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Igor Krupnik, Michael A. Lang, and Scott E. Miller
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Persistent Elevated Abundance of Octopods in an Overfished Antarctic Area

Michael Vecchione, Louise Allcock, Uwe Piatkowski, Elaina Jorgensen, and Iain Barratt

ABSTRACT. Trawl surveys conducted between 1996 and 2007 show that populations of octopods have significantly higher abundances around Elephant Island, off the Antarctic Peninsula, than in similar areas nearby. This elevated abundance was first detected following the cessation of commercial fishing and has persisted for many years beyond, possibly indicating an enduring shift in the structure of the ecosystem.

INTRODUCTION

Concern about the effects of overfishing on marine ecosystems has increased substantially in recent years (e.g., Jackson et al., 2001). One of these potential effects is a shift in the suite of dominant predators in the ecosystem (Fogarty and Murawski, 1998; Choi et al., 2004). Unusually high abundances of squids and octopods in some areas have been related to man's removal of their finfish predators and competitors (Caddy and Rodhouse, 1998). Furthermore, anthropogenic changes in polar regions are of particular conservation concern (e.g., Smith et al., 2002). In Antarctica, a bottom-trawl fishery primarily targeting mackerel icefish (*Champsocephalus gunnari*) and marbled notothenia (*Notothenia rossii*) developed in 1978 around Elephant Island, in the South Shetland Archipelago off the Antarctic Peninsula. The fishery continued until 1988/1989 but rapidly depleted the populations of the target species (Kock and Stransky, 2000). We report here that in this overfished area, populations of octopods have significantly higher abundances than in similar areas nearby. This elevated abundance has persisted for years beyond the cessation of commercial fishing, possibly indicating an enduring shift in the structure of the ecosystem.

MATERIALS AND METHODS

R/V *Polarstern* cruises ANT XIV/2 (November–December 1996), ANT XIX/3 (January–February 2002), and ANT XXIII/8 (December 2006 to January 2007) were conducted to assess the status of fish stocks in the region around Elephant Island monitored internationally under the Convention on Conservation

Michael Vecchione, National Marine Fisheries Service, Systematics Laboratory, National Museum of Natural History, P.O. Box 37012, MRC 153, Washington, DC 20013-7012, USA. Louise Allcock, Martin Ryan Marine Science Institute, National University of Ireland, Galway, University Road, Galway, Ireland. Uwe Piatkowski, Institute for Marine Research, Universitat Kiel, Dusternbrooker Weg 20, D-24105, Kiel, Germany. Elaina Jorgensen, National Marine Fisheries Service, Alaska Fisheries Science Center, 7600 Sand Point Way N.E., Seattle, WA 98115, USA. Iain Barratt, Ecology and Evolutionary Biology, School of Biological Sciences, Queen's University Belfast, 97 Lisburn Road, Belfast BT9 7BL, UK. Corresponding author: M. Vecchione (vecchiom@si.edu). *Accepted 19 May 2008.*

of Antarctic Marine Living Resources. Sampling stations were selected randomly from depth strata between 50 and 500 m. These stations were sampled by 30-min tows with a large double-warp otter trawl. The 2002 cruise also conducted similar sampling off the southern South Shetland Islands and off Joinville Island across the Bransfield Strait (both areas with shelves of similar widths and depths to the Elephant Island area), as well as an intensive sampling series of 20 tows in a shallow-water grid near Elephant Island. The 2006–2007 cruise similarly sampled additional stations across the Bransfield Strait close to the peninsula and in the western Weddell Sea (Figure 1). We identified and counted all cephalopods collected on these cruises, including both the cod end sample and specimens entangled in the net mesh. The material included many more species than were recognized previous to this work (Allcock, 2005). We first noticed the abundance patterns reported here during the 2002 cruise and have since examined the 2006–2007 cruise as a test of our unpublished 2002 hypothesis. Because the sample sizes, depths, etc., were balanced between the Elephant Island area and the out-groups in 2002, we emphasize these results and present the 1996 and 2006–2007 results for temporal comparisons.

For some of the comparisons presented below, we have eliminated the shallow-grid samples and pooled the observations from the southern South Shetland Islands, close to the Antarctic Peninsula, Joinville Island, and Weddell Sea (termed "out-groups" below) because this created similar-sized sets of samples with similar ranges and variances in depth, a controlling factor in the abundance and diversity of Antarctic octopods (Figure 2). Intensive shallow-grid sampling was not conducted in the out-group areas. A

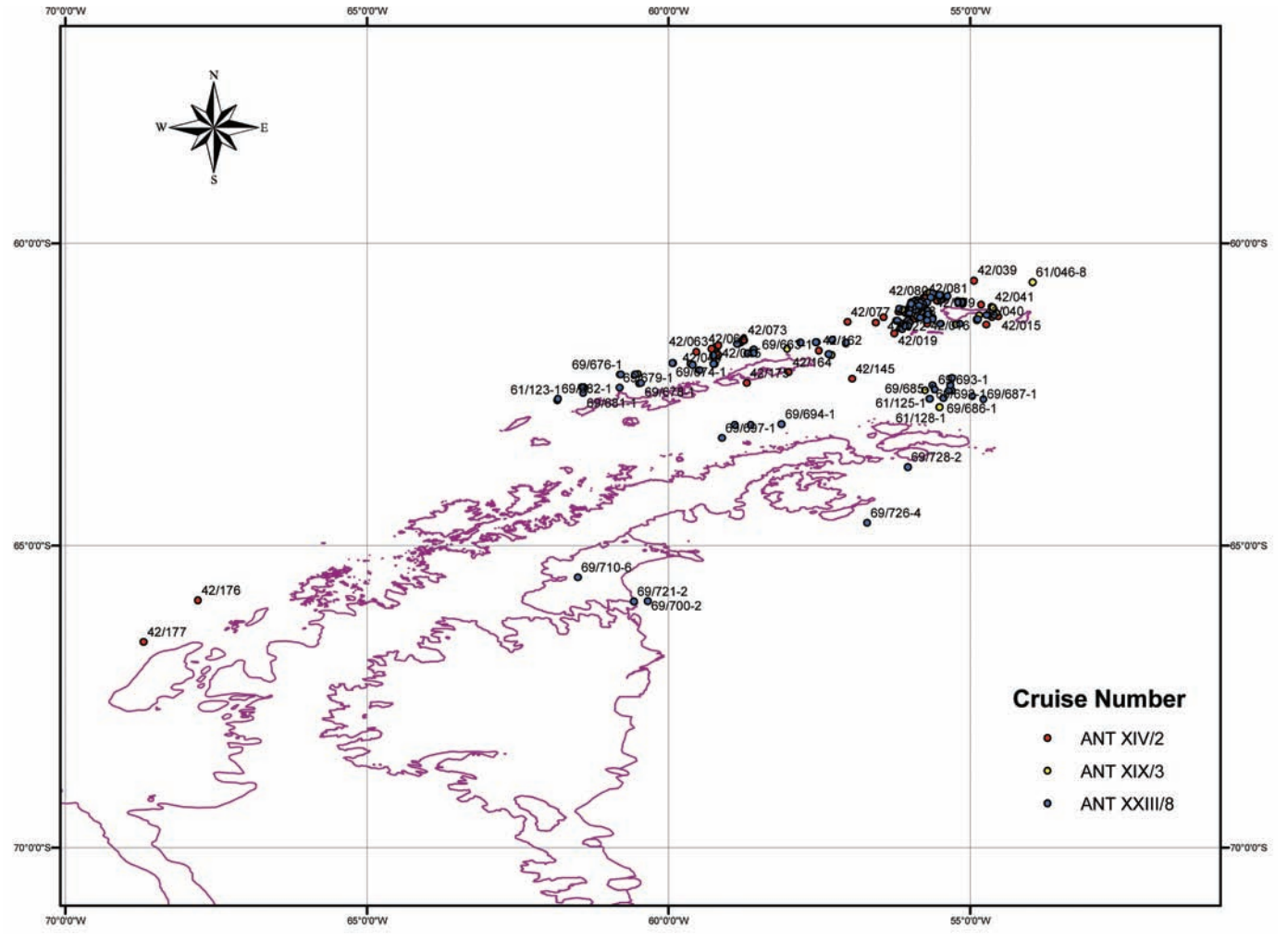

FIGURE 1. Study area showing sampling locations.

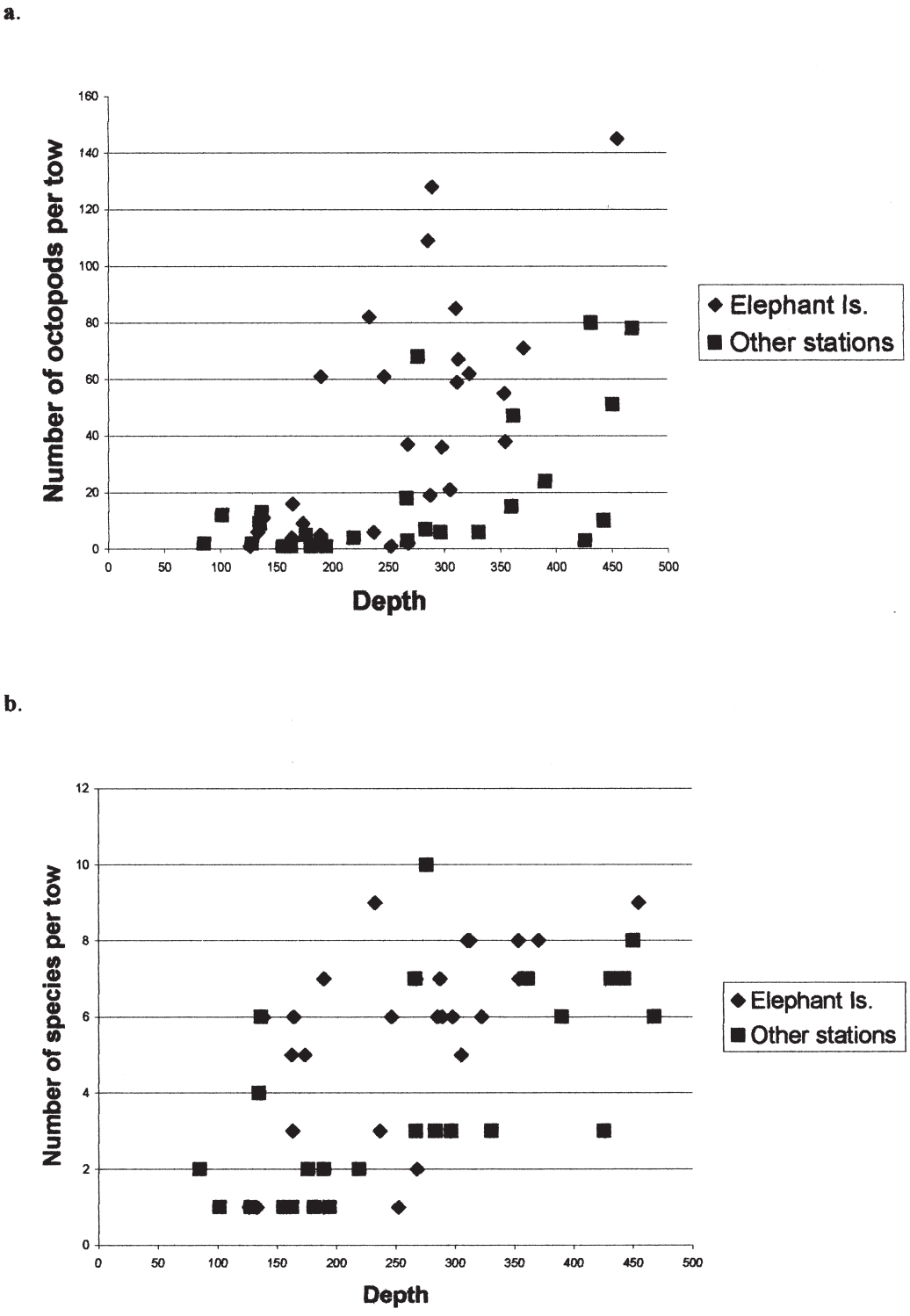

FIGURE 2. Relationship between mean depth of tow and octopod catch in 2002 trawl samples from around Elephant Island and similar nearby areas: (a.) total number of octopods per tow, (b.) approximate number of octopod species per tow.

TABLE 1. Summary of octopod collections by cruise year and location.

Year	Location	Number of stations	Parameter[a]	Maximum	Mean	95% confidence interval	Minimum
2006–2007	Elephant Island	51	Depth (m)	486	208	26	62
			catch	169	18	8	0
			no. spp.	8	3	0.5	0
2006–2007	out-group	38	depth (m)	490	275	35	87
			catch	35	7	2	0
			no. spp.	5	2	0.5	0
2002	Elephant Island	28	depth (m)	455	257	32	127
			catch	145	42	16	1
			no. spp.	9	6	1	1
2002	shallow grid	20	depth (m)	209	146	18	74
			catch	306	37	15	4
			no. spp.	7	4	1	2
2002	out-group	26	depth (m)	468	266	49	85
			catch	80	18	10	1
			no. spp.	10	4	1	1
1996	Elephant Island	38	depth (m)	477	243	33	89
			catch	135	52	10	9

[a]Depth is based on mean depth of each tow, catch is the number of octopods per tow, and no. spp. is the approximate number of species per tow; no. spp. is not included for 1996 cruise because identifications have not yet been revised based on updated taxonomy resulting from 2002 cruise.

summary of the collections is presented in Table 1. Statistical comparisons used two-sample t-tests assuming unequal variances, with the a priori confidence level for significance at $\alpha = 0.05$ (two tailed). Depths presented are based on the mean depth of each tow, calculated as the average of the depth at the beginning and at the end of the tow.

RESULTS

Although the depths of the 28 Elephant Island stations sampled in 2002 were slightly shallower than the 26 out-group stations, the difference was not statistically significant. However, the total number of octopods collected per tow at Elephant Island averaged over twice as high (Table 2) as that at the out-group stations (significant, $p < 0.001$). Had we included the 20 shallow-grid stations, the difference in catch between the areas would have been even greater (Table 1) because these tows included two catches that were anomalously high (98 and 306 octopods) for that depth range and strongly dominated by one shallow-dwelling species, *Pareledone charcoti* (Joubin, 1905). Although the difference between areas in number of species collected was not great, it was statistically significant. This is likely because an increased number of specimens in the catch generally includes a higher number of species (Figure 3) rather than because of a difference in species richness in the two areas. Depths of the 38 stations sampled around Elephant Island in 1996 were not significantly different from those sampled in 2002, nor was the average catch significantly different from the 2002 catch in the same area. Only three samples were collected in 1996 from the southern South Shetland Islands (in the same area as the out-groups in 2002) with the same net at similar depths; the catches in these samples were very low (12, 7, and 5 octopods). The few samples that were collected from Joinville Island in 2002 included the lowest numbers of octopods caught that year, but those were qualitatively similar to the octopod fauna of the Weddell Sea (Allcock et al., 2001).

In 2006–2007, both the mean depth and number of octopods per sample around Elephant Island were less than in 2002. The mean depth at the out-group stations in 2006–2007 was somewhat greater than in 2002 and significantly greater than the Elephant Island stations in 2006–2007. However, the number of octopods per sample around Elephant Island was >2.5 times higher than in the out-group samples, a statistically significant difference (Table 3). As in

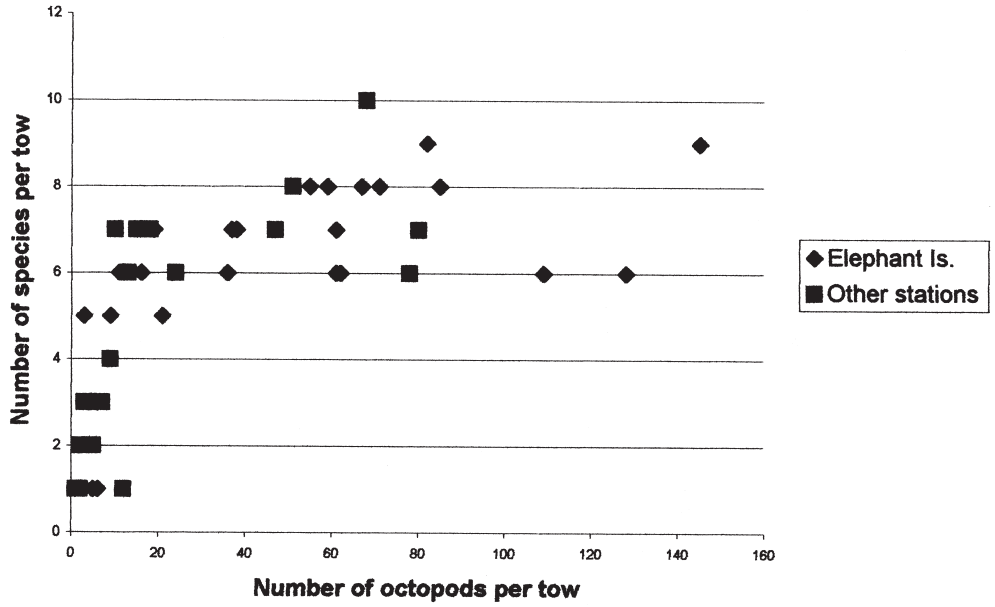

FIGURE 3. Relationship between number of octopods collected and approximate number of species collected in 2002.

2002, the larger catches of octopods around Elephant Island included a significantly greater number of species than in the smaller out-group samples.

DISCUSSION

We have no quantitative information about the abundance of octopods in the area of Elephant Island prior to the onset of commercial fishing in the area. Therefore, some unknown natural factor in that location could have resulted in high octopod abundances relative to levels in similar areas nearby. However, at least eight bottom-trawl surveys of the fish fauna around Elephant Island were conducted between 1976 and 1987 (Kock and Stransky, 2000), and we know of no indication of elevated octopod abundance in those surveys. Conversely, during a U.S. trawl survey in 1998, octopod abundance was higher around Elephant Island than off the South Shetland Islands (C. Jones, NMFS Antarctic Program, Southwest Fisheries Science Center, personal communications, 2002). These sampling efforts, together with the present surveys, revealed that bycatch fish species had recovered by the early 1990s but populations of target species had not fully recovered (Kock and Stransky, 2000; K.-H. Kock, Institute for Sea Fisheries, personal communication, 2002). The abundance of octopods may have increased coincidently with the recovery of populations of finfish bycatch.

We are not sure why the overall abundance of octopods around Elephant Island was lower in 2006–2007 than during previous surveys. Perhaps this is because the sampling was concentrated at somewhat shallower depths, which resulted in fewer catches with very high numbers of octopods (Figure 2). However, details of the configuration of the trawl, such as height of the footrope above the rollers and the presence of a "tickler" chain, were modified during this cruise to reduce the bycatch of sessile megafauna (e.g., sponges and cnidarians). It seems quite likely that these modifications affected the net's sampling characteristics for benthic octopods. An indication that high numbers of octopods remained around Elephant Island during 2006–2007 is found in the very high numbers of small specimens caught at three stations (59 specimens at station 614-3, 24 at 642-1, and 15 at 654-6) using a different gear type, an Agassiz beam trawl, not included in the comparisons presented here.

The pattern reported here is consistent with other reports from around the world of elevated cephalopod abundances coincident with reduction of finfish populations by commercial harvesting. As the inferred increase in octopod abundance appears to be coincident with recovery of bycatch fish populations, release from predation pressure

TABLE 2. Two-sample t-test assuming unequal variances comparing areas in February 2002.[a]

Parameter	Elephant Island	Out-groups
Station depths		
Mean	256.9892857	265.8461538
Variance	6694.207844	14457.90058
Observations	28	26
df	44	
t statistic	−0.314090727	
$P(T \leq t)$ one-tail	0.377468272	
t critical one-tail	1.680230071	
$P(T \leq t)$ two-tail	0.754936545	
t critical two-tail	2.0153675	
Number of octopods per tow		
Mean	42.85714286	18.07692308
Variance	1652.941799	609.6738462
Observations	28	26
df	45	
t statistic	2.728499663	
$P(T \leq t)$ one-tail	0.004521735	
t critical one-tail	1.679427442	
$P(T \leq t)$ two-tail	0.009043469	
t critical two-tail	2.014103302	
Number of species per tow		
Mean	5.535714286	4
Variance	6.406084656	7.36
Observations	28	26
df	51	
t statistic	2.146507581	
$P(T \leq t)$ one-tail	0.018305786	
t critical one-tail	1.675284693	
$P(T \leq t)$ two-tail	0.036611573	
t critical two-tail	2.007582225	

[a]Out-groups are pooled samples from southern South Shetland Islands plus Joinville Island. On the basis of these analyses, the depths of the stations sampled do not differ significantly between the areas, but both the number of octopods per tow and the number of octopod species per tow were significantly higher in the area around Elephant Island than in other areas.

rather than competitive processes seems to be responsible for the good fortune of the octopods. Because ecological processes in polar regions tend to be comparatively slow, such ecosystem-level impacts of fishing may take longer to become apparent than at lower latitudes but also may be very persistent.

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TABLE 3. Two-sample t-test assuming unequal variances comparing areas in December 2006 to January 2007.[a]

Parameter	Elephant Island	Out-groups
Station depths		
Mean	208.2411765	274.6736842
Variance	8640.174871	11619.0328
Observations	51	38
df	73	
t statistic	−3.047557645	
$P(T \leq t)$ one-tail	0.001605534	
t critical one-tail	1.665996224	
$P(T \leq t)$ two-tail	0.003211069	
t critical two-tail	1.992997097	
Number of octopods per tow		
Mean	18.23529412	7.184210526
Variance	733.5835294	45.66785206
Observations	51	38
df	58	
t statistic	2.799243278	
$P(T \leq t)$ one-tail	0.003472082	
t critical one-tail	1.671552763	
$P(T \leq t)$ two-tail	0.006944163	
t critical two-tail	2.001717468	
Number of species per tow		
Mean	3.215686275	2.473684211
Variance	3.77254902	1.877667141
Observations	51	38
Hypothesized mean difference	0	
df	87	
t statistic	2.11239907	
$P(T \leq t)$ one-tail	0.018759109	
t critical one-tail	1.66255735	
$P(T \leq t)$ two-tail	0.037518218	

[a]Out-groups are pooled samples from areas other than Elephant Island. In these analyses, the number of octopods per tow and the number of octopod species per tow were significantly higher in the area around Elephant Island than in other areas, but the sampled depths around Elephant Island were shallower, which could be a confounding factor.

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