

Estimation of Size Selectivity for Oval Squid *Sepioteuthis lessoniana* in the Squid Jigging Fishery of Tokushima Prefecture

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This paper examines size selectivity in the squid jigging fishery for the oval squid *Sepioteuthis lessoniana* in Tokushima Prefecture using an extended SELECT model for analyzing size frequency distributions of squid caught by the squid jigging and by set nets. The SELECT model is extended to utilize size frequency distributions constructed from repeat measurements of catch in the squid jig as the test gear and the set nets as the control gear where data on the fishing efforts is not available with variable fishing efficiencies. As a result, size selectivity $r(l)$ of squid jigs of a body size from 12 to 15 cm is expressed as a logistic function of the mantle length l , $r(l) = \exp(-10.0 + 0.485 l) / [1 + \exp(-10.0 + 0.485 l)]$. This equation indicates that oval squid of a size smaller than the jig is not caught by the jig. As the squid attacks the jig as a prey, the size selectivity of the squid jig found here is a type of prey size selectivity.

Key words: size selectivity, squid jig, oval squid, *Sepioteuthis lessoniana*, SELECT model, prey size selectivity

Squid jigging and small sized set net fisheries catch the oval squid *Sepioteuthis lessoniana* in the offshore waters adjacent to the Kii Channel, along the Pacific Ocean coast of Tokushima Prefecture (Fig. 1).¹⁾ Squid jigs used there are colored, prawn shaped lures with a double ring of barbless hooks, and a single jig is set on each jig-line.²⁾ To catch oval squid, several jig-lines are usually trolled slowly *i.e.*, at a speed of less than 1.5 knots, at night without any fishing lights by small scale boats.²⁾ When a squid attacks the jig as prey, it is retained on the hooks of the jig and then quickly pulled up to the surface by the fisherman. This implies that the success of squid jigging depends on the feeding behavior of the squid. Segawa³⁾ observed that after approaching and positioning itself relative to the prey with its high visual acuity, oval squid seize the prey first using the tentacles and then grasp it firmly by the second and third arms. Segawa³⁾ also found that the oval squid feed on relatively large prey with squid growth and that the rate of success of prey capture is lower when the squid attacks a prey of a size larger than its own body size. Thus, oval squid appear to feed on prey of a size smaller than their own body size and may select not to attack prey larger than their own body size.

Most squid jigs used off Tokushima Prefecture are ready-made, and some are handcrafted by the fishermen themselves. According to the method for the measuring squid jig size by Fuwa *et al.*,⁴⁾ ready-made squid jigs are about 12 cm body length (length of prawn-shaped part of the jig, apart from the hooks), 14.5 cm total length including the hooks, and 6.7 cm in girth. Some handcrafted jigs are approximately 15 cm body length (18 cm total length) with 8.1 cm girth, which are larger than the ready-made ones. It is therefore expected that the oval squid of size larger than a body size relative to the jig size were caught

(or selected) by the squid jigging fishery. This suggests that squid jigging has size-selective property.

In general, the selection of a size class by a fishing gear can be considered as the difference in the size frequency distributions of the catch using that gear from that of the fish population in the fished area. The size frequency distribution of the total fish population can be estimated by using fishing gear which can retain all fish of the length in question, non-selective gear. Myhre⁵⁾ and Hovgård and Riget⁶⁾ obtained size selectivity of long-line fisheries by comparing the size distributions of catches by long-lines and by trawls for the same area on the assumption that trawling is non-selective for the size range in question due to the small enough mesh of the codend. The SELECT model has been developed to estimate the size selectivity from data in paired gear experiments, that is, by comparison of the test gear catch to a control gear catch.⁷⁻¹¹⁾ Xu and Millar¹⁰⁾ extended the SELECT model to use for data of unequal sampling effort between the two gears; large meshed pots as the test gear and small meshed pots as the control gear, and obtained trap selectivity estimates in the pot fishery for male snow crab *Chionoecetes opilio*. In the SELECT model, the proportion of crabs encountering the larger meshed pots to the total crabs, parameter p , is specified as the combination of relative fishing efficiency and fishing effort.¹⁰⁾ In measurement of samples obtained from catch landed at fish markets, data on the fishing efforts of the gears are often unavailable. For this case, the SELECT model extended by Xu and Millar¹⁰⁾ which requires fishing effort data is inapplicable. When measurement surveys are conducted repeatedly over a long period, the size distributions of the population will change due to body growth. Therefore combining data during a period over which growth occurs will not satisfy the necessary assumptions

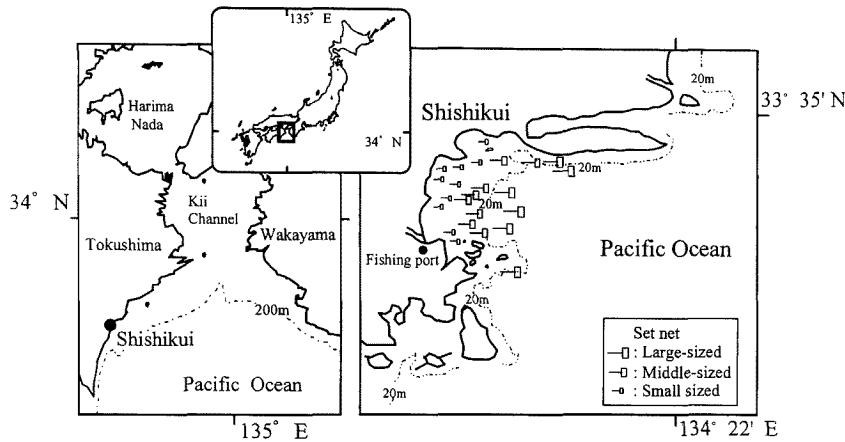


Fig. 1. Map of the coastal area of Tokushima Prefecture, showing the site, Shishikui, where measurements of oval squid *Sepioteuthis lessoniana* for analysis were carried out.

for the SELECT model that the survey is carried out on the same population, that is one of a constant density at each length. With some passive fishing gears, fishing efficiencies will depend on the behavior of the species, and therefore is likely to change with environmental and fishing conditions, e.g., water temperature, light intensity etc. This means that parameter p including the relative fishing efficiency will vary with environmental and fishing conditions during the surveys. In these cases, the data obtained during the whole period should not be combined in the SELECT analysis process.

The squid jigging fishery occurs only in the autumn and winter seasons, from October to the following February off Tokushima Prefecture, while the set net fishery catches squid almost all year. Ueta and Kaneda²⁾ pointed out that squid caught in the squid jigging fishery were larger than those by the set net fishery. In fact, the minimum size of squid caught by the jigging fishery is larger than that in set net fishery during the jig-fishing season, although there is no marked difference in the maximum size between the jigging and the set net fisheries. For example, the monthly minimum size of oval squid caught by squid jigging are about 5 cm larger in mantle length than those by set net (Fig. 2). This implies the possibility of estimating the size selectivity of the squid jigging fishery by comparison of the size frequency distributions of the jig catch and the set net catch. Oval squid however grow during the squid jig-fishing season (Fig. 2), which means that densities at each size of the squid population will vary. In addition, the fishing effort and sampling effort are usually variable at each measurement time, and the fishing ability of each fisherman also varies largely. In these cases, the squid size data for each measurement time should not be combined for the SELECT analysis.

This paper extends the SELECT model to allow analysis under these conditions and presents data on the size selectivity in the squid jigging fishery with its application to size frequency distributions of mantle length constructed from repeat measurements of the squid catch in the squid jigging and the set net fishery.

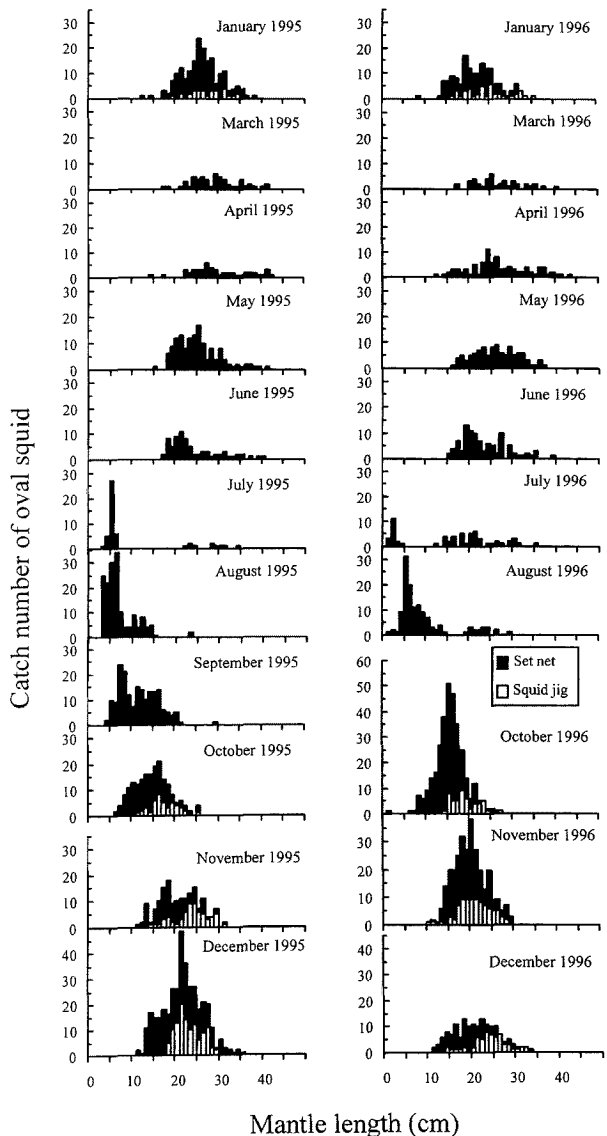


Fig. 2. Mantle length distributions of oval squid *Sepioteuthis lessoniana* caught by set net and by squid jig, in 1995 and 1996.

Material and Methods

Data Collection

Squid jigs are trolled between the set nets in shallow waters (from 10 to 20 m depth) off Shishikui, Tokushima Prefecture (Fig. 1), and therefore the jigging and set net fisheries operate on the same population on the same day. Size measurement of oval squid caught by the set nets and the squid jigs were carried out at the Shishikui Fishing Port approximately monthly from October 1994 to November 1997. Both of ready-made (12 cm body length) and handcrafted (15 cm body length) jigs were used by fishermen who landed oval squid at this port. Size frequency distributions of the catch by squid jigs and by set nets were constructed by measuring the mantle length of the oval squid to the nearest millimeter and grouping the lengths by 1 cm intervals. Monthly size frequencies in 1995 and 1996 are shown as an example in Fig. 2. In the set net fishery squid of a mantle length larger than 1-2 cm size group in July and August of 1996 were caught. Ueta and Segawa¹²⁾ also reported that minimum mantle length of oval squid caught by set net was 1.4 cm in July. These results indicate that set nets can retain squid of very small size compared to the squid jigging, and hence in this paper we regard the set net as a non-selective fishing gear and its catch as representative of the size frequency of the squid population in the area. Sixteen-days of size measurement data of squid landed on the same day at the Shishikui Fishing Port by the set net and the squid jigging fisheries were chosen for further analysis (Table 1, Fig. 3).

The measurement data of each day should not be combined for each gear, even for the 16 days data in which the two gears were operated on the same population. The reasons are as follows. Firstly, oval squid grow during the jig-fishing season, from October to the following January, which means that monthly changes in the density of the oval squid population at each size class will occur. Moreover, the growth rate of oval squid varies yearly (Ueta *et al.*, unpublished). Secondly, because the measurement survey at the fish port collected squid samples as much as possible, the sampling effort will vary between days. Data on the number of fishermen was available as a fishing effort, but there are large daily-variations in the number of fishermen even in the measurements of 16 days data (Table 1). Thirdly, Munekiyo and Kawagishi¹³⁾ found that the daily catch of oval squid in a small sized set net changed periodically with peaks which correlated with full-moon periods. Ueta and Kaneda²⁾ also reported that the periodicity in landings of oval squid by squid jigging is related to the age of the moon and pointed out that the effect of light intensity and transparency of the water on squid catch was due to squid visual behavior. This means that fishing efficiency of the gears are affected by light intensity and this could also vary between days. Accordingly, in the SELECT model the parameter for the proportion of squid encountering the jig to the total of squid which is specified as the combination of relative fishing efficiency, fishing effort and sampling effort should be determined independently at each measurement day.

Table 1. Fishing effort (number of fishermen catching oval squid) on each day

Date	Number of fisherman catching oval squid	
	Set net	Squid jig
19-Oct-94	5	2
21-Nov-94	5	4
16-Dec-94	8	5
17-Jan-95	11	3
19-Oct-95	6	1
10-Nov-95	6	4
07-Dec-95	9	5
18-Dec-95	9	3
31-Jan-96	6	5
24-Oct-96	7	4
25-Nov-96	11	5
25-Dec-96	9	7
23-Jan-97	3	2
24-Feb-97	8	2
14-Oct-97	9	6
12-Nov-97	5	8

Method of Analysis

The SELECT model should be extended to utilize length data measured during each period t ($t=1$ to T) when the environmental conditions, fishing conditions and fish population density are constant.

In the SELECT model, the proportion Φ_{it} of the catch of size l by the test gear to the total one during the period t is expressed by the following equation,

$$\Phi_{it} = \frac{n_{it}}{N_{it} + n_{it}} \quad (1)$$

where N_{it} and n_{it} denote the number of fish of size l caught during the period t by the control gear and by the test gear, respectively. Here, p_t denotes the proportion of l -length fish encountering the test gear to the total during the period t . The parameter p_t includes the relative fishing efficiency and fishing effort of each period t , and is assumed to be variable between the periods. In contrast, size selectivity of the test gear is constant during all periods.

The proportion of the catch by the test gear to the total catch during the period t is described as a function of l ,

$$\Phi_t(l) = \frac{p_t r(l)}{1 - p_t + p_t r(l)} \quad (2)$$

where $r(l)$ is the retention probability of a fish of size l .

In general, bell-shaped curves are usually employed for size selectivity in hook and line fisheries as well as in gillnet fisheries,^{6,7)} because large fish are unlikely to take baited hooks if the bait is too small a size and also unlikely to be hooked by a small hook. For the giant squid *Dosidicus gigas* off California, it is reported that the catch rate of small size jigs (from 12 to 18 cm) for large squid is lower than that of large size jigs because large squid often fall away from the hook due to their heavy bodies and the weakness of the tissue in their tentacles and arms.¹⁴⁾ This suggests that size selectivity in the squid jigging fishery is also a bell-shaped curve. However, squid jigs of a size larger than 12.0 cm in body length are not too small for oval squid up to 45 cm mantle length off the Shishikui area (Fig. 2). In

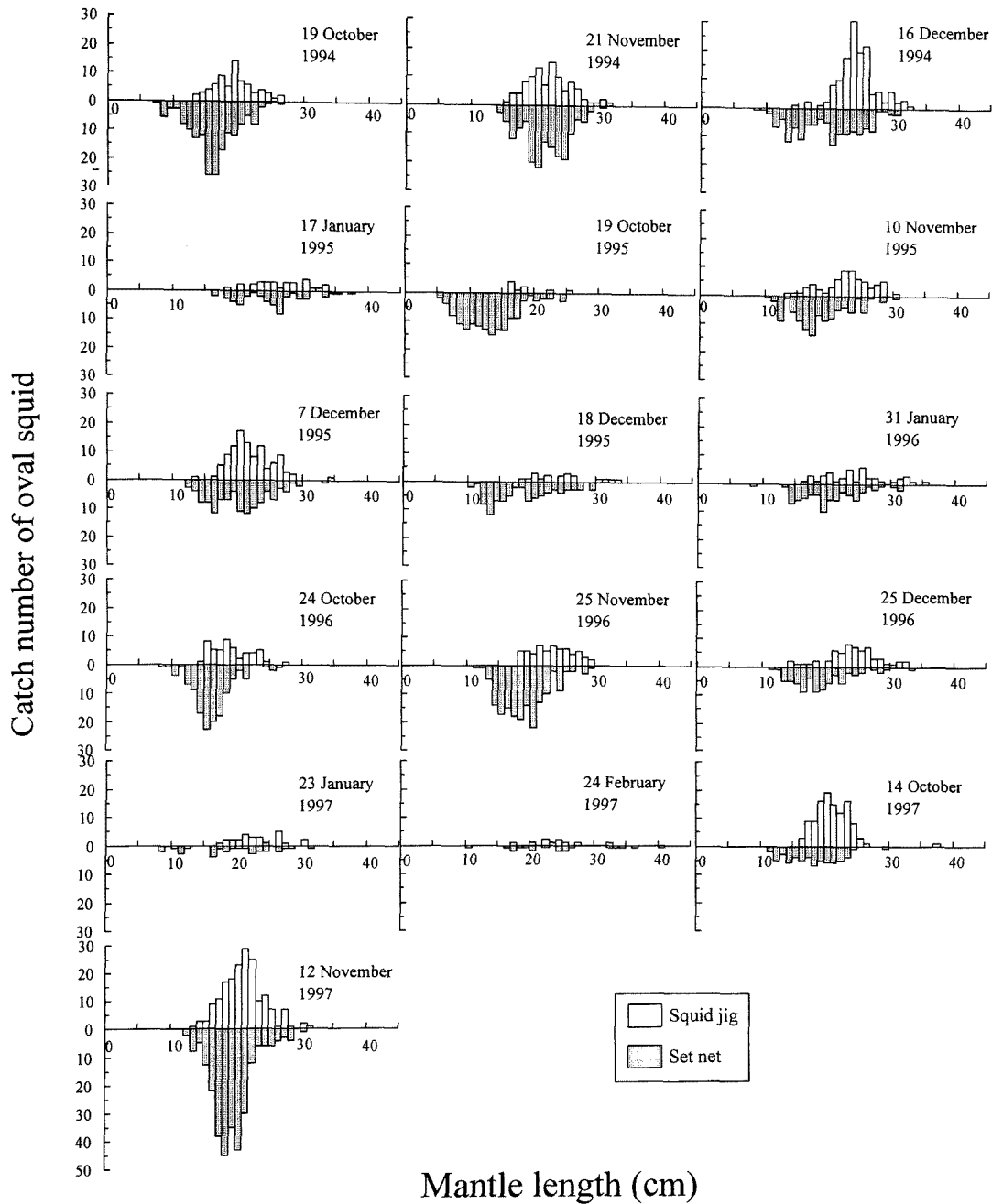


Fig. 3. Mantle length data on catch by squid jig and set net used in this analysis.

fact, there was no decline in catch rate of large squid as shown later. Accordingly, it is reasonable to postulate that the selectivity curve for oval squid in the squid jigging fishery will be a sigmoid curve, similar to that of a trawl, and the logistic function commonly used for trawl selectivity can be employed as,

$$r(l) = \frac{\exp(a + bl)}{1 + \exp(a + bl)} \quad (3)$$

where a and b are parameters of the logistic function. Substituting Eq. (3) into Eq. (2), $\Phi_t(l)$ is described as,

$$\Phi_t(l) = \frac{p_t \cdot \exp(a + bl)}{1 - p_t + \exp(a + bl)} \quad (4)$$

The parameters, a , b , and p_t ($t=1$ to T) are determined by using the maximum likelihood method.¹⁵⁾ The likelihood to be maximized is as follows,

$$L(a; b; p_1, p_2, \dots, p_T) = \prod_t \prod_l \frac{n_{tl}!}{N_{tl}! \cdot n_{tl}!} \Phi(l)^{n_{tl}} [1 - \Phi(l)]^{N_{tl}} \quad (5)$$

Instead of Eq. (5), the following log-likelihood function ex-

cluding the constant term in Eq. (5) was maximized,

$$\log L(a; b; p_1, p_2, \dots, p_T) = \sum_i \sum_j [n_{ij} \ln \Phi(l) + N_{ij} \ln (1 - \Phi(l))] \quad (6)$$

Solver on MS-Excel was utilized for maximization of the log-likelihood function.^{11,16)}

Results

The curves describe accurately data for each day, although there are large variations in estimates of p_t (Fig. 4 and Table 2). As a result of the fit of the curves using the likelihood ratio test, there was no evidence of lack of fit ($P=0.20$; model deviance, 184.05 and degree of freedom, 169). Apart from several days, the proportion of catch in squid jigging fishery to the total increases with the mantle length as a sigmoid curve, and there is no decline in selectivity at relatively larger sizes as reported for the giant

squid off California.¹⁴⁾ These results support the assumption that the size selectivity of squid jigs can be expressed as a logistic function within the range of mantle lengths and indicates the validity of the model with p_t for each day. On certain days *e.g.*, 17 January, 19 October, and 18 December, 1995 and 23 January and 24 February, 1997 there were large fluctuations in the proportion of catch in the squid jigging fishery to the total calculated from Eq.(1), owing to the relatively low numbers sampled (Fig. 3). In particular, when we tried to obtain selectivity curves independently for each day, the parameters did not converge on the data of 19 October, 1995. Days with such insufficient data should not be combined with other days because of the reasons mentioned above. However even such insufficient data is also available for the analysis process proposed in this study.

The size selectivity curve in the squid jig fishery was obtained (Fig. 5) by using estimates of the logistic parameters a and b (Table 2).

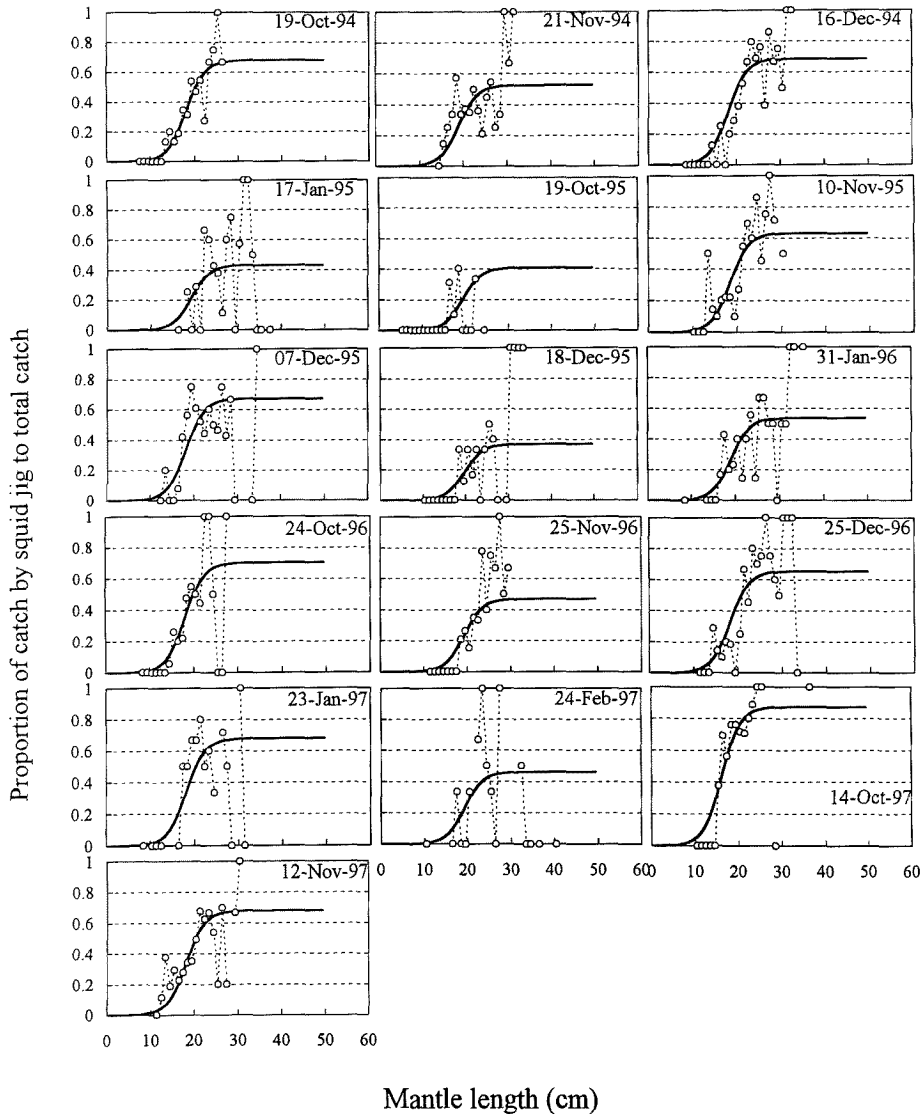
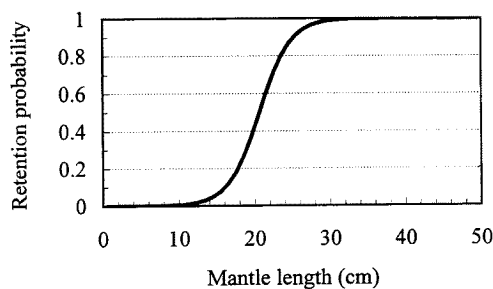


Fig. 4. Fits of the estimated curves to the observed proportions of total oval squid taken by squid jigs.

Table 2. Estimate of parameters

Parameters	Estimate	Proportion of jig fishermen to total
Logistic curve		
<i>a</i>	-10.01	
<i>b</i>	0.4850	
Split ratio of each day, <i>p_i</i>		
19-Oct-94	0.6891	0.29
21-Nov-94	0.5269	0.44
16-Dec-94	0.6885	0.38
17-Jan-95	0.4322	0.21
19-Oct-95	0.4199	0.14
10-Nov-95	0.6356	0.40
07-Dec-95	0.6762	0.36
18-Dec-95	0.3701	0.25
31-Jan-96	0.5402	0.45
24-Oct-96	0.7125	0.36
25-Nov-96	0.4731	0.31
25-Dec-96	0.6576	0.44
23-Jan-97	0.6800	0.40
24-Feb-97	0.4602	0.20
14-Oct-97	0.8415	0.40
12-Nov-97	0.6256	0.62

**Fig. 5.** Logistic selection curve for oval squid *Sepioteuthis lessoniana* by squid jigs.

$$r(l) = \frac{\exp(-10.0 + 0.485 l)}{1 + \exp(-10.0 + 0.485 l)} \quad (7)$$

In addition, from these logistic-parameter estimates, mantle length of the 50% selection and selection range ($=L_{75} - L_{25}$) were calculated to be 20.6 cm and 4.53 cm, respectively.

Estimates of parameters p_i in Table 2 have a weak significant correlation (correlation coefficient, $r=0.54$, $P<0.05$) to the proportion of squid jig fishermen to the total fishermen in Table 1. The most likely explanation of such a weak correlation is that the parameter p_i depends not only on the number of fishermen but also on the fishing skill of each fisherman and the operation time etc.

Discussion

Squid jigs with prawn shaped body from 12 to 15 cm caught oval squid of a mantle length over about 12 cm, and the retention probability for squid of a mantle length larger than 30 cm is close to 1 (Fig. 5). When a squid attacks a jig as prey, the squid is caught by the hooks. In general, the feeding behavior of squid to prey is as follows. First the squid positions itself relative to the prey,

Table 3. Total length and lengths of arms and tentacle of oval squid of 100, 200, and 300 mm mantle length, estimated from the equations²⁴⁾ respectively

	Mantle length*		
	100	200	300
Total length*	184.7	368.2	551.7
Length* of			
First arm	27.1	55.4	83.7
Second arm	35.9	72.0	108.1
Third arm	44.9	89.2	133.5
Fourth arm	42.2	84.5	126.8
Tentacle	75.2	154.6	234.0

* in mm.

and then before the squid seizes the prey with its tentacles and arms the squid judges with their high visual acuity whether the prey size is appropriate or not.^{17,18)} Segawa³⁾ reported that the feeding behavior of oval squid is the same as this generalized behavioral pattern. A likely explanation of the size selectivity found in the squid jig fishery is a type of prey size selectivity, that is the oval squid attack the prey of an appropriate size for seizure. Ueta (unpublished data) observed that oval squid are most likely to attack a prey smaller than their body size in a rearing experiment and also that oval squid of small size are often preyed on by smallscale blackfish *Girella melanichthys* of a size larger than the squid. For the squid *Sepioteuthis sepioidea*, LaRoe¹⁷⁾ found that different food items were only suitable for a definite size range and that the squid would not attack prey that were either too large or too small. O'Dor *et al.*¹⁹⁾ described experiments with the herring *Clupea harengus* L. as prey for *Illex illecebrosus*, and showed that fish were captured up to a length roughly equal to the mantle length of the squid. Reviewing a range of experiments with cuttlefish, Boletzky and Hanlon¹⁸⁾ found that as a general rule the total length of a prey fish or prawn should not be much greater than the total length of the cuttlefish. These findings strongly support evidence that oval squid of a body size larger than the jig size (from 12 to 15 cm) attack the jig and are caught. For fish, prey size selectivity has been reported (e.g., Werner²⁰⁾). The effect of bait size on size selectivity in long line fisheries has been pointed out.²¹⁾ Size selectivity of long lines by the size of bait²²⁾ and also by the size of artificial bait²³⁾ has been discussed in terms of prey size selectivity.

Segawa³⁾ reported that the success rate in squid feeding is lower when squid attack a prey larger than its own body size. Werner²⁰⁾ discussed the relationship between the mouth size of fish compared to prey size in terms of the time duration needed to complete feeding on the prey. Oval squid seize prey with the tentacle and then grasp it firmly with the second and third arms.²⁾ Oval squid of a mantle length less than 10 cm were seldom caught by squid jigs, and the retention probability of 30 cm mantle length is close to 100% (Fig. 5). Segawa²⁴⁾ estimated regression equations for mantle length against total length and the tentacle and each arm length. From these equations, these lengths for oval squid of 10, 20 and 30 cm mantle length respectively are estimated (Table 3). As mentioned above, the mean girth of squid jigs used off Tokushima Prefecture are 6.7 cm for ready-made ones and 8.1 cm for handcraft-

ed ones. These girth values are close to twice that of the second arm (35.8 mm) and third arm (44.9mm) of a squid of 10 cm mantle length. This implies that oval squid with long enough arms to grasp the squid jig, attack the jig and then are caught. However, oval squid are occasionally caught with their tentacles hooked and therefore catch by squid jig does not require the squid to grasp the jig with their arms. A possible explanation for prey size selectivity with vision is that the oval squid are likely to attack the prey that they can seize tightly enough by their arms.

To confirm the size selectivity by jig size, comparative fishing experiments with squid jigs of different sizes would be useful. Furthermore, for a better understanding of the mechanism of size selectivity in the squid jigging fishery, it would be helpful to observe squid behavior forward a trolled jig with a small sized underwater video camera in the same way as Akiyama *et al.*²⁵⁾ observed fish behavior to a trolled lure.

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