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Fishery biology of *Loligo edulis* in Moroiso Bay, Kanagawa Prefecture, Japan

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Abstract: The swordtip squid, *Loligo edulis* Hoyle, 1885 was collected from set-net fishery in Moroiso Bay, Miura Peninsular, Kanagawa Prefecture, Japan, during April 2002 and September 2003. A total of 2,127 individuals (1,146 males and 981 females) from the mantle length between 33 and 213 mm were examined. The maturation, reproductive cycles and spawning period were determined for both sexes. Age and growth were analyzed from statolith increments and hatching date was estimated by the back calculation. Statoliths of 350 males (35–187 mm mantle length) and 232 females (39–213 mm mantle length) were examined.The estimated age ranged from 79 to 298 days for male and 83 to 277 days for female. The hatching dates were estimated to be from May 2002 to April 2003. The spawning season occurred throughout the year and the main spawning period took place between June and August. Exponential growth model was used to describe the relationship of mantle length and the estimated age of hatching month group.

Keywords: *Loligo edulis, fishery biology, age, hatching dates, maturation*

1. Introduction

Loligo edulis (HOYLE, 1885) is a neritic loliginid squid distributed over the Indo-West Pacific region from central Japan to South China Sea, and northern Australia (ROPER *et al.,* 1984; CARPENTER and NIEM, 1998). In the southern parts of Japan Sea, the landing of *L. edulis*, caught mainly by jigging, set-net and bottom trawls, fluctuated throughout the year (NATSUKARI and TASHIRO, 1991).

Studies on fishery biology of *L. edulis* were conducted under two major research projects in the western Japanese waters (SEIKAI Reg. Fish. Res. Lab. *et al.,* 1978; YAMAGUCHI Pref. Open Sea Fish. Exp. St. *et al.,* 1983 and 1986). The life cycle of *L. edulis* was estimated to be one year based on the validated statolith increments and the spawning season extended throughout the year from the information of the degree of maturity and the size of this species (TASHIRO, 1977; NATSUKARI *et al.,* 1988). Wide variation in growth rates and existence of seasonal forms were reported on *L. edulis* in the western coast of Japanese waters (OGAWA *et al.,* 1983; YAMADA *et al.,* 1986; NATSUKARI *et al.,* 1988).

In Tokyo Bay and Sagami Bay, monthly change of the catches of the commercially important squids was reported based on the data of the landings for six years from 1984 to 1990 (KUBOSHIMA, 1992). Landing of *L. edulis* from set-net fisheries in the east coast of Sagami Bay is throughout the year and the monthly catches had a peak between January and February (KUBOSHIMA, 1992). Although *L. edulis* is an important species for the fisheries in Miura Peninsula, Kanagawa Prefecture, there have been little information about the aspects of fisheries biology in this area, such as growth, maturation and reproduction. In the present paper, study of the fishery biology on maturity, age and growth of *L. edulis* were carried out based on the monthly specimens through a year collected from the set-net

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fishery in Moroiso Bay located at the tip of Miura Peninsula.

2. Materials and methods

Specimens of *L. edulis* used in the present study were collected once a month from April 2002 to September 2003 from set-net in Moroiso Bay. After removal of statoliths for age determination, specimens were initially fixed with 10% formalin and preserved in 40% isopropyl alcohol (ROPER and SWEENEY, 1983). Specimens were dissected to determine sex and maturity stages. Dorsal mantle length (ML in mm), nidamental gland length (NGL in mm), and testis length (TL in mm) were measured with a digital caliper to the nearest 0.1 mm. The total body weight (BW in g) was measured to the nearest 0.1 g with a digital balance. A total number of 2,127 individuals of *L. edulis* with mantle length ranged from 33 to 187 mm (n=1,146) and 36 to 213 mm (n=981) for male and female, respectively, were examined.

Sex ratio (F/M) was analyzed monthly and significant differences between the calculation ratio and the expected ratio 1:1 (female: male) were tested using the Chi-Square test.

Since the sexual maturity stages were determined based on the definition of stages I to VI of LIPINSKI and UNDERHILL (1995), in the present study stages I and II were defined as immature stage, stage III as maturing stage, stages IV and V as mature stage, and stage VI as spent.

Testis length index for males and Nidamental gland length index for females were expresses as follows;

Testis length index (TLI) = (Testis length/-Mantle length) ×100,

Nidamental gland length index (NGLI) = (Nidamental gland length/Mantle length) × 100.

Monthly mean value of maturity index (TLI and NGLI) was used for an index to determine the size of maturity and seasonal change of the size in maturity.

The relationship between the mantle length (ML in mm) and total body weight (BW in g) was expressed as $BW = aML^b$, where a and b are constants, which was fitted by the least-squares linear regression of log transformed variables. The effect of sex on exponent b of the ML-BW relationships was investigated using a test for homogeneity of slopes (ANCOVA).

For age determination specimens were randomly selected from the samples collected between October 2002 and September 2003 and if the specimens of any sampling months were less than 30 individuals, all the specimens were used. Statoliths from a total of 350 males (ML raged from 35 to 187 mm) and 232 females (ML ranges from 39 to 213 mm) were readable and used for the age estimation.

Paired statoliths were dissected from fresh specimens following the method of DAWE and NATSUKARI (1991). The right statolith was used for counting increments and the left one was kept in reserve. Statoliths were mounted on microscopic slides in Eukitt™ mounting reagent (*Sigma-Aldrich Inc.*) and allowed to dry for 1 week. Ground and polished statoliths were made with abrasive waterproof paper and 3M rubbing film. Statolith increments were observed under an optical microscope (×400) and images were taken for increment analyses. Counting the increments was made from the natal ring (NATSUKLARI *et al.,* 1988) to the edge of the rostrum (Fig.1). To estimate the degree of counting error (t-test) the increments on the same statolith were counted twice for 20 statoliths and no significant difference ($p>0.05$) was detected between the first and the second count for the same statolith.

Since the daily deposition of statolith increments has been validated in a number of loliginid species (JACKSON, 1990; RODHOUSE and HATFIELD, 1990; JACKSON, 1994; LIPINSKI *et al.* 1998) including *L. edulis* (NATSUKARI *et al.,* 1988), age in the present study was estimated relying on the assumption that the increments of *L. edulis* formed daily. Date of hatching was estimated by the back-calculation departing from the date of the capture. Spawning time was estimated to be one month before hatching based on the embryonic studies of NATSUKARI and TASHIRO (1991).

Since the asymptotic growth models has been demonstrated not relevant to describe cephalopod growth (ALFORD and JACKSON, 1993; JACKSON *et al.,* 2000) and the recent extensive studies of myopsid squid growth of the family

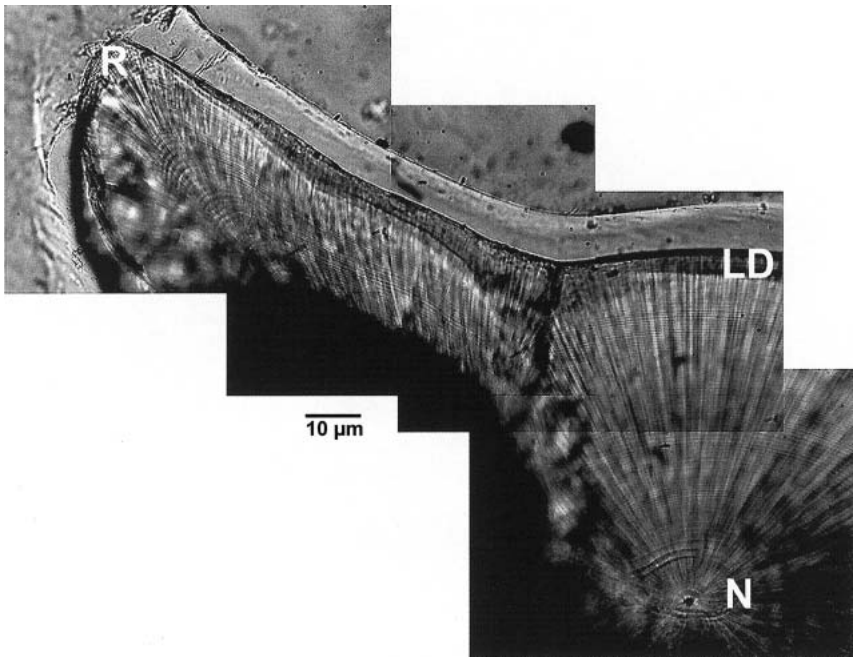

Fig. 1. Polished anterior-side up statolith of an immature male *Loligo edulis* observed under light microscopy. ML 75.1 mm, BW 19.8 g, TSL 1.35 mm, 134 increments counted. (N = nucleus, R = rostrum, LD = lateral dome).

Loliginidae using statolith ageing techniques have been revealed a short lifespan less than and/or about 1 year (*Loligo chinensis*, JACKSON and CHOAT, 1992; *L. vulgaris*, NATSUKARI and KOMINE, 1992; *L. pealei*, BRODZIAK and MACY, 1996). The non-asymptotic growth models, included linear, exponential and power curves have been applied in many studies (*L. vulgaris*, ROCHA and GUERRA, 1999; *L. gahi*, HATFIELD, 2000; *L. plei*, JACKSON and FORSYTHE, 2002; *L. forbesi*, CHALLIER *et al.,* 2006). In the present study the exponential curve was chooses to described the growth of *L. edulis* because the exponential functions can describe growth over the life cycle including the embryonic phase of loliginid squids (FORSYTHE and HANLON, 1989; HANLON *et al.,* 1989) not because of the fitting growth models give a better correlation coefficients (CHALLIER *et al.,* 2006).

Squid hatched in the same month was grouped together to analyze the hatching season and growth. To calculate the growth curves the value of 2.0 mm in ML was assigned for the size of hatchlings of *L. edulis* (NATSUKARI and TASHIRO, 1991). The exponential equation, $ML = 2.0e^{at}$ was applied to the relationship between the estimated age (t in days) and mantle length (ML in mm); where a is constant.

The statistic analysis for their residual sum of squares and the corresponding mean error using the dummy-variable approach (QUINN and KEOUGH, 2002) on the relationships between estimated age and mantle length in each hatching month group by sex. All statistical analyses were conducted with a 0.05 significant level.

3. Results

3.1 Size composition

The minimum ML was 33 mm for male and 36 mm for female both captured in April 2002 and the maximum was 187 and 213 mm ML for male captured in March and female in June 2003, respectively (Fig.2). Small squid less than 45 mm ML occurred in April-May and September-November. Larger individuals over 130 mm ML were collected during May-June, August 2002 and January, and March to September 2003 (Fig.2). There was a tendency that

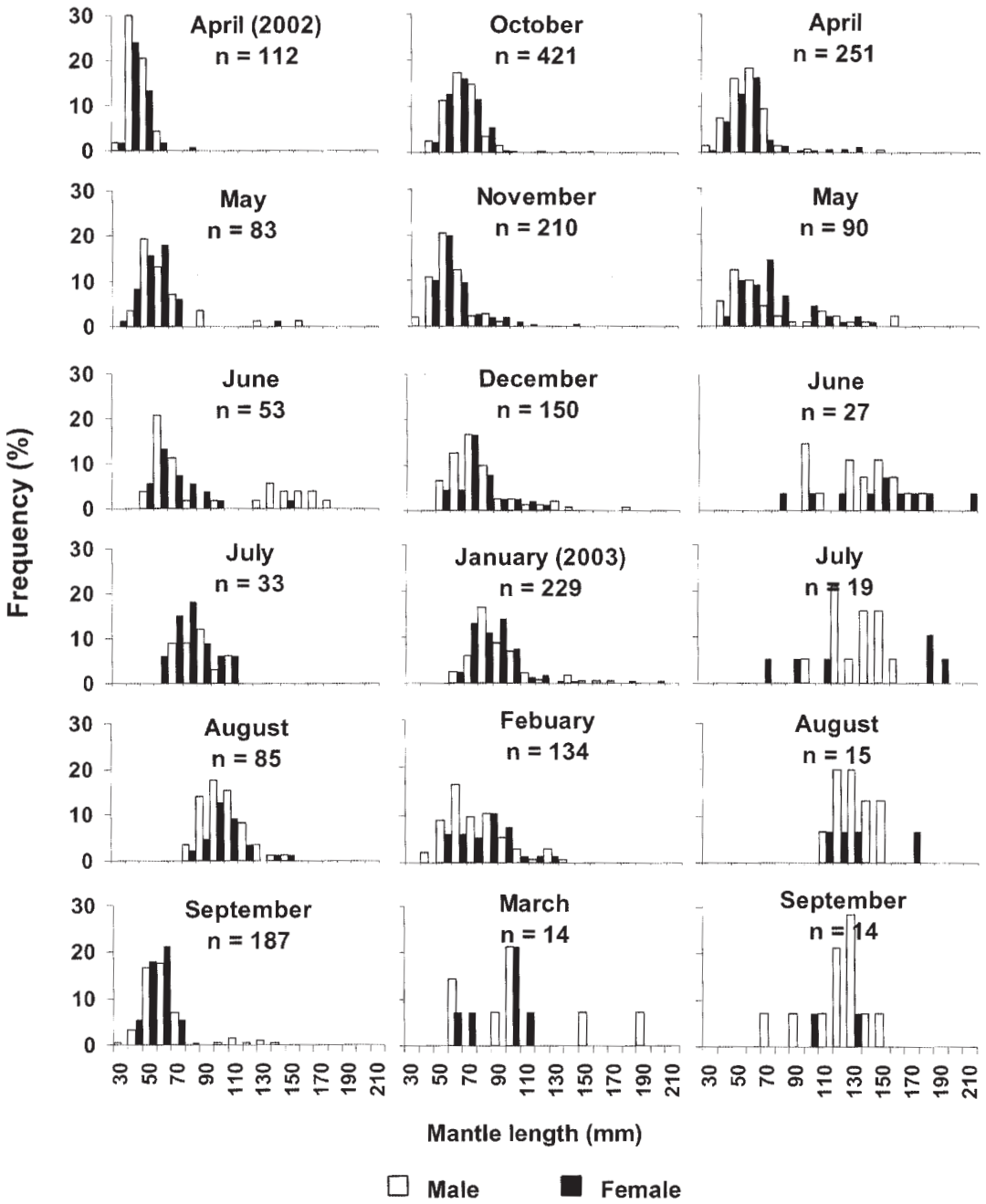

Fig. 2. Monthly length frequency distribution of *Loligo edulis* collected from April 2002 to September 2003.

the main mode of the length distribution increased from April (45–55 mm ML) to August 2002 (95–105 mm ML), slightly increased (45–75 mm ML) during a period from September 2002 to January 2003, and main mode shifted to relatively larger size (larger than 100 mm ML) from May to August, 2003 (Fig.2).

The equations relating the body weight to mantle length of males and females were expressed as $BW=0.00037ML^{2.53}$ ($r^2=0.99$, n=615,

Table 1 Summary of size range in mantle length and maturity indices of testis length index (TLI) and nidamental gland length index (NGLI) of each stage from Ⅰ to Ⅴ for males and females *Loligo edulis*

*Maturity stages	Male									Female								
	n	Mantle length				Testis length index				n	Mantle length				Nidamental gland length index			
		min	max	mean	S.D.	min	max	mean	S.D.		min	max	mean	S.D.	min	max	mean	S.D.
Ⅰ	63	35	77	55.9	9.2	9.2	22.6	15.3	3.0	1	48		–	–	2.8		–	–
Ⅱ	163	33	120	70.8	15.5	7.0	34.6	16.8	4.0	273	36	134	74.1	17.5	5.7	13.0	9.5	1.0
Ⅲ	79	63	141	104.3	16.1	15.0	46.1	29.3	8.5	27	85	177	124.5	21.7	8.8	16.2	11.4	1.8
Ⅳ	34	98	181	135.6	16.6	31.6	46.2	40.6	3.2	8	95	183	139.5	30.4	10.3	29.2	20.7	6.9
Ⅴ	12	131	187	155.7	15.2	37.6	44.2	40.7	1.8	6	123	213	177.8	33.3	19.8	34.8	28.3	5.0

*stage Ⅰ and Ⅱ are defined as immature, stage Ⅲ as maturing and stage Ⅳ and Ⅴ as matured stages, respectively.

33–187 mm in ML) and $BW = 0.00036ML^{2.54}$ ($r^2 = 0.98$, n = 526, 36–213 mm in ML), respectively. There was no significant difference in the exponent b between males and females ($F = 0.41$, d.f. 1,1137, $p > 0.05$).

3.2 Sex ratio

Monthly sex ratio (F/M) varied from 0.5 in August (2002) to 1.5 in July (2002) with a mean ± SD of 0.9 ± 0.3. Although males were more numerous than females over the entire sampling period, seasonal variation of sex ratio was not significantly different from 1.0 ($p > 0.05$) except in August 2002 and February 2003 ($p < 0.05$), with significantly outnumbered male at the ratio of 0.5 and 0.7.

3.3 Maturation stages and size

Immature squid (stage Ⅰ and Ⅱ) were predominant in both sexes (Table 1). The maximum size of immature male and female was 120 and 134 mm ML, respectively, both captured in January. The minimum size of maturing (stage Ⅲ) male was 63 mm ML captured in October and that of female was 85 mm ML captured in June. Length distribution in each maturity stage overlapped each other especially among maturing (stage Ⅲ) and matured (stage Ⅳ) stages (Table 1). The mean size of mature squid (Stage Ⅳ and Ⅴ) ranged from 135.6 to 155.7 and 139.5 to 177.8 for males and females, respectively. The minimum size of mature males (stage Ⅳ) was 98 mm ML captured in June and females of 95 mm ML captured in November. Males larger than 141 mm ML and females larger than 177 mm ML were all matured (Table 1).

Testis length index increased with increase in ML and majority of the males larger than about 120 mm ML were matured with the index of 35–44 % (Fig.3). In females nidamental gland length index of stages I, II and III was relatively constant around 10 % regardless the ML of less than about 180 mm ML and that of the matured females larger than about 110 mm ML was increased more than 20% (Fig.3).

Seasonal change in maturation

The seasonal changes of the proportion of the number of each maturity stage indicated that maturing and mature squid increased from May to August in both sexes they often held a highest proportion in August, they abruptly decrease after September 2002 (Fig.4). Although a large proportion of matured males appeared also in March 2003, number of maturing and mature female was very small from September to March (Fig.4).

Seasonal changes in testis length index of males and nidamental gland length index of females showed a main peak in August 2002 in both sexes with a secondary peak only for males in March 2003 (Fig.5). These results indicated that the main maturation period for *L. edulis* in Miura Peninsula was estimated to be June to August with a secondary maturation peak in March only for males. However, small number of maturing and mature individuals was appeared all through the study period (Fig.5).

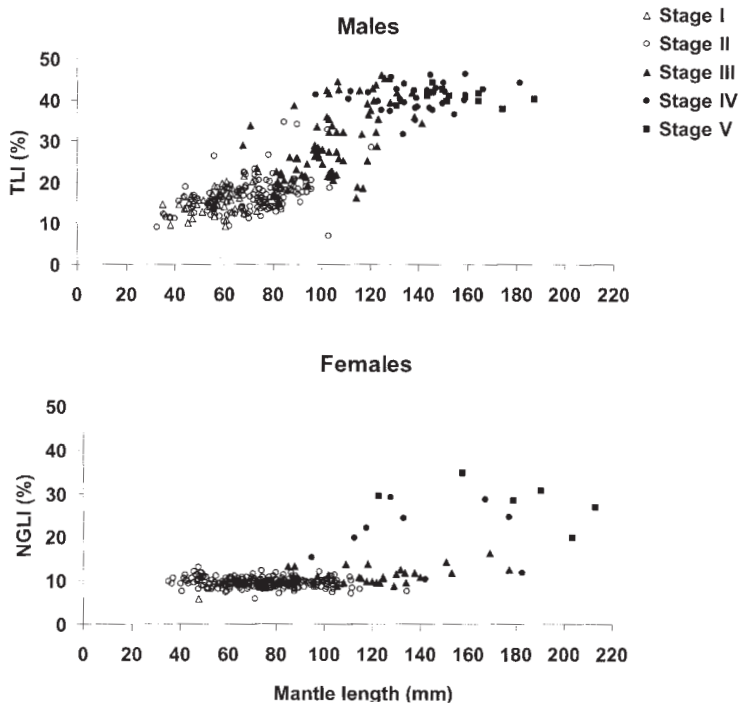

Fig. 3. Relationship between mantle length and maturity index for males and females *Loligo edulis* from April 2002 to September 2003.

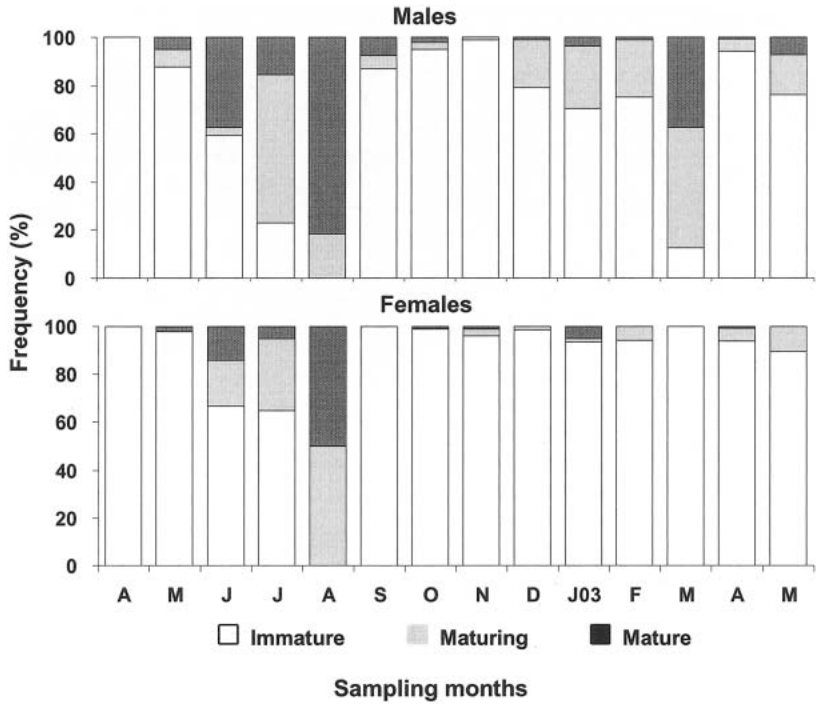

Fig. 4. Percentage of immature, maturing, and mature individuals of *Loligo edulis* for males and females from April 2002 to May 2003.

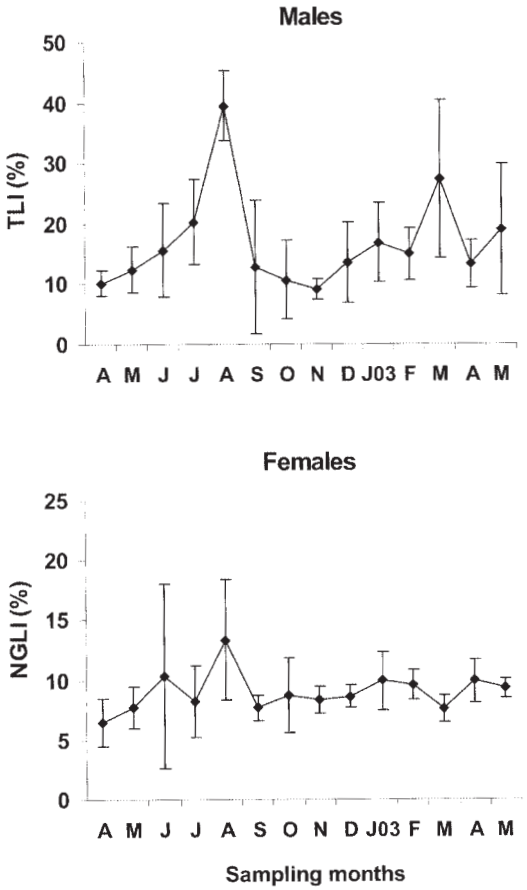

Fig. 5. Monthly mean variation of the maturity index for males and females *Loligo edulis* from April 2002 to May 2003. Vertical bars represent one standard deviation.

3.4 Age and hatching date

Age of *L. edulis* estimated from the number of increments of statoliths ranged from 79 days (42 mm ML) to 298 days (144 mm ML) for male and 83 days (39 mm ML) to 277 days (128 mm ML) for female. Most of the estimated ages of squid collected in October to December 2002 were relatively young within a range from 80 to 170 days (Fig.6). Although most of the squid collected from January to May was older than previous month, there was no clear tendency of the monthly change in age structure (Fig.6). The number of specimens from June to September was small, but the range of the estimated age was wide and older in range from 125 to 298 days. The mean age ±SD in each month ranged from 126.1±16.4 (October 2002) to 255.0±26.1 (August 2003) for male and from 130.4±29.6 (October 2002) to 220.0 ±52.4 (August 2003) for female.

Based on the back calculation for the hatching dates of specimens from October 2002 to September 2003, the squid were hatched from May 2002 to May 2003 for males and May 2002 to April 2003 for females (Fig.7). For males, mode of the hatching month shifted monthly from May-July hatching (in October sampling month) to December-May hatching (in February sampling month) (Fig.7). That of females also showed the similar tendency with males (Fig.7). The result that the monthly age structure of collected specimens indicated no typical seasonal changes (Fig.6), also confirmed the continuous recruitment of young squid of the similar ages older than 3 months after hatching in the area (Fig.7).

Although the size at estimated age of the squid varied wide, there was a tendency that mantle length increased with increase in age and the relationships between ML and estimated age (t in days) in each hatching month from May 2002 to February 2003 were expressed by exponential curves with growth coefficient ranging from 0.020 to 0.026 (Fig.8). The value a of the squid hatched in June 2002 was 0.026 and it decreased to the minimum value of 0.020 in October to November and February 2003 (Fig.9). There was no significant different in the relationship between ML and estimated age between males and female of each hatching month from May 2002 to February 2003 (F=35.4, d.f. 11,538, p=0.967).

3.5 Spawning and recruitment period

Main spawning season of the population in Moroiso area was estimated from June to August based on the results of maturation stages and reproductive organ length indices (Fig.4 and 5). Spawned eggs in the area will hatch after one month from July to September. *L. edulis* hatching at main spawning season in the area will recruit and captured by set-net in Moroiso Bay during a period from November to February from 3 to 6 months after hatching (Fig.7).

Although the proportion of matured

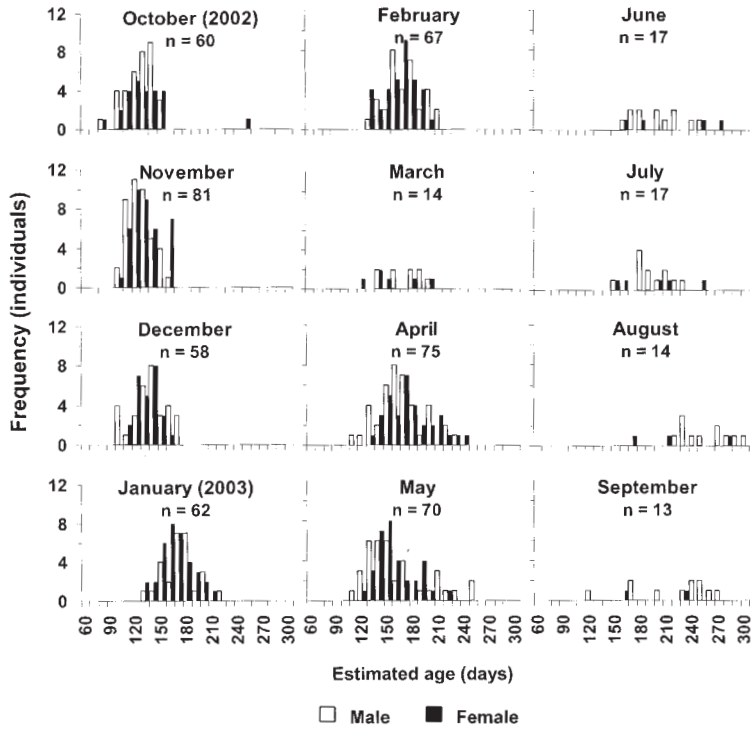

Fig. 6. Monthly estimated age frequency distribution of *Loligo edulis* collected from October 2002 to September 2003.

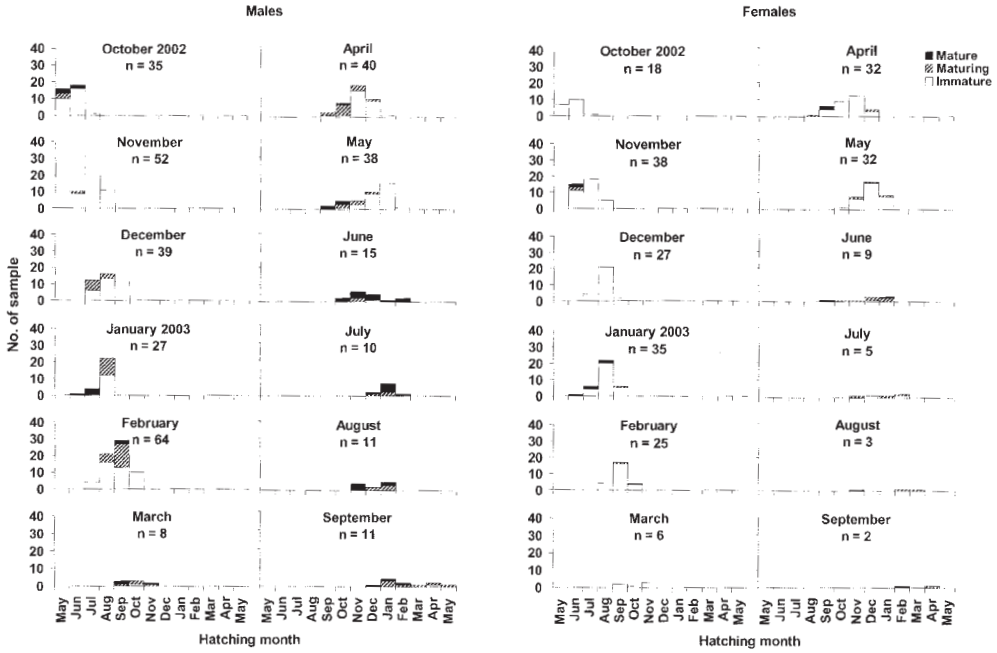

Fig. 7. Monthly distribution of hatching dates of each sampling month from October 2002 to September 2003 of *Loligo edulis* males and females.

individuals was very small, the secondary spawning season was estimated to be from January to April (Fig.4 and 5) and would be hatched between February and May, which would be recruited to the fishery ground and landed from June to October (Fig.8) even though the amount was very small.

4. Discussion

In Kyushu and southwestern coast of the Japan Sea, *L. edulis* was an important fisheries resource and catches was fluctuate from May to December with two peaks during June-July and October-November (FURUTA, 1978; OKAJIMA *et al.,* 1983). In contrast with the Japan Sea coast, annual catches on the coast of Sagami Bay and Tokyo Bay were reported relatively small with two peaks in January and March, respectively. And a lower peak existed during November-December which was the same period to the east coast of Sagami Bay and Tokyo Bay (KUBOSHIMA, 1992). In the present study, adult and young *L. edulis* occurred throughout the year which was similar to the description of KUBOSHIMA (1992) in the east coast of Sagami Bay.

There was no significant difference in the relationship between mantle length and body weight among sexes of *L. edulis* in Moroiso. The relative growth coefficients from the power equation (exponent *b*) of the relationship between ML-BW have been reported varies with seasons and locations from the east China Sea to Hyogo Prefecture region over a range of 1.8–2.2 and 1.7–2.4 for males and females, respectively (YAMADA *et al.,* 1983). The exponent of 2.53 for male and 2.54 for female of this study in Pacific coast took a little higher value compare with those at the western Japan Sea.

The minimum size of fully matured specimens in the present study was 98 mm and 95 mm ML for male and female, respectively, which were larger than that of 70–80 mm ML in male and smaller than that of 110–120 mm in female reported in Nagasaki Prefecture (TASHIRO, 1977; SEIKAI Reg. Fish. Res. Lab. *et al.,* 1978). CHOTIYAPUTTA (1994) reported that "*L. edulis* sub sp." matured at a size of 30 mm ML in the Gulf of Thailand. The degree of maturity and size of squids has a great variation according to season and locality (JACKSON, 1993) especially for tropical loliginid squids such as *L. chinensis* and *L. duvauceli* in Thai waters (CHOTIYAPUTTA, 1994).

In Moroiso Bay, matured individuals occurred throughout the year and the main maturation period was estimated to be June to August with a secondary maturation peak in March only for males based on the maturity index and back calculated hatching date. On the coast of Kyushu the spawning season of the species extends throughout the year (SEIKAI Reg. Fish. Res. Lab. *et al.,* 1978) but in the north or east it tends to become shorter (NATSUKARI and TASHIRO, 1991). In the northern area of Yamaguchi and Hyogo Prefectures, the spawning period of the species was shorter with three main spawning periods in spring, summer and autumn (YAMADA *et al.,* 1983). Because Moroiso is located nearly the northern limit for this species in the Pacific coast (NATSUKARI and TASHIRO, 1991), the main spawning season in the present study was limited in shorter period from June to August and the number of matured squid in other season was very small especially in females.

The estimated hatching dates for *L. edulis* in the present study revealed the seasonal change of the hatching and growth in each hatching month for the monthly collected specimens. The squid caught from April to June hatched mainly from September to February. The seasonal change of the growth coefficient *a* in present study suggested the difference in growth rates of *L. edulis* in different hatching months or seasons in Moroiso Bay. The environmental conditions such as temperature and food availability were suggested to be the main factors affecting the growth of the seasonal groups of squid (COELHO and O'DOR, 1993). Based on the analysis of seasonal samples of tropical loliginid squid, JACKSON and CHOAT (1992) also pointed out that there was considerable seasonal variation in growth. To analyze the growth of *L. edulis* the further study will be needed in relation with environmental factors and maturity condition of the squids.

The life span of *L. edulis* was reported to be 1 year (TASHIRO, 1977; SEIKAI Reg. Fish. Res. Lab. *et al.,* 1978) and that was supported by

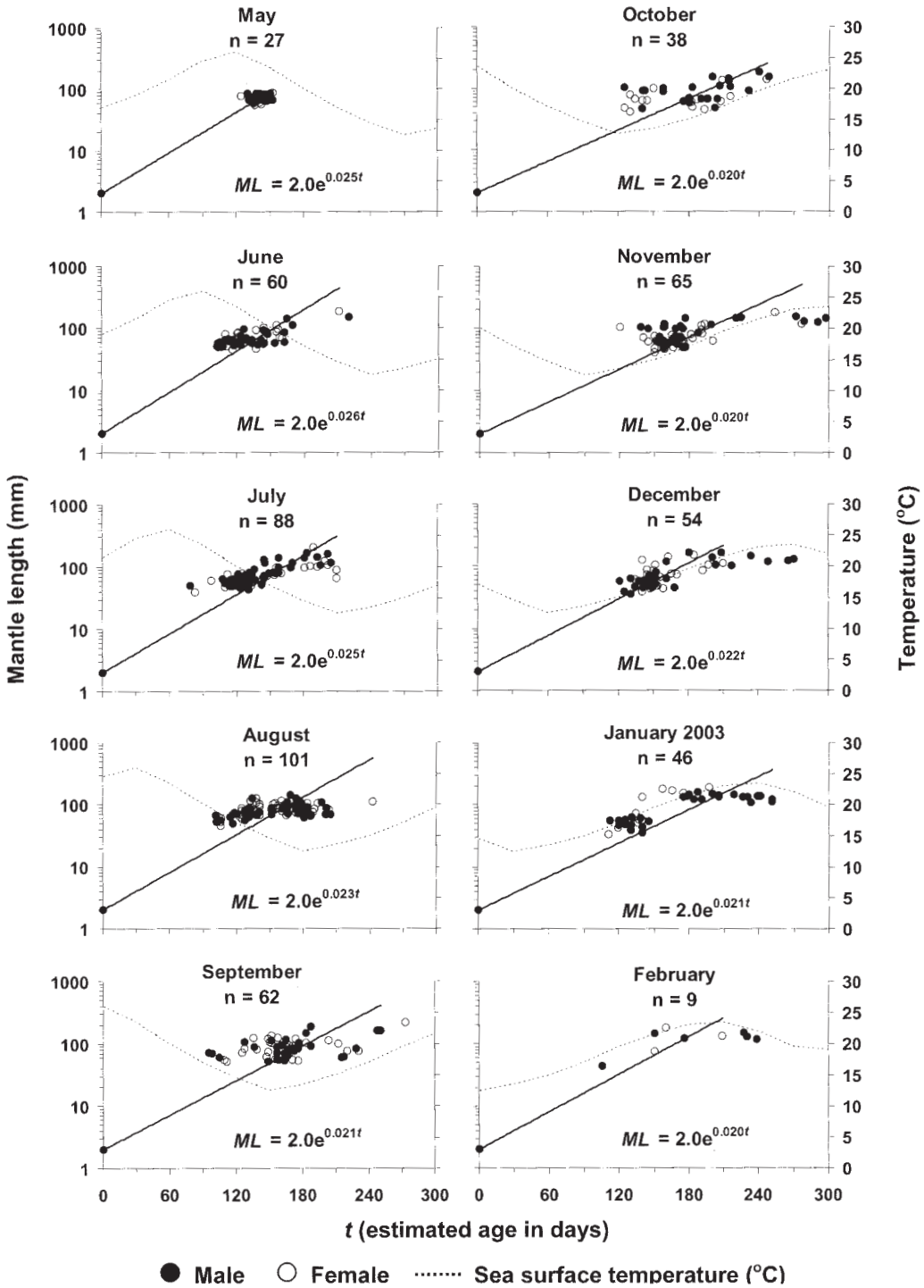

Fig. 8. Relationships between estimated age from statolith increments (days) and mantle length (mm) of *Loligo edulis* by month of hatching couple with sea surface temperature (℃) from May 2002 to February 2003.

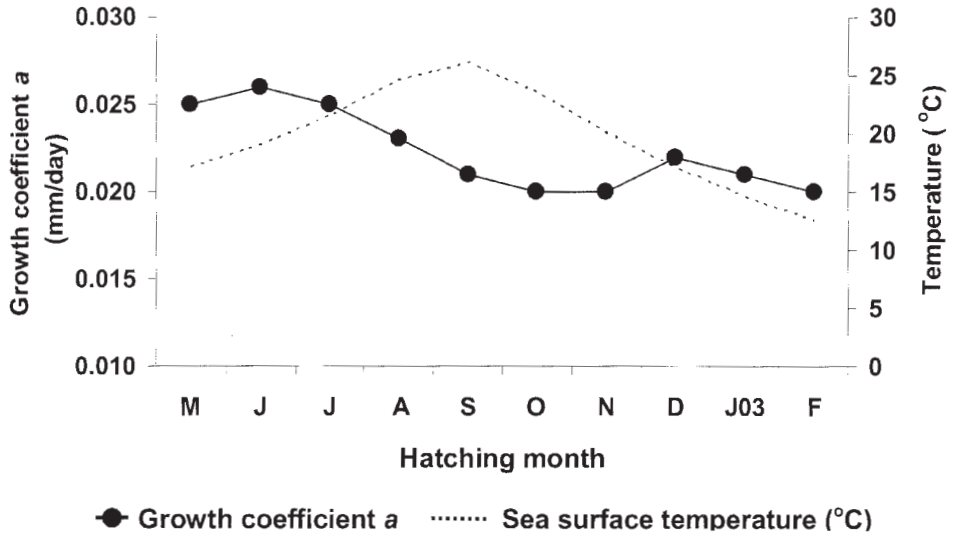

Fig. 9. Relationships between hatching month and growth coefficient *a* of *Loligo edulis* couple with sea surface temperature (℃) from May 2002 to February 2003.

age analysis of statolith increments (NATSUKARI *et al.,* 1988). In contrast, the maximum age estimated in the present study was less than 9 months for females and 10 months for males which younger than previous study (NATSUKARI *et al.,* 1988). The present study is the only report of the age analysis of *L. edulis* in the Pacific coast and there will be a possibility that *L. edulis* in the Pacific coast have a better growth and mature and spawn in shorter period compare with those in the Japan Sea (NATSUKARI *et al.,* 1988).

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