock size in the squid *Loligo forbesi* in Scottish waters (UK). *Fish. Res.*, **69**: 211–227 (2004).

Young, I. A. G., G. J. Pierce, J. Murphy, H. I. Daly, and N. Bailey. Application of the Gómez-Muñoz model to estimate catch and effort in squid fisheries in Scotland. *Fish. Res.*, **78**: 26–38 (2006a).

Young, I. A. G., G. J. Pierce, G. Stowasser, M. B. Santos, J. Wang, P. R. Boyle, P. W. Shaw, N. Bailey, I. Tuck, and M. A. Collins. The Moray Firth directed squid fishery. *Fish. Res.*, **78**: 39–43 (2006b).

Young, J. W., Olson, R. J., and Rodhouse, P. G. K. eds. (2013). The role of squid in pelagic ecosystems. *Deep Sea Res. Part II*, **95**: 1–224.

Young, M. A., R. G. Kvitek, P. J. Iampietro, C. D. Garza, R. Maillet, and R. T. Hanlon. Seafloor mapping and landscape ecology analysis used to monitor variations in spawning site preference and benthic egg mop abundance for the California market squid (*Doryteuthis opalescens*). *J. Exp. Mar. Biol. Ecol.*, **407**: 226–233 (2011).

Young, R. E. The systematics and areal distribution of pelagic cephalopods from the seas off southern California. *Smith. Contr. Zool.*, **97**: 1–159 (1972).

Young, R. E., and J. Hirota. Review of the ecology of *Sthenoteuthis oualaniensis* near the Hawaiian Archipelago. **In**: *Contributed Papers to International Symposium on Large Pelagic Squids*, pp. 131–143 (T. Okutani, Ed.), Japan Marine Fishery Resources Research Center, Tokyo (1998).

Yuuki, Y. Spawning and growth of *Watasenia scintillans* in the southwestern Japan Sea. *Bull. Jpn. Soc. Fish. Oceanogr.*, **49**: 1–6 (1985).

Zeidberg, L. D. Allometry measurements from *in situ* video recordings can determine the size and swimming speeds of juvenile and adult squid *Loligo opalescens* (Cephalopoda: Myopsida). *J. Exp. Biol.*, **207**: 4195–4203 (2004).

Zeidberg, L. D. *Doryteuthis opalescens*, opalescent inshore squid. **In**: *Advances in squid biology, ecology and fisheries Part I–Myopsid Squids*, pp. 159–204 (R. Rosa, R. K. O'Dor and G. J. Pierce, Eds.), Nova Science Publ., New York (2013).

Zeidberg L. D., J. L. Butler, D. Ramon, A. Cossio, K. Stierhoff, and A. Henry. In-situ observations of the distribution and abundance of market squid (*Doryteuthis opalescens*) egg beds off California. *Mar. Ecol. Evol. Pers.*, **33**: 326–336 (2012).

Zeidberg L. D., and W. M. Hamner. Distribution of squid paralarvae, Loligo opalescens, (Cephalopoda: Myopsida) in the Southern California Bight in the three years following the 1997–1998 El Niño. *Mar. Biol.*, **141**: 111–122 (2002).

Zeidberg L. D., W. M. Hamner, N. P. Nezlin, and A. Henry. The fishery of the California market squid, *Loligo opalescens* (Cephalopoda, Myopsida), from 1981–2003. *Fish. Bull.*, **104**: 46–59 (2006).

Zeidberg, L. D., G. Isaac, C. L. Widmer, H. Neumeister, and W. F. Gilly. Egg capsule hatch rate and uncubation duration of the California market squid, *Doryteuthis* (formerly *Loligo*) *opalescens*: insights from laboratory manipulations. *Mar. Ecol.*, **32**: 468–479 (2011).

Zeidberg, L. D., and B. H., Robison. Invasive range expansion by the Humboldt squid, *Dosidicus gigas*, in the eastern North Pacific. *Proc. Natl. Acad. Sci. USA*, **104**: 12948–12950 (2007).

Zeidberg, L. D., and B. H. Robison. Reply to Watters et al.: Range expansion of the Humboldt squid. *Proc. Natl. Acad. Sci. USA*, **105**: E6 (2008).

Zhang, Z. L., S. Z. Ye, M. J. Hong, C. C. Shen, and X. H. Su. Biological characteristics of the Chinese squid (*Loligo chinensis*) in Minnan-Taiwan Shallow fishing ground. *J. Fujian Fish.*, **116**: 1–5 (2008).

Zuev, G. V., and K. N. Nesis. Biology and primary squid species (1971). **In**: *English Translations of Selected Publications on Cephalopods by Kir N. Nesis*, Vol. **2**, pp. 71–257 (M. J. Sweeney, Compiler). Washington: Smithsonian Institution Libraries (2003).

Zuev, G. V., C. M. Nigmatullin, and V. N. Nikol'skii. 1985. *Nektonnye Okeanicheskie kal'mary (Nektonic oceanic squids). Agropromizdat, Moscow.* 224 pp (1985).

Zumholz, K., and U. Piatkowski. Research cruise data on the biology of the lesser flying squid, *Todaropsis eblanae* in the North Sea. *Aquat. Living Resour.*, **18**: 373–376 (2005).

Zúñiga, M. J., L. A. Cubillos, and C. Ibáñez. A regular pattern of periodicity in the monthly catch of jumbo squid (*Dosidicus gigas*) along the Chilean coast (2002–2005). *Cienc. Mar.*, **34**: 91–99 (2008).