Selectivity of Gillnet for Neon Flying Squid, *Ommastrephes bartrami* (LeSueur) in the North Pacific

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This paper attempted to estimate mesh selectivity of gillnets for neon flying squid in the north Pacific Ocean. The 11 linear regressions ($P<0.05$) were obtained using the data on catch ratios derived from mesh size combinations between two slightly different mesh sizes of 12 kinds of research gillnet (namely 33, 37, 42, 48, 55, 63, 72, 76, 86, 96, 105 and 115 mm in stretched mesh size). There was an increase in the optimum length with the increase in mesh size but standard deviation showed somewhat increase with the increase in the mesh size. The selectivity curves were well fitted to the length frequency distributions obtained from samples for the mesh sizes from 48 mm through 86 mm. For the mesh sizes of 33, 37 and 42 mm the DML (Dorsal Mantle Length) compositions were distributed towards the right hand-limb of the curves. The DML distributions from the 96 mm and larger meshes showed a trend towards the left hand-limb of the curves. The selectivity curves for different mesh sizes indicate that large mesh sizes catch a greater size range of squid, and the gillnet fishery in the north Pacific Ocean captures effectively neon flying squid within the range of 9~43 cm DML.

Key words : neon flying sguid, selectivity of gillnet, optimum length

Introduction

Gillnets are not only very useful fishing gear in harvesting widely scattered fish but also one of efficient research tools to sample fish population from scientific viewpoint. It is known, however, they are so highly selective that the use of appropriate mesh size of gillnet will be of help to reduce fishery mortality on certain size classes of fish, that is, the catch of juvenile, hence it makes possible to catch a desirable size range of fish (Hamley, 1975).

The selectivity of gillnet has been studied on commercially important fish stocks in various areas of the world (*e.g.*, Ishida, 1962; Pope *et al.*, 1975; Kubodera and Yoshida, 1981; Dayaratne, 1988; Petrakis and Stergiou, 1996). However, this kind of work has not been done much so far for Cephalopods, especially neon flying squid which is one of the most abundant aquatic animals in the north Pacific Ocean. Kubodera and Yoshida (1981) studied the gillnet selectivity for neon flying squid based on the data collected from the research gillnet (11 different mesh sizes) for salmon in the north Pacific, and concluded that the gillnet was non-selective for neon flying squid.

Korean gillnet fishery for the north Pacific neon flying squid started in the late 1970s. The fishing vessels had exerted their fishing efforts mainly for catching this fish species in the area of 30~46°N and 141°E~151°W from April or May through December every year. Annual total catch of neon flying squid in the north Pacific amounted to more than 100,000 tonnes during 1988~1990 with a peak of about 134,000 tonnes in 1989, contributing greatly to both total production and economic sectors in fisheries industry of Korea. This fishery was completely stopped on January 1, 1993 in accordance with the UN Resolution 46/215 issued in 1991.

The National Fisheries Research and Development Institute (NFRDI) of the Republic of Korea had conducted research cruises by the research vessel, Pusan 851, around the main fishing grounds of neon flying squid in the north Pacific during 1989~1990, with the view of understanding relationship between oceanographic conditions and its abundance as well as of studying gillnet selectivity patterns. The present paper attempted to estimate selectivity parameters, selectivity curves etc. of neon flying squid gillnet with 12 different mesh sizes.

Materials and Methods

Data Collection. Basic data used in this study were from the research vessel (Pusan 851, gross tonnage 1,126) of NFRDI, which conducted research cruises for

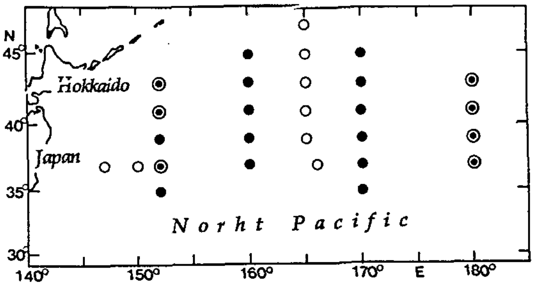

Fig. 1. Sampling stations of gillnets for neon flying squid, *Ommastrephes bartrami* in the north Pacific during the period of July to August in 1989～1990.
● : 1989 only, ○ : 1990 only,
⊙ : 1989 and 1990

neon flying squid in the north Pacific Ocean from July to August in 1989～1990 (Fig. 1). The sampling stations were chosen in traditional fishing areas where neon flying squid are abundant so that any possible bias in collecting samples from the population can be minimized.

Research gillnet for neon flying squid was designed for 14 different mesh sizes, namely 33, 37, 42, 48, 55, 63, 72, 76, 86, 96, 105, 115, 138 and 157 mm in stretched mesh size with hanging ratio of 54% (Gong, *et al.*, 1992, 1993). The length of gillnet was 50 m long and 8 m high. The data obtained from the 138 and 157 mm mesh sizes were not included in this study because the catches of both mesh sizes were very rare. The gillnets were ready to set between 15 : 00 and 16 : 00, depending on sea conditions and completed setting before the sunset and hauled at the sunrise.

A total of 2,090 neon flying squid were sampled at random from the experimental setting of research gillnet during the survey period (Table 1). The fish specimens sampled were preserved in fresh condition with ice for laboratory measurement to obtain some biological data in details. All fish were measured by dorsal mantle length (DML) from the tip of the fin to the dorsal posterior margin of the mantle to the nearest centimeter. In addition, round weight of each individual was measured to the nearest gram. The mantle length compositions were constructed from the data obtained by the gillnets of 12 different mesh sizes. These were compared to selectivity curves estimated for each gillnet mesh sizes. In analysing the whole data collected, individuals sampled per selectivity experiment were pooled regardless of time due to low number of samples each length class, and effect for each month was not considered in this study.

Estimation of Selectivity Parameters. Indirect methods of estimating selectivity parameters were used on the basis of the catch ratios between catches taken by gillnets of slightly different mesh sizes (Holt, 1963). The natural logarithms of the catch ratio (c_1/c_2) between two slightly different mesh sizes m_1 and m_2 are linearly related to fish lengths:

$$\ln\left(\frac{c_1}{c_2}\right)=a+bL$$

where L is the mid point of the length class, a and b are the intercept and slope of the linear regression, respectively.

The intercept and slope of the regression were used to compute the optimum lengths Lm_1 and Lm_2 for mesh sizes m_1 and m_2, respectively:

$$Lm_1=-2\left[\frac{am_1}{b\,(m_1+m_2)}\right]$$

$$Lm_2=-2\left[\frac{am_2}{b\,(m_1+m_2)}\right]$$

Under the assumption that the mode in size composition corresponds to optimum length, the selectivity factor (SF), the ratio of the optimal length to stretched mesh size, was estimated from,

$$SF=-2\left[\frac{a}{b\,(m_1+m_2)}\right]$$

In this study, 12 slightly different mesh sizes were used and a total of 11 pairs of estimations for the regression parameters a and b were obtained from the above equation. To estimate overall selectivity factor (SF_{all}), the following equation was based (Sparre *et al.*, 1989),

$$SF_{all}=-2\left[\frac{\sum_{i=1}^{n-1}(a_i/b_i)(m_i+m_{i+1})}{\sum_{i=1}^{n-1}(m_i+m_{i+1})^2}\right]$$

where a_i and b_i are the intercept and slope, respectively,

Table 1. Dorsal mantle length (DML) distribution of neon flying squid, *Ommastrephes bartrami* sampled with 12 type of gillnets (33 to 115mm stretched mesh size) by the R/V Pusan 851 in 1989 and 1990

DML \ Mesh size	33		37		42		48		55		63		72		76		86		96		105		115		Total	
10.5	1	*4*																							1	*4*
11.5	1	*4*	2	*4*																					3	*8*
12.5	1	*4*			3	*8*																			4	*12*
13.5	20	*73*	23	*47*	8	*21*	1	*4*			1	*3*													53	*148*
14.5	56	*204*	53	*108*	10	*26*	6	*23*			1	*3*													126	*364*
15.5	28	*102*	18	*37*	5	*13*	2	*8*	2	*7*															55	*167*
16.5	13	*47*	31	*63*	25	*64*	16	*62*	4	*14*															89	*250*
17.5	5	*18*	27	*55*	38	*98*	30	*116*	17	*62*	6	*15*													123	*364*
18.5	3	*11*	14	*29*	33	*85*	23	*89*	22	*80*	7	*18*	3	*5*											105	*317*
19.5	2	*7*	2	*4*	19	*49*	34	*132*	35	*127*	15	*38*	2	*3*	1	*2*										
20.5	1	*4*	1	*2*	11	*28*	18	*70*	20	*72*	13	*33*	13	*21*	4	*6*	1	*1*			1	*1*			83	*238*
21.5							4	*16*	24	*87*	18	*46*	8	*13*	11	*17*	2	*2*			1	*1*			68	*182*
22.5							2	*8*	14	*51*	16	*40*	21	*35*	10	*15*	1	*1*							64	*150*
23.5									12	*43*	16	*40*	28	*46*	11	*17*	7	*8*							74	*154*
24.5					1	*3*			13	*47*	18	*46*	27	*45*	21	*32*	6	*7*	3	*3*			1	*1*	90	*184*
25.5									4	*14*	18	*46*	38	*63*	26	*39*	26	*31*	7	*8*					119	*201*
26.5					1	*3*			1	*4*	12	*30*	32	*53*	48	*72*	30	*35*	10	*11*	1	*1*			135	*209*
27.5											6	*15*	39	*64*	33	*50*	40	*47*	25	*28*	4	*5*			147	*209*
28.5											2	*5*	19	*31*	20	*30*	39	*46*	25	*28*	14	*16*	2	*2*	121	*158*
29.5													10	*17*	20	*30*	39	*46*	22	*24*	18	*20*	3	*3*	112	*140*
30.5					1	*3*							6	*10*	19	*29*	42	*50*	39	*43*	14	*16*	4	*4*	125	*155*
31.5													1	*2*	4	*6*	26	*31*	28	*31*	16	*18*	10	*11*	85	*99*
32.5															4	*6*	24	*28*	18	*20*	14	*16*	10	*11*	70	*81*
33.5													2	*3*	2	*3*	9	*11*	12	*13*	12	*14*	5	*5*	42	*49*
34.5																	10	*12*	5	*6*	5	*6*	6	*6*	26	*30*
35.5															1	*2*	2	*2*	7	*8*	4	*5*	4	*4*	18	*21*
36.5																			2	*2*	2	*2*	7	*7*	11	*11*
37.5																					1	*1*	2	*2*	3	*3*
38.5																					1	*1*	2	*2*	3	*3*
39.5																			2	*2*	1	*1*	2	*2*	5	*5*
40.5																			1	*1*	1	*1*	2	*2*	4	*4*
41.5																			1	*1*	1	*1*	1	*1*	3	*3*
42.5																							2	*2*	2	*2*
43.5																							2	*2*	2	*2*
44.5																					1	*1*	1	*1*	2	*2*
45.5																							2	*2*	2	*2*
46.5																							3	*3*	3	*3*
47.5																							2	*2*	2	*2*
No. of individual (A)	131	*478*	171	*349*	155	*401*	136	*528*	168	*608*	149	*378*	249	*411*	235	*356*	304	*358*	207	*229*	112	*127*	73	*75*	2,090	*4,298*
Amount of gear used (B)	63		67		72		77		112		112		112		111		111		111		111		111		1,170	
No. of sample (C)	301		234		287		409		682		423		461		395		399		256		140		86		4,073	
Correction factor (D)	3.65		2.04		2.57		3.91		3.62		2.53		1.65		1.51		1.18		1.11		1.13		1.06			

Numerals in ordinary face : raw data, Numerals in italic : standardized values per 100 gillnets
$D=(C\times 100)\ /\ (A\times B)$

of the regression derived from two successive mesh sizes m_i and m_{i+1}.

The common standard deviation ($SD_{com.}$) was estimated as the mean value of the individual estimates for each consecutive pair of mesh sizes (Sparre *et al.*, 1989):

$$SD_{com.}=\left[\frac{1}{(n-1)}\sum_{i=1}^{n-1}-2\left(\frac{a_i(m_i-m_{i+1})}{b_i^2(m_i+m_{i+1})}\right)\right]^{1/2}$$

The optimum length for mesh size m was then computed from the relationship:

$$Lm=(SF)m$$

The probability of capture (P) for a given length L in a gillnet consisting of a mesh size m was calculated by the following expression (Holt, 1963):

$$P=\exp\left[-\frac{(L-Lm)^2}{2\,(SD)^2}\right]$$

Holt (1963)'s method is based on the assumption that nets used have the same area when set. In this study, therefore, numbers caught for each mesh size were redistributed by using correction factor and expressed per 100 gillnets because of different number of fishing effort exerted by each mesh size at each sampling station.

Results and Discussion

Length frequency distributions of neon flying squid sampled by 12 different mesh size of research gillnet showed that the compositions from the 33, 37 and 42 mm mesh sizes did not differ much from each other, ranging from 10 cm to 20 cm DML. But the more mesh size increases, the wider length ranges become with increase of modal size (Table 1). The modal lengths from the samples were 14 cm DML for the 33 mm gillnet, 19 cm for 48 mm net, 25 cm for 72 mm net and 30 cm DML for the 96 mm gillnet, respectively. Table 1 also shows the standardized values as number per 100 gillnets in each mesh size.

The 11 linear regressions were obtained using the data on the natural logarithms of catch ratios derived from mesh size combinations between two slightly different mesh sizes against the most abundant length classes in frequency distributions. The slope b and intercept a of the regressions, coefficient of determination (r^2), standard deviation, optimum length and selection factor for each mesh size are presented in Table 2. The r^2 values were all statistically significant ($P<0.05$), showing that the natural logarithms of catch ratios and fish lengths in DML were related linearly. The values of selectivity factors varied between a maximum of 4.39 and a minimum of 3.06, showing a decreasing trend with increase of

Table 2. Parameters of the regression of neon flying squid, *Ommastrephes bartrami* catch ratio against length class between two slightly different gillnets

Mesh size (mm)		a	b	SE of b	r^2	N	Optimum length (cm)		SF	SD
m_1	m_2						L_1	L_2		
33	37	−5.515	0.359	0.078	0.87	5	14.50	16.25	4.39	2.21
37	42	−9.816	0.603	0.127	0.90	8	15.24	17.30	4.12	1.85
42	48	−6.185	0.356	0.121	0.91	7	16.22	18.54	3.86	2.55
48	55	−10.116	0.528	0.140	0.90	7	17.84	20.45	3.72	2.22
55	63	−8.016	0.352	0.119	0.88	10	21.22	24.30	3.86	2.96
63	72	−10.487	0.432	0.103	0.92	8	22.65	25.89	3.60	2.74
72	76	−6.020	0.216	0.101	0.89	11	27.14	28.65	3.77	2.64
76	86	−8.983	0.311	0.099	0.88	14	27.14	30.72	3.57	3.39
86	96	−7.544	0.235	0.103	0.91	9	30.38	33.91	3.53	3.88
96	105	−11.477	0.335	0.020	0.99	6	32.69	35.75	3.40	3.02
105	115	−13.720	0.407	0.034	0.96	7	32.15	35.21	3.06	2.74

N : number of points used in the regressions (*i.e.* number of length class for which frequencies overlap). L_1 and L_2 : the estimated optimum lengths for nets of mesh sizes m_1 and m_2, respectively. SE of b : standard error of the slope. SF : selectivity factor. SD : standard deviation.

mesh size. As expected, in general, there was an increase in the optimum length with the increase in mesh size but standard deviation increased somewhat, ranging 1.85 to 3.88, with the increase in the mesh size. The probabilities of capture for different mesh sizes were estimated from the optimum length and a given length in the length composition (Table 3). The selectivity curves for different meshes using the probability of capture were plotted on the observed length frequencies (Fig. 2). The selectivity curves were well fitted to the original length frequency distributions obtained from samples for the mesh sizes from 48 mm through 86 mm. For the mesh sizes of 33, 37 and 42 mm the DML compositions were distributed towards the right-limb of the curves. The DML distributions from the 96 mm and larger meshes were located towards the lower end of the curves. This is because flying squids have large fins at posterior part of mantle. Once the fins pass the net, they work like a barb. It was observed, however, most of fish were landed on board with entanglement of the fins in the large meshes.

The overall selectivity factor, common standard deviation and optimum selection length for each mesh size were calculated using the data in Table 2 (Table 4). The optimum selection lengths increased from 11.61 cm for the 33 mm gillnet to 19.34 cm for the 55 mm, to 30.25 cm for the 86 mm and to 40.45 cm for the 115 mm gillnet. All in all, the selectivity curves for different mesh sizes showed that large mesh sizes caught a greater size range of fish, and the gillnet fishery in the north Pacific Ocean captured effectively neon flying squid within the range 9~43 cm DML (Fig. 3), based on the selection ranges estimated from one SD on each side of optimum length. Few fish larger than 43 cm were recorded in the study area. Kubodera and Yoshida (1981) reported that the selectivity curves estimated from the small size classes were relatively efficient in catching larger squids compared to the curve from the large size classes.

It is known that mesh selectivity is also affected by several factors such as elastic and/or inelastic stretching of the net, strength and flexibility of the twine, and also visibility of the twine (Clark, 1960; Hamley, 1975). It was not allowed to account for these factors in this study. According to Roper *et al.* (1984)'s report the maximum dorsal mantle length of this fish species is 50 cm in females

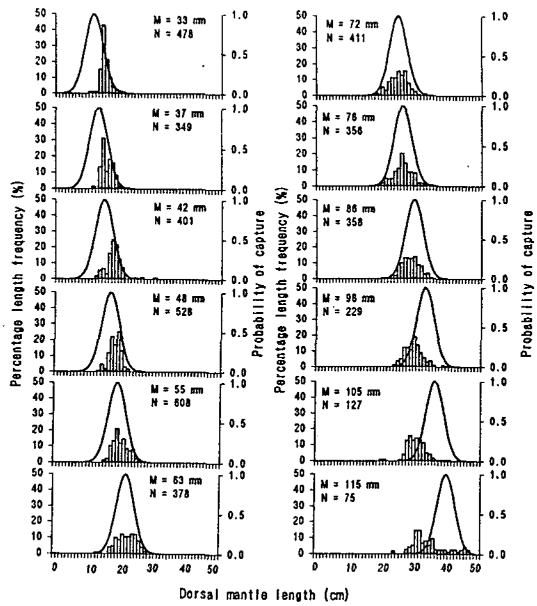

Fig. 2. Length-frequency of neon flying squid, *Ommastrephes bartrami* for each gillnet with the estimated selectivity curve.

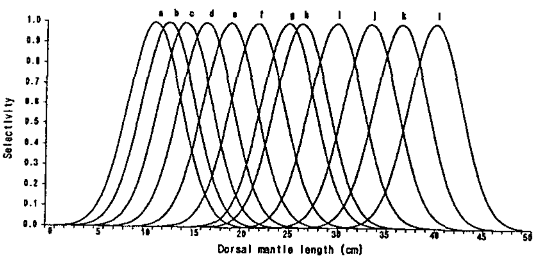

Fig. 3. Selectivity of 33~105 mm gillnets to neon flying squid, *Ommastrephes bartrami*.
Mesh size,a : 33 mm, b : 37 mm, c : 42 mm, d : 48 mm, e : 55 mm, f : 63 mm, g : 72 mm, h : 76 mm, i : 86 mm, j : 96 mm, k : 105 mm, l : 115 mm.

and males somewhat smaller than females, and length at maturity is a little less than 40 cm in females and between 29 and 32 cm DML in males. Nakamura (1988) studied maturity of this fish species in the surrounding waters of Izu-Ogasawara Islands in spring that mature squid among the specimens accounted for fully or nearly 100% in number, while mature males outnumbered mature females. From his study, DML of mature squid caught by the gillnets ranged 29 cm to 39 cm for male and from 40 cm to 46 cm for female. The probability of capture for squids of less than 29 cm DML by using gillnets

Table 3. Estimated probability of capture for each length class of neon flying squid, *Ommastrephes bartrami* for different mesh size of gillnet

Class mid-	Probability of capture for different mesh size (mm)											
point (cm)	33	37	42	48	55	63	72	76	86	96	105	115
2.5	0.00											
3.5	0.01	0.00										
4.5	0.04	0.01										
5.5	0.08	0.02	0.00									
6.5	0.18	0.06	0.01									
7.5	0.33	0.13	0.03	0.00								
8.5	0.53	0.26	0.07	0.01								
9.5	0.75	0.44	0.16	0.03	0.00							
10.5	0.92	0.66	0.30	0.07	0.01							
11.5	1.00	0.86	0.49	0.15	0.02							
12.5	0.95	0.98	0.71	0.28	0.04	0.00						
13.5	0.79	0.98	0.90	0.47	0.10	0.01						
14.5	0.57	0.86	1.00	0.69	0.21	0.02						
15.5	0.37	0.66	0.97	0.88	0.38	0.05	0.00					
16.5	0.20	0.45	0.82	0.99	0.58	0.12	0.01					
17.5	0.10	0.26	0.61	0.98	0.80	0.24	0.02	0.00				
18.5	0.04	0.14	0.40	0.84	0.95	0.41	0.05	0.01				
19.5	0.02	0.06	0.23	0.63	1.00	0.63	0.11	0.03				
20.5	0.01	0.02	0.11	0.42	0.92	0.83	0.21	0.08	0.00			
21.5	0.00	0.01	0.05	0.24	0.73	0.97	0.38	0.16	0.01			
22.5		0.00	0.02	0.12	0.52	0.99	0.59	0.31	0.02			
23.5			0.01	0.05	0.32	0.89	0.80	0.50	0.05			
24.5			0.00	0.02	0.17	0.70	0.96	0.72	0.11	0.00		
25.5				0.01	0.08	0.48	1.00	0.90	0.22	0.01		
26.5				0.00	0.03	0.29	0.91	1.00	0.39	0.03		
27.5					0.01	0.15	0.73	0.96	0.61	0.07	0.00	
28.5					0.00	0.07	0.51	0.81	0.82	0.16	0.01	
29.5						0.03	0.31	0.60	0.96	0.30	0.03	
30.5						0.01	0.17	0.39	1.00	0.49	0.06	
31.5						0.00	0.08	0.22	0.90	0.71	0.14	0.00
32.5							0.03	0.11	0.71	0.90	0.27	0.02
33.5							0.01	0.05	0.50	1.00	0.46	0.04
34.5							0.00	0.02	0.30	0.96	0.68	0.10
35.5								0.01	0.16	0.82	0.87	0.20
36.5								0.00	0.07	0.61	0.99	0.36
37.5									0.03	0.40	0.98	0.56
38.5									0.01	0.23	0.85	0.78
39.5									0.00	0.11	0.65	0.94
40.5										0.05	0.43	1.00
41.5										0.02	0.25	0.93
42.5										0.01	0.13	0.76
43.5										0.00	0.06	0.54
44.5											0.02	0.34
45.5											0.01	0.18
46.5											0.00	0.09
47.5												0.04
48.5												0.01
49.5												0.00
50.5												

Table 4. Common selectivity factor (SF_{all}), common standard deviation ($SD_{com.}$) and estimated optimum lengths of neon flying squid, *Ommastrephes bartrami* for gillnets of 33, 37, 42, 48, 55, 63, 72, 76, 86, 96, 105 and 115 mm mesh sizes

SF_{all}	$SD_{com.}$	Optimum length (cm)											
		L_{33}	L_{37}	L_{42}	L_{48}	L_{55}	L_{63}	L_{72}	L_{76}	L_{86}	L_{96}	L_{105}	L_{115}
3.52	2.75	11.61	13.01	14.77	16.88	19.34	22.16	25.32	26.73	30.25	33.76	39.63	40.45

of mesh sizes from 33 mm to 55 mm was 100% and decreased gradually with increase of mesh size. The probability of capture with the 76 mm research gillnet for larger than 29 cm DML neon flying squid was 20.3%, the 86 mm net 67.3%, the 96 mm net 96.1% and 100% from both the 105 mm and 115 mm nets, respectively (Table 3). This implies that the use of the gillnets of mesh size < 86 mm stretched mesh size is reasonable to maximize recruitment of juvenile from biological point of view.

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