遠洋水研報　第35号　1-111頁　平成10年3月
Bull. Nat. Res. Inst. Far Seas Fish., No. 35, 1-111, March 1998

Fishery Biology of Arrow Squids, *Nototodarus gouldi* and *N. sloanii*, in New Zealand Waters

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The arrow squid stock in New Zealand waters, consisting of *Nototodarus gouldi* and *N. sloanii*, is one of the important squid resources for the Japanese squid fishery. The present study revealed some biological characteristics of the two species such as growth, maturation, migration, and annual variation of abundance based on the statistics of the Japanese squid fisheries and biological data of squid collected by the various research activities. The results of ageing based on daily increment counts show that spawning occurs throughout the year. The both species are distributed mainly on the shelf throughout their life span with some inshore-offshore migration with age, but they do not migrate on large scale. The analysis of CPUE for each month class shows the seasonal cohorts in each area fluctuate independently. This phenomenon points out that the small-scale environmental factors may be relatively important for the fluctuation of each cohort. The main target of management for a fishery on annual squid is to allow enough spawners to escape. Considering the characteristics of arrow squid, effort regulation is the best way to manage the fishery. At the present situation, the regulation on rough scale regardless the fishing areas may be the most practical way under the existence of self regulation characteristics if the fishery which tends to target most abundant cohort.

Key words: Arrow squid, *Nototodarus gouldi*, *Nototodarus sloanii*, biology, statolith.

Contents

Preface

Arrow squid resources in New Zealand waters, consisting of *Nototodarus gouldi* and *N. sloanii*, have been utilized by the jigging and trawl fisheries since the early 1970s and rapidly became one of the most important fishery resources, starting from an insignificant bycatch. A jig fishery developed by Japanese, Korean, and Taiwanese vessels around the mainland of New Zealand produced 30,000-60,000 metric tons annually in the 1980s. A trawl fishery developed by Japanese, Russian, and Korean vessels produced 30,000-60,000 metric tons in the 1980s. The total catch of flying squids (Ommastrephidae) attained to 800,000-900,000 metric tons annually in the world in the mid-1980s. The catch of arrow squids in New Zealand waters occupied more than 10% of the world catch of flying squids, but in the late 1980s, the catch of flying squids increased to more than 1,300,000 metric tons due to the drastic increase of catch of Argentine shortfin squid (*Illex argentinus*). The percentage of arrow squid catch became lower in the recent years.

1997年12月12日受理　遠洋水産研究所業績　第347号
Received December 12, 1997. Contribution No. 347 of the National Research Institute of Far Seas Fisheries.

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The Japanese fisheries have utilized the several resources of flying squids in the world. Major resources are Japanese common squid (*Todarodes pacificus*) around Japan, neon flying squid (*Ommastrephes bartrami*) in the north Pacific, Argentine shortfin squid on the Patagonian Shelf, northern shortfin squid (*Illex illecebrosus*) in the northwest Atlantic, and arrow squids around New Zealand. Total Japanese catch of flying squid attained to nearly 500,000 metric tons in the mid 1980s and then drastically increased to more than 700,000 metric tons in the late 1980s which occupied about 60% of the world catch of flying squids. The Japanese catch of arrow squids around New Zealand occupied nearly 15% of the Japanese flying squid catch until the late 1980s when the drastic increase of Argentine shortfin squid occurred. In the 1990s the catch of arrow squid decreased substantially due to the socioeconomic situations, but the arrow squids resources are still important for the Japanese fisheries, especially for the distant water squid jigging fishery, because these stocks make it possible for this fishery to operate in the various waters seasonally throughout the year.

Few biological studies had been made on arrow squids before the development of the fishery and the resource was assumed to be composed of one species (Kawakami, 1976; Roberts, 1978). The development of squid fisheries stimulated research on squid. Several biochemical-genetic and morphological studies revealed the presence of two *Nototodarus* species in New Zealand waters (Smith *et al*., 1987). Other research activities have provided information on species composition, distribution, size composition, and stock abundance (Roberts, 1979; Roberts, 1983; Uozumi *et al*., 1987; Hatanaka *et al*., 1989; Hurst *et al*., 1990). These results presented some general ideas on biology of arrow squids (Smith *et al*., 198). However, there are few studies on biology of arrow squids systematically by seasonal brood and by areas throughout their life span.

Biological data were accumulated through the research cruises and samplings from the fisheries during the recent two decades. There were ten trawl surveys and two larval net surveys which were carried out jointly between Japanese and New Zealand scientists. Many research cruises by trawl and squid jigging vessels, which belonged to Japan Marine Resource Research Center, were carried out to make feasibility study on fisheries and to collect biological information on arrow squid. Furthermore, more than one thousand samples of statolith of arrow squids have been collected through these research activities.

Based on all available data including catch and effort statistics of the Japanese squid fisheries around New Zealand, the present study was focused on fishery biology of arrow squids. The main purpose of the present study is to provide biological information such as growth, maturation, distribution, migration, and fluctuation of abundance and so on for more precise and accurate stock assessment and rational management of arrow squids. Based on the results on these biological information, it was discussed on the stock structure of both species and on the practical assessment and management methods.

I. Arrow squids fisheries around New Zealand

Arrow squids fishery commenced in the late 1960's by the Japanese fishery. This fishery developed under some influence of the other squid fisheries in the world including the one around Japan. Furthermore, this fishery, especially the fisheries of foreign countries, has been affected by the management regime of the New Zealand Government. There are two kinds of the squid fisheries, trawl and squid jigging fisheries, in New Zealand waters. In this Chapter, the historical development of the Japanese and other nations' squid fisheries around New Zealand was reviewed.

1. Materials and methods

(1) Catch and effort statistics of the Japanese jigging fishery around New Zealand

The Japanese squid jigging companies have submitted the report of catch and effort voluntarily to National Research Institute of Far Seas Fisheries (NRIFSF) since 1979 till 1986. Since 1987, the report of catch and effort has been submitted to the Japanese Government mandatorily from every fishing vessel. These data have been compiled at the NRIFSF. Each record in the voluntary report was composed of squid catch (number of trays by size categories) in a day, locality, maximum depth of gear, bottom depth, surface temperature and hours operated. The size of squid was categorized into 12 classes by the number of squid in a tray. Mean weight of a tray is 8.5 kg and catch in weight was estimated by the number of trays and mean weight of a tray. In the mandatory report, each record was composed of daily catch in weight, locality, and number of jigging lines.

(2) Catch statistics compiled by the Japan National Squid Jigging Association

The Japan National Squid Jigging Association (JNSJA) has collected catch statistics from all Japanese squid jigging vessels operated around New Zealand waters since 1973. This statistics are composed of weekly catch in weight and number of vessel operated around New Zealand. There is no information on the localities of vessels operated.

(3) Catch and effort statistics of the Japanese trawl fishery around New Zealand

The reports of catch and effort have been mandatorily submitted to the Japanese Government by the fishing companies and have been compiled at the NRIFSF. In this paper, the statistics from 1975 to 1991 were used. Each record in the database of the statistics compiled by the NRIFSF is composed of fishing effort (number of hauls and hours trawled) and catch in weight by species in 30 minutes in latitude x 30 minutes in longitude square block in a day for each vessel operated. One 30x30 square block where the vessel mainly operated in a day was selected. Furthermore there are the target species, main depth operated and mesh size in record as the additional

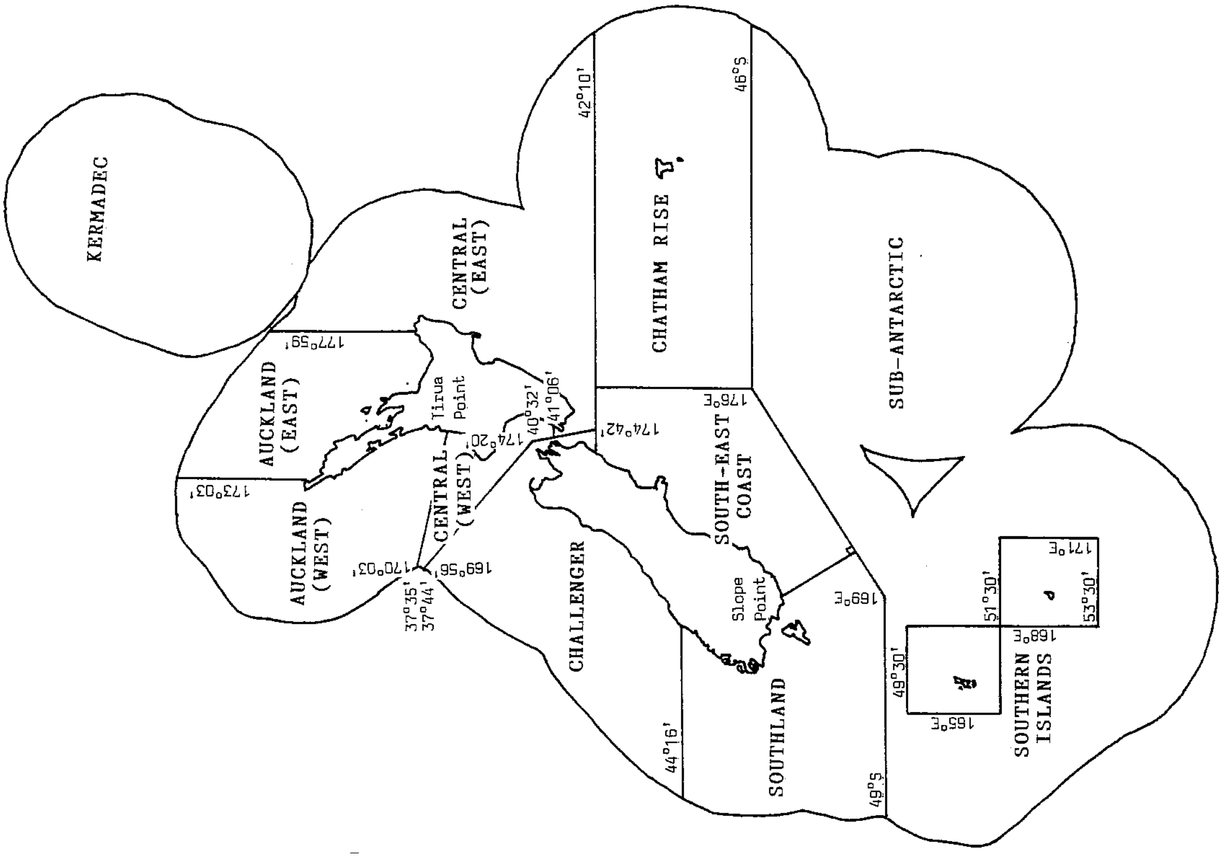

Fig. I-1. Statistical subareas in New Zealand waters.

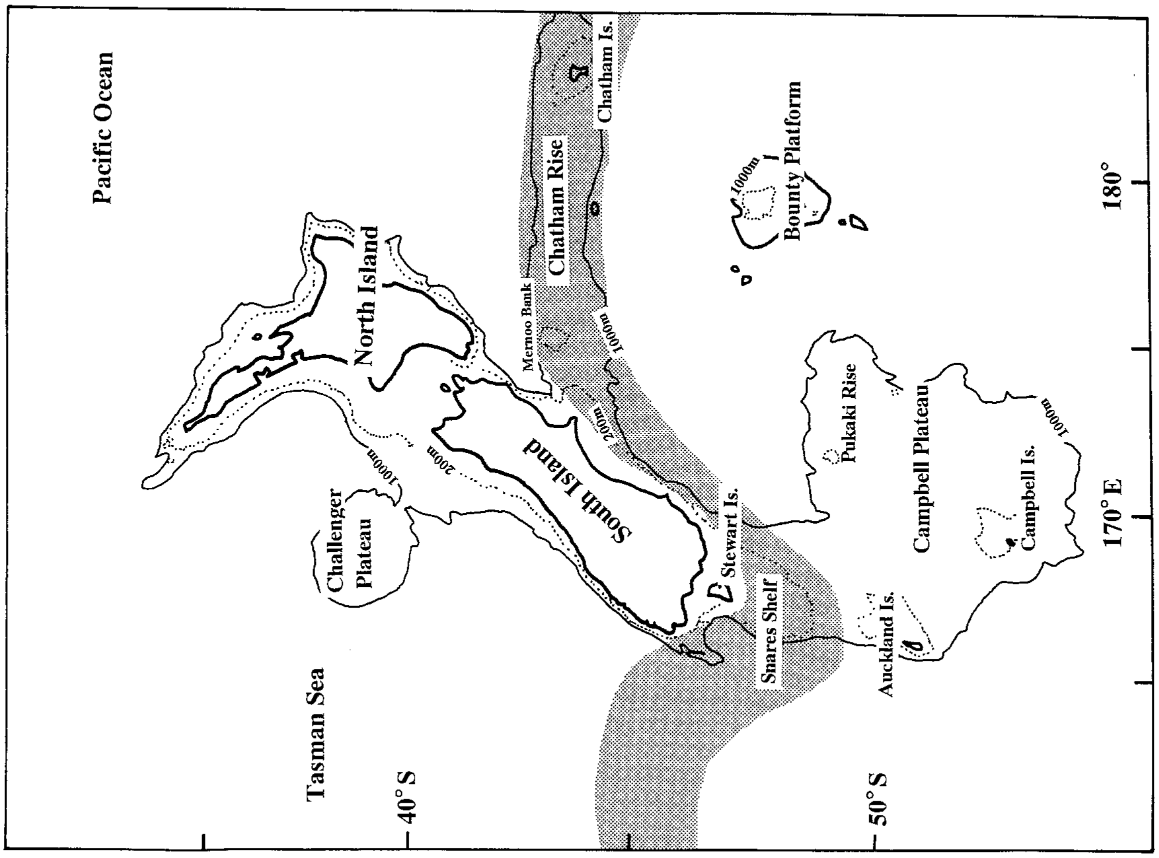

Fig. I-2. Hydrological features and place names mentioned in the text.

information. All operations by the Japanese trawlers were reported during the period from 1975 to 1991.

(4) Catch of joint venture vessels

After 1977 when the Government of New Zealand declared the 200 nautical miles exclusive economic zone (200 EEZ), some Japanese vessels, which have been chartered by the New Zealand fishing companies, so-called "Joint Venture vessels (JV vessels)", have operated. The Government of Japan permits the products of these JV vessels are exempt from the Japanese customs duty, when the JV vessels import their products to Japan, because all officers and crews of these vessels are Japanese citizens. Therefore, the catches of these JV vessels are included in the catch statistics compiled by the Japanese Government.

(5) Statistical subareas in New Zealand waters

The statistical subareas for fisheries in New Zealand waters were defined by the New Zealand Government after the declaration of 200 mile EEZ. Some changes in the boundaries among the subareas were done in the 1980's (Anon., 1984 and 1988). In this study the latest definitions on the subareas is adopted. Fig. I-1 shows the statistical subareas and Fig. I-2 shows places mentioned in the text.

(6) Fishing year

The New Zealand Government used a fishing year from 1st April to 31 March since 1978, but changed it to one from 1st October to 30 September in 1983. The Japanese Government uses the other fishing year, which starts from 1st November to 30th October. The present study uses the latter one throughout this paper which is convenient for analyses of the database for the Japanese jigging fishery, because this database have been constructed using the fishing year used by the Japanese Government.

2. Historical review of the arrow squids fisheries around New Zealand

(1) Historical changes of arrow squids catch and number of vessels

A. Japanese squid jigging fishery

The Japanese squid jigging fishery in New Zealand waters embarked on operation in 1969/70 fishing year, but the number of vessels operated was only two in this year (Fig. I-3). The number of vessels rapidly increased to 73 in 1972/73 and peaked at 156 vessels in 1973/74 when the Government of Japan has introduced the limited entry licensing system in the Japanese squid jigging fishery around New Zealand. Then the number of vessels continued to decrease gradually in the 1980's and in 1989/90 the number decreased drastically to less than 50 vessels. The low level of the vessels operated in this waters has continued in the recent years.

The catch of arrow squids by the Japanese squid jigging fishery increased gradually and fluctuated at around 30,000 metric tons (mt) in the 1980's, though the relatively high catches, more than 40,000 mt, were obtained in 1977/78, 83/84, and 88/89 fishing years (Fig. I-3). In 1989/90 fishing year the catch sharply decreased to 8,000 mt from about 50,000 mt in the previous year according to the drastic decrease of the vessels.

Since 1978/79 fishing year when the Government of New Zealand declared the 200 EEZ, the Japanese joint venture vessels (JV vessels) have operated in New Zealand waters. The catch of JV vessels occupied around 20-30% of the total catch by the Japanese vessels till 1985/86. Since then the percentage of the JV vessels in the catch increased rapidly mainly due to the increase in number of the JV vessels and the decrease of the Japanese national quota for the Japanese squid jigging fishery. From 1989/90 the New Zealand waters has been closed for the Japanese squid jigging vessels and only JV vessels have continued their operations.

B. Japanese trawl fishery

The Japanese trawl fishery commenced in 1959 around New Zealand, but a few number of vessels operated in this area until the mid-1970's (Fig. I-4). Since 1973/74 fishing year number of vessels had increased rapidly and attained to 26 vessels in 1976/77, a year before the Government of New Zealand declared the 200 EEZ. During 1977/78 - 1984/85 fishing years the number of vessels was stable at around 20 vessels and then increased again to 33 vessels in 1988/89, but decreased rapidly since the next year.

The catch of arrow squids by the Japanese trawl fishery had been lower level than 5,000 mt before 1978/79, except for the extremely high catch in 1976/77. The catch had fluctuated at around 17,000 mt

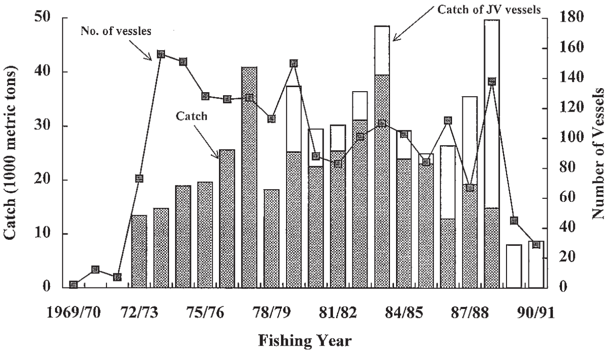

Fig. I-3. Historical changes in arrow squids catch and number of vessels of the Japanese squid jigging fishery around New Zealand. Fishing year is from 1st November to 30th October.

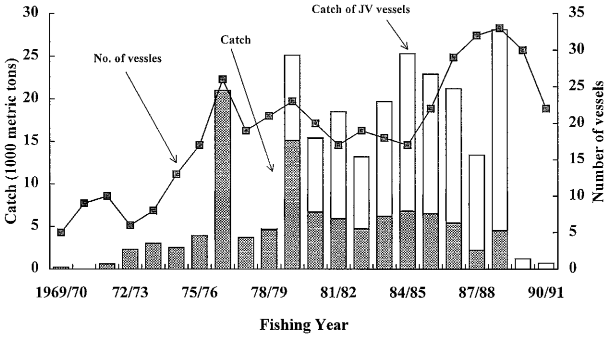

Fig. I-4. Historical changes in arrow squids catch and number of vessels of the Japanese trawl fishery around New Zealand. Fishing year is from 1st November to 30th October.

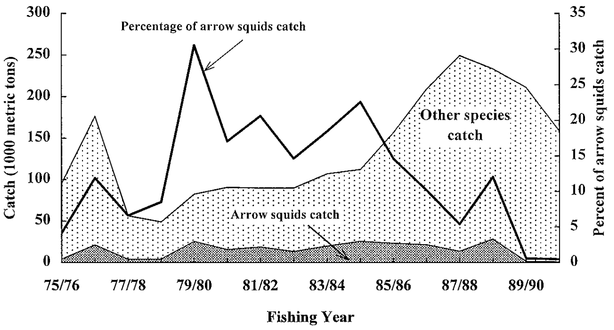

Fig. I-5. Historical changes on the percentage of arrow squids catch in the total catch by the Japanese trawl fishery including the Joint Venture vessels in New Zealand waters.

in the 1980's and the drastic decrease was observed in 1989/90 when the catch attained only to 1,200 mt. This low level has still continued in the most recent years. The JV vessels have operated in New Zealand waters since 1978/79, as same as in the squid jigging fishery. The catch of JV vessels occupied large part of the squid catch by the Japanese trawlers and the percentage of catch by the JV vessels in the total squid catch of the Japanese trawlers has increased gradually from 57% in 1980/81 to 84% in 1988/89. Since 1989/90 the percentage of JV catch occupied 100%, because the Japanese national squid quota for trawl fishery became zero since this fishing year.

The Japanese trawl fishery has caught various groundfishes in New Zealand waters, but the four major species groups, hoki (*Macruronus novaezelandiae*), jack mackerels (*Trachurus declivis* and *T. novaezelandiae*), barracouta (*Thyrsites atun*) and arrow squids occupied more than 70% of the total catch. The arrow squids have ranked second among these major species groups in the 1980's (Uozumi, 1988). Fig. I-5 shows the historical change on the percentage of arrow squids catch. The percentage increased to about 20% gradually in the late 1970's and stable at around 20% in the early 1980's. Since 1984/85 the percentage continued to decrease year by year, because the catch of other species, mainly hoki, increased rapidly in the late 1980's. In 1989/90 the squid catch occupied only 0.6% in the total catch mainly due to the rapid decrease of the arrow squids catch.

(2) Relationship among the catches of squids by the Japanese fisheries and the price of squids

The Japanese arrow squids fisheries in New Zealand waters are closely related with the Japanese squid fisheries in the other waters, mainly around Japan and in the southwest Atlantic Ocean. The catch of Japanese common squid (*Todarodes pacificus*) had been at a high level more than 400,000 mt till 1973 and decreased rapidly to 91,000 mt in 1986 (Fig. I-6). Since 1986 the catch increased gradually to 242,000 mt in 1991. On the contrary, the price of squid at the fish market in Japan increased rapidly from cheaper than 100 yens/kg to 400-500 yens/kg in the 1970's. In the period from the late 1970's to mid 1980's when the squid price was increasing, the Japanese squid fisheries started and developed well in New Zealand waters. A few years later trawl fishery started to fish Argentine shortfin squid (*Illex argentinus*) in the southwest Atlantic Ocean and squid jigging fishery also started the operation in this waters since 1985 (Fig. I-6).

In 1987 the large amount catch of Argentine shortfin squid, 252,000 mt, was obtained by the Japanese squid jigging fishery and this high level catch continued for three years. The catch of Japanese common squid also started to increase from 1987. These events caused the sharp decline in the squid price. This sharp decline was one of the major reasons for the decrease of the arrow squids catch in addition to the decrease of the national quota for arrow squids. Furthermore, large part of squid jigging vessels operated in New Zealand waters shifted their fishing grounds to the southwest Atlantic Ocean to fish Argentine shortfin squid, because of extremely higher catch per vessel (1,200-1,600 mt per vessel in a fishing year) compared with it in New Zealand waters (300-800 mt per vessel) (Yamada *et al.*, 1989).

The full-scale Japanese arrow squids fisheries around New Zealand commenced in the early 1970's to supplement the shortage of squid supply due to the decrease of the squid catch around Japan and developed stably till the late 1980's. Since the mid 1980's the fisheries started to scale down due to the development of the squid fisheries in the other waters and catch in the recent years has been lower than 20% of the mean total catch in the 1980's.

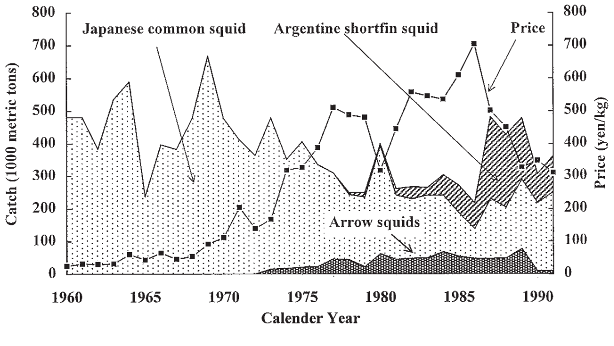

Fig I-6. Historical changes on squid catch by the Japanese fisheries and market price of short-fin squids. The market price shows the price of squid at fish markets in Japan. Catch of squids are cited from Anon (1993) and the prices of squids are cited from Anon (1966-93).

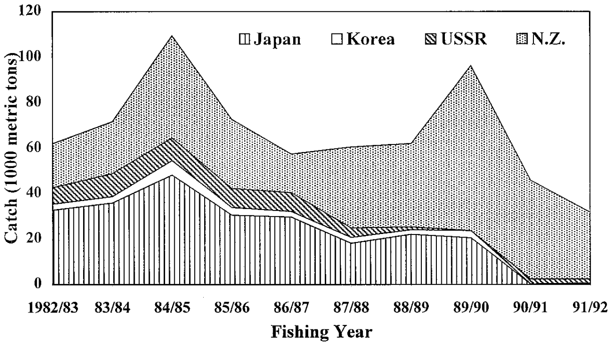

Fig. I-7. Annual catch of arrow squids by nation around New Zealand. Catch of New Zealand includes the catch of all Joint Venture vessels including the Japanese ones (After Anala, 1992). Fishing year in 1981/82 and 82/83 was from 1st April to 31st March. Fishing year in 1983/84 was 18 months from 1st April to 30th September. Fishing year in the other years was from 1st October to 30 September.

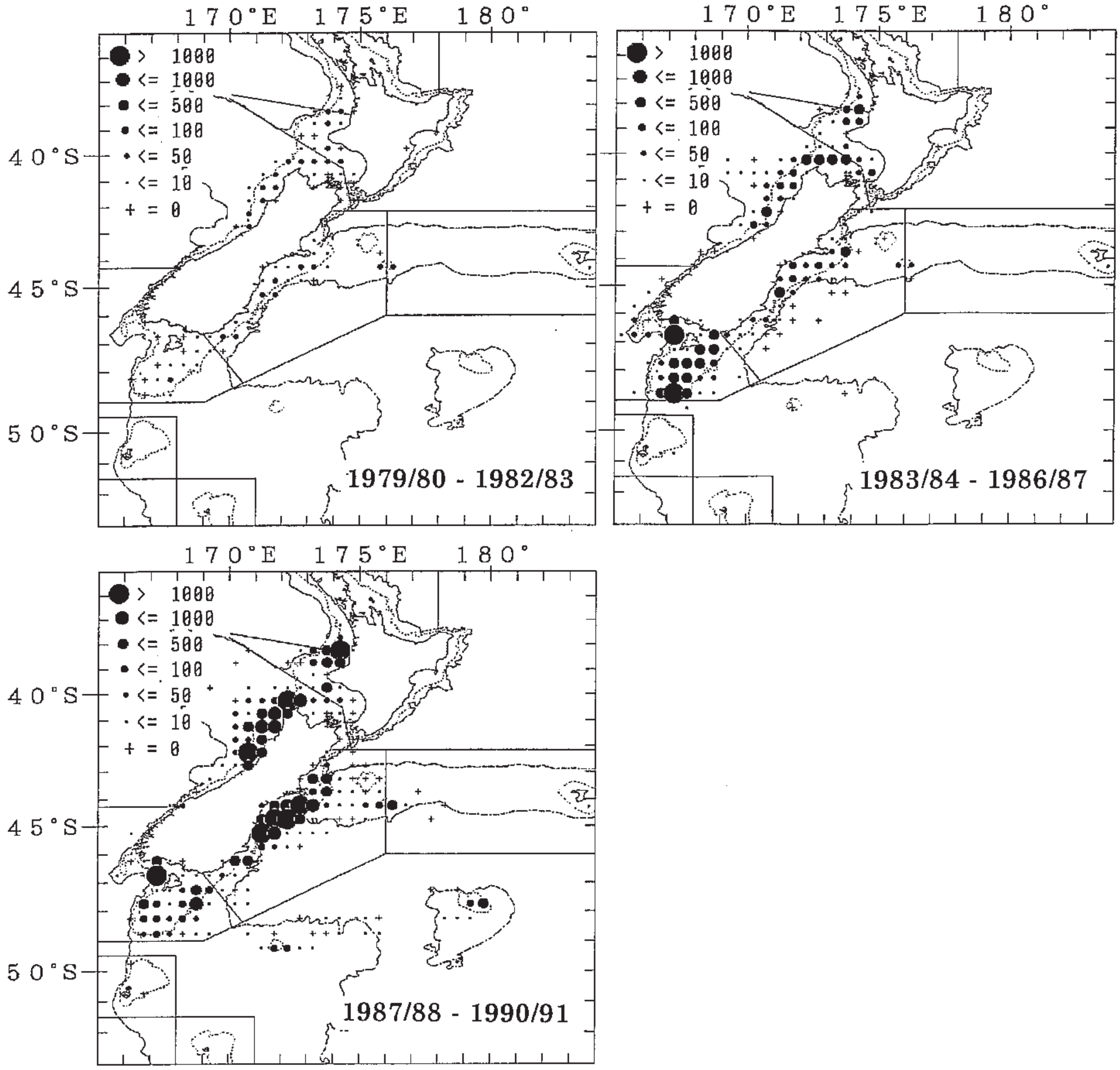

Fig. I-8. Mean annual catch of arrow squids by 30x30 minutes block for the Japanese squid jigging fishery around New Zealand from 1979/80 to 1990/91 fishing years.

(3) Arrow squids fisheries by the other nations

The arrow squids resources have been exploited not only by the Japanese fisheries, but also by USSR trawlers, Korean squid jigging vessels and New Zealand domestic trawlers. Furthermore, the Taiwanese squid jigging vessels have also operated as JV vessels. Fig. I-7 shows the historical changes of arrow squids catch by nation. The catch of New Zealand includes the catch of all JV vessels (Japanese, USSR, Korean and Taiwanese JV vessels). The squid catch of New Zealand domestic fishery has been less than 400 mt. Total catch of arrow squids fluctuated at about 70,000 mt in the 1980's with a peak of 109,000 mt in 1984/85 fishing year. Then the catch decreased rapidly to about 32,000 mt in 1991/92 fishing year.

The catch of foreign nations including Japan occupied 60-70% of the total catch till mid 1980's and then decreased gradually mainly due to the decrease of the foreign nations' quotas. In the recent two years, the percentage of foreign nations catch attained only to several percent. The Japanese catch occupied more than 75% of the foreign nations' catch till 1990/91 when Japan lost the national quotas of squid. The catch of JV vessels by nations is not available, but the catch of Japanese JV vessels occupied most of total JV vessels' catch, compared with the catch in Figs. I-3 and 4.

(4) Historical change of fishing grounds

A. Fishing grounds of the Japanese squid jigging fishery

There is no detailed information on the fishing grounds in the earlier stage of the squid jigging fishery in New Zealand waters before 1979/80, except for some internal reports of the Japan National Squid Jigging Association (JNSJA,1976-79). After these reports, the most of vessels operated in the waters off west coast of the mainland and off east coast of the South Island. Minor part of the vessels operated off south coast of the South Island.

Fig. I-8 shows mean catch (mt) by 30 minutes square block for every four fishing year period from 1979/80

Table I-1. Arrow squids catch (metric tons) by subarea for the Japanese squid jigging fishery including JV vessels around New Zealand. Catches by subarea in 1979/80-85/86 were estimated from sample statistics by subarea and total catch.

Fishing Year	Auckland East	Auckland West	Central East	Central West	Challenger	South-East Coast	Chatham Rise	South-land	SUB-Antarctic	Southern Islands	ALL
79/80	0	87	0	2,016	10,591	7,689	4,535	12,424	0	0	37,350
80/81	0	0	0	2,660	16,086	7,592	2,284	839	0	0	29,462
81/82	0	217	0	5,959	8,809	13,852	1,217	112	0	0	30,166
82/83	0	1,562	19	5,983	20,173	6,879	1,612	136	0	0	36,364
83/84	0	53	0	1,452	2,887	9,260	2,474	32,314	0	0	48,490
84/85	0	69	0	310	4,085	13,254	1,017	9,902	0	560	29,197
85/86	0	0	0	91	5,240	6,166	5	13,401	0	0	24,905
86/87	0	875	0	2,012	5,101	1,289	1	17,150	0	0	26,435
87/88	0	2,458	0	5,889	23,051	2,707	7	1,342	0	0	35,455
88/89	0	0	0	70	3,225	42,459	0	3,931	0	0	49,687
89/90	0	137	0	782	13	3,121	614	1,501	1,876	1	8,045
90/91	0	184	0	1,763	934	46	0	5,775	1	0	8,704

to 90/91 fishing year. During 1979/80-82/83 the catch was mainly obtained from the waters off west coast of the mainland and off east coast of the South Island as same in the previous periods. In the next four fishing year period, the fishing ground was formed off south coast of the South Island in addition to the fishing grounds appeared in 1979/80-82/83. During 1987/88-90/91 the fishing grounds were formed as same in the previous period.

The fishing grounds of the Japanese squid jigging fishery were formed mainly in the coastal waters around the South Island and west coast of the North Island, though some minor catch was obtained from the shallower waters such as the Veryan Bank, Pukaki Rise and Bounty Platform. The main fishing grounds have been formed widely on the island shelves around the mainland.

These historical changes of the fishing grounds were also reflected in the catch by subarea shown in Table I-1. During 1979/80-82/83, more than 70% of the total catch were obtained from Challenger and South-East Coast Areas, though the percentage of the catch between the two subareas was fluctuated during these four fishing years. In the next four years, 50-60% of the total catch was obtained from Southland Area, while the percentage of Challenger Area was decreased to less than 20%. In the recent four years, the main fishing area changed year by year. In the most fishing years observed, the catch from one subarea composed of the major part (more than 50%) of the total catch, though the main fishing area changed year by year.

B. Fishing grounds of the Japanese squid trawl fishery

Fig. I-9 shows mean catch (mt) of the Japanese trawl fishery by 30 minutes square block for every four fishing year period from 1975/76 to 90/91. In the earliest four year period before the declaration of 200 mile EEZ, the fishing grounds were formed in the waters off east coast of the South Island where was the main fishing ground of the Japanese trawl fishery, which targeted jack mackerels and barracouta. In this period arrow squids were caught as one of the by-catch species. In 1979/80-82/83 after the declaration of 200 mile EEZ, the fishing ground in east coast of the South Island disappeared due to close of this fishing ground for the foreign trawlers by New Zealand Government, while the fishing grounds were formed in the south coast of the South Island and around the Auckland Islands. In the later periods, the fishing grounds had been formed in the same areas as those in 1979/80-82/83 years. The fishing grounds have been formed mainly on the edge of the island shelves (the Snares shelf and Auckland Islands shelf).

Table I-2 shows the annual arrow squids catch by subarea for the Japanese trawl fishery. In 1975/76 and 76/77, more than 50% of the total squid catch was obtained from South-East Coast Area, but after 1979/80 the squid catch in this subarea has been negligible and more than 80% was obtained from Southland and Southern Islands Areas. In the history of the squid trawl fishery, a few catch were obtained from the western side of the New Zealand waters. Table I-3 shows the percentage of arrow squid catch in the total catch by subarea for the Japanese trawl fishery. Catch of arrow squid occupied more than about 80% of total catch in Southern Islands Area (around the Auckland Island). In Southland Area, squid catch occupied 20-40% of the total. These percentage showed the importance of squid for the trawl fishery in these area. In the other subareas, the low percentage of squid catch (less than 10%) means squid is minor by-catch species.

C. Difference in fishing ground between the fisheries

The geographical difference in fishing ground is very clear between the Japanese squid jigging and trawl fishery. The fishing grounds of squid jigging fishery usually form around the mainland of New Zealand, but ones of trawl fishery are located in southern area of the South Island and around the Auckland Island. The one reason for these differences is a management regime for the fisheries by the New Zealand Government. The trawl fishery is prohibited to operate in the coastal waters off east coast of the South Island (Canterbury Bight) and the squid jigging fishery is prohibited to operate in the Southern Is. Area (around the Auckland

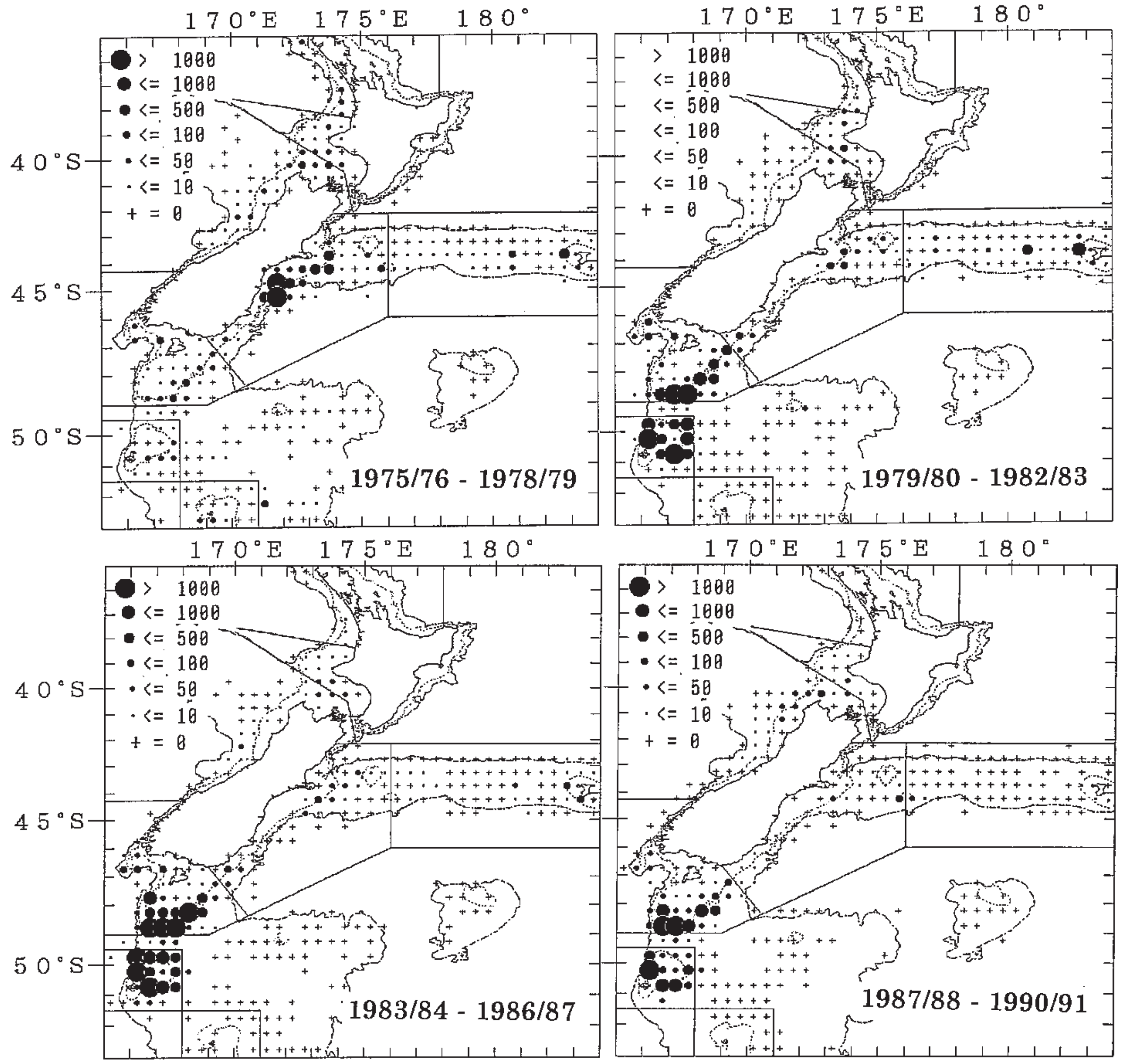

Fig. I-9. Mean annual catch of arrow squids by 30x30 minutes block for the Japanese trawl fishery around New Zealand from 1975/76 to 1990/91 fishing years.

Island). However there is no limitation for trawl operation in the waters off west coast of the mainland where one of good fishing grounds for the squid jigging fishery is located, but there has been no suitable fishing ground for the trawl fishery in the area.

The waters off west coast of the mainland is one of the major fishing ground for jack mackerels (Jones, 1990). The jack mackerels are one of the important fish for the Japanese trawl fishery in New Zealand (Uozumi, 1988). The fishing season for the jack mackerels is mainly austral summer which is also a good season for squid (see later section). It is probable that jack mackerels may be more beneficial species than squid in the Japanese trawl fishery. Then jack mackerels tended to be a main target species in summer season in this area. Furthermore, the squid caught with finfishes such as jack mackerels is usually harmed seriously by spines of the fishes caught and the price of harmed squid become significantly lower.

Figs. I-8 and 9 showed the fishing ground of squid jigging fishery formed widely on a shelf, but that of trawl fishery formed in the edge of a shelf. Fig. I-10 shows the effort distribution which was directed to squid by depth range in the Southland Area (Snares Shelf). This figure clearly shows the difference in depth between the fisheries. The effort of squid jigging fishery was concentrated in the waters shallower than about 160 m depth. On the contrary, the effort of the trawl fishery was distributed between 160 and 220 m depth. The depth of the shelf edge in this area is about 150 m depth. This vertical distribution of fishing effort also indicated that the fishing ground of squid jigging fishery located on the shelf and one of trawl located in the upper layer of continental slope.

(5) Fishing season of the arrow squids fisheries

A. Japanese squid jigging fishery

Mean percentages of each monthly catch to the annual catch for the twelve fishing years from 1979/80 to 90/91 are shown in Fig. I-11. This figure shows the change of relative value (percentage of each monthly catch) to clarify the seasonal patterns of the catch,

Table I-2. Arrow squids catch (metric tons) by subarea for the Japanese trawl fishery including JV vessels around New Zealand.

Fishing Year	Auckland East	Auckland West	Central East	Central West	Challenger	South-East Coast	Chatham Rise	South-land	SUB-Antarctic	Southern Islands	ALL
75/76	0	40	0	44	53	2,058	2	955	760	0	3,909
76/77	0	163	6	161	392	19,957	16	273	12	1	20,978
77/78	0	94	0	482	623	291	2,092	122	1	0	3,702
78/79	0	41	12	154	127	2,416	219	682	30	456	4,136
79/80	0	0	0	70	19	250	376	10,575	45	13,727	25,062
80/81	0	35	0	265	160	287	501	10,412	24	3,728	15,413
81/82	0	23	0	190	65	302	79	6,476	5	11,371	18,504
82/83	0	39	0	256	42	1,059	2,632	5,868	116	3,145	13,153
83/84	0	10	0	219	118	149	379	9,727	61	9,090	19,748
84/85	0	7	0	160	63	587	240	12,965	2	11,309	25,330
85/86	0	3	0	63	51	371	72	13,190	139	8,976	22,867
86/87	0	12	0	205	94	320	93	13,670	24	6,827	21,244
87/88	0	8	0	305	945	170	110	9,718	42	2,111	13,407
88/89	0	1	0	30	68	255	3	9,807	12	17,935	28,109
89/90	0	0	0	16	22	78	4	590	41	472	1,223
90/91	0	0	0	24	11	10	2	639	28	16	730

Table I-3. Percentage of arrow squids catch to total by subarea for the Japanese trawl fishery including JV vessels around New Zealand.

Fishing Year	Auckland East	Auckland West	Central East	Central West	Challenger	South-East Coast	Chatham Rise	South-land	SUB-Antarctic	Southern Islands
75/76	-	1.2	0.0	0.9	0.1	8.7	0.1	6.5	8.2	0.0
76/77	-	1.6	2.0	2.5	0.4	36.1	0.8	2.9	0.7	0.9
77/78	-	2.3	0.0	7.2	15.5	6.2	7.0	2.0	0.2	0.0
78/79	-	2.9	1.5	3.6	2.5	22.8	5.6	4.0	1.0	18.3
79/80	-	0.0	0.0	3.5	0.1	9.0	3.7	38.6	0.8	81.4
80/81	-	2.0	0.0	3.6	0.8	6.4	2.6	37.2	0.6	84.3
81/82	-	0.8	0.0	3.6	0.4	3.6	0.6	23.3	0.1	92.1
82/83	-	1.2	-	3.0	0.2	12.9	13.9	25.3	3.2	84.1
83/84	-	0.4	-	2.2	0.6	1.9	2.6	28.2	1.6	67.0
84/85	-	0.3	-	1.4	0.3	7.4	1.5	36.4	0.0	71.1
85/86	-	0.4	-	0.9	0.1	1.7	0.4	37.3	1.4	79.3
86/87	-	0.9	-	1.9	0.1	1.8	0.5	40.5	0.3	74.0
87/88	-	1.5	0.0	3.3	0.6	1.1	0.9	35.8	0.3	81.9
88/89	-	0.1	-	0.4	0.0	2.6	0.0	39.5	0.1	98.8
89/90	-	0.0	-	0.2	0.0	0.5	0.1	3.9	0.4	90.6
90/91	-	0.0	-	0.2	0.0	0.1	0.0	8.7	0.2	34.8

because the catch varied largely from year to year. The catch was obtained from December to May and major part of the annual catch was obtained during January to March. In Auckland West and Central West Areas, most of the catch was obtained from March to April. In Challenger almost all of the catch were obtained from December to January. In South-East Coast the catch was obtained from February to April and peaks were often observed in March. In Southland the catch was obtained from January to March and the catches in the other months were negligible.

The monthly pattern of catch suggested that there is clear seasonal pattern of the operations in the squid jigging fishery. The Japanese squid jigging fishery has operated the fishing activity in New Zealand waters in austral summer and early autumn from December to May , especially from January to March. Furthermore, the fishing ground changed seasonally, namely the fishing activity started in Challenger in the early fishing season (December/January) and then the vessels shifted their fishing ground to east and south coast of the south Island and continued their operation till March. In the late fishing season (March/April), the fishing ground changed to the west coast of the North Island.

B. Japanese trawl fishery

Mean monthly changes of catch, expressed by the percentage of monthly catch to annual one in the 1980's when the arrow squids catch had been stable, are shown in Fig. I-12. Major part of the annual arrow squids catch was obtained from January to May, though the catch was obtained all the year round. The fishing season is similar to it in the squid jigging fishery. In the Central West, the catch was mainly obtained in December and January. In Challenger,

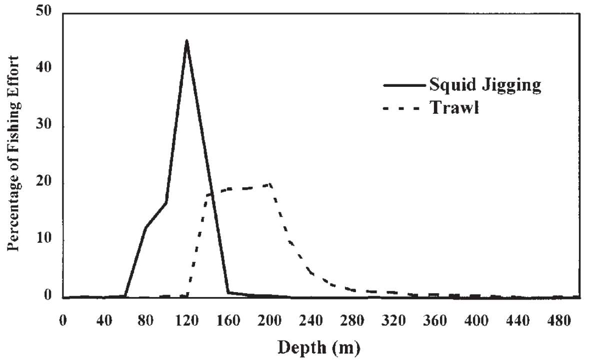

Fig. I-10. Percentage of fishing effort directed to squid by depth range in Southland Area.

there were two clear peaks of catch in January and July. The small peak in July was also observed in Central West, though the amount of the catch obtained from the western coast of the mainland was very small as shown in Table I-2. In Southland and Southern Islands where are the main fishing ground for squid trawl fishery, the catch was mainly obtained from January to May, mainly from February to April.

C. Comparison of fishing season between the fisheries

The peak of fishing season is summer for both fisheries. However the period of fishing season for the trawl fishery is longer than that of squid jigging fishery and the catch of squid by trawl occurs throughout the year. Most of the Japanese trawlers operated in New Zealand waters throughout the year. The trawl fishery targets squid seasonally in summer and catch squid as by-catch in the other seasons. On the contrary, the Japanese squid jigging vessels visit in New Zealand waters at the beginning of austral summer and leave for Japan at the end of summer, because they catch Japanese common squid around Japan in northern summer. This situation of the Japanese squid jigging vessels causes the shorter fishing season than trawl.

II. Identification of Todarodinae squids, their geographical distributions, and mixing of *Nototodarus gouldi* and *N. sloanii* in New Zealand waters

There were a few studies on cephalopods, especially for Ommastrephidae squids, in New Zealand waters before the commencement of the squid fisheries (Kawakami, 1976). It was believed that there was only one species of Todarodinae in the New Zealand before 1976, but now it is known that the five species of this subfamily are distributed in the waters (Uozumi, 1990). In the progress of the fishery biology on the arrow squids, there were some difficulties and confusions related to the species identification and species composition of the catch. Furthermore, there was a confusional nomenclature in the genus *Nototodarus* before 1987 (Smith *et al.*, 1987). In this chapter, diagnostic characters of Todarodinae squids are shown and the taxonomic problems are reviewed historically based on the various literatures and the original data.

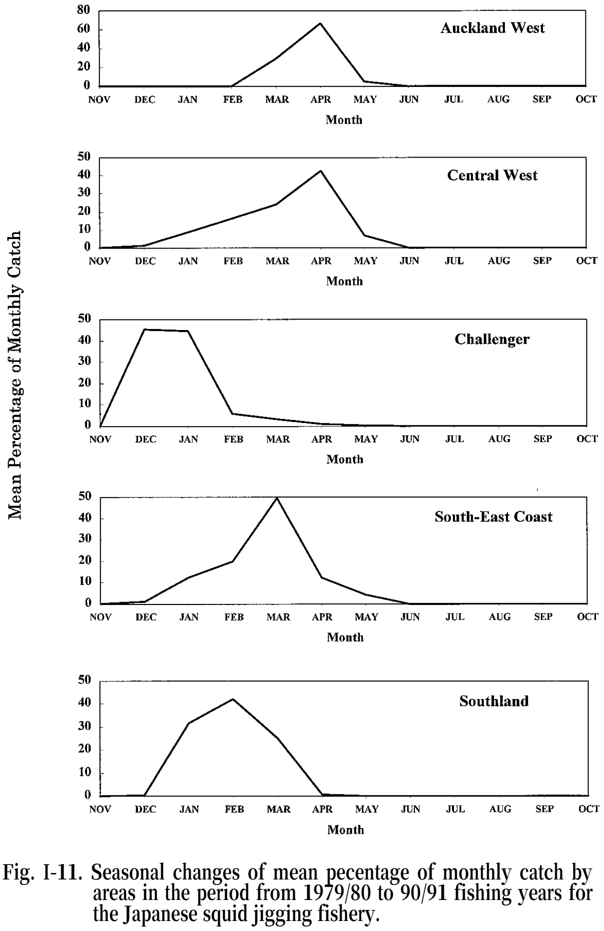

Fig. I-11. Seasonal changes of mean pecentage of monthly catch by areas in the period from 1979/80 to 90/91 fishing years for the Japanese squid jigging fishery.

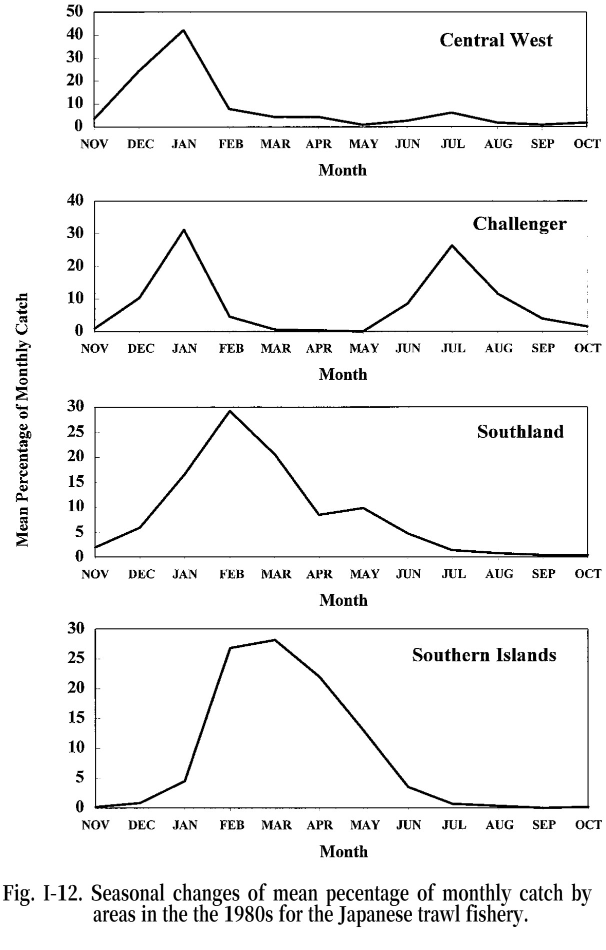

Fig. I-12. Seasonal changes of mean pecentage of monthly catch by areas in the the 1980s for the Japanese trawl fishery.

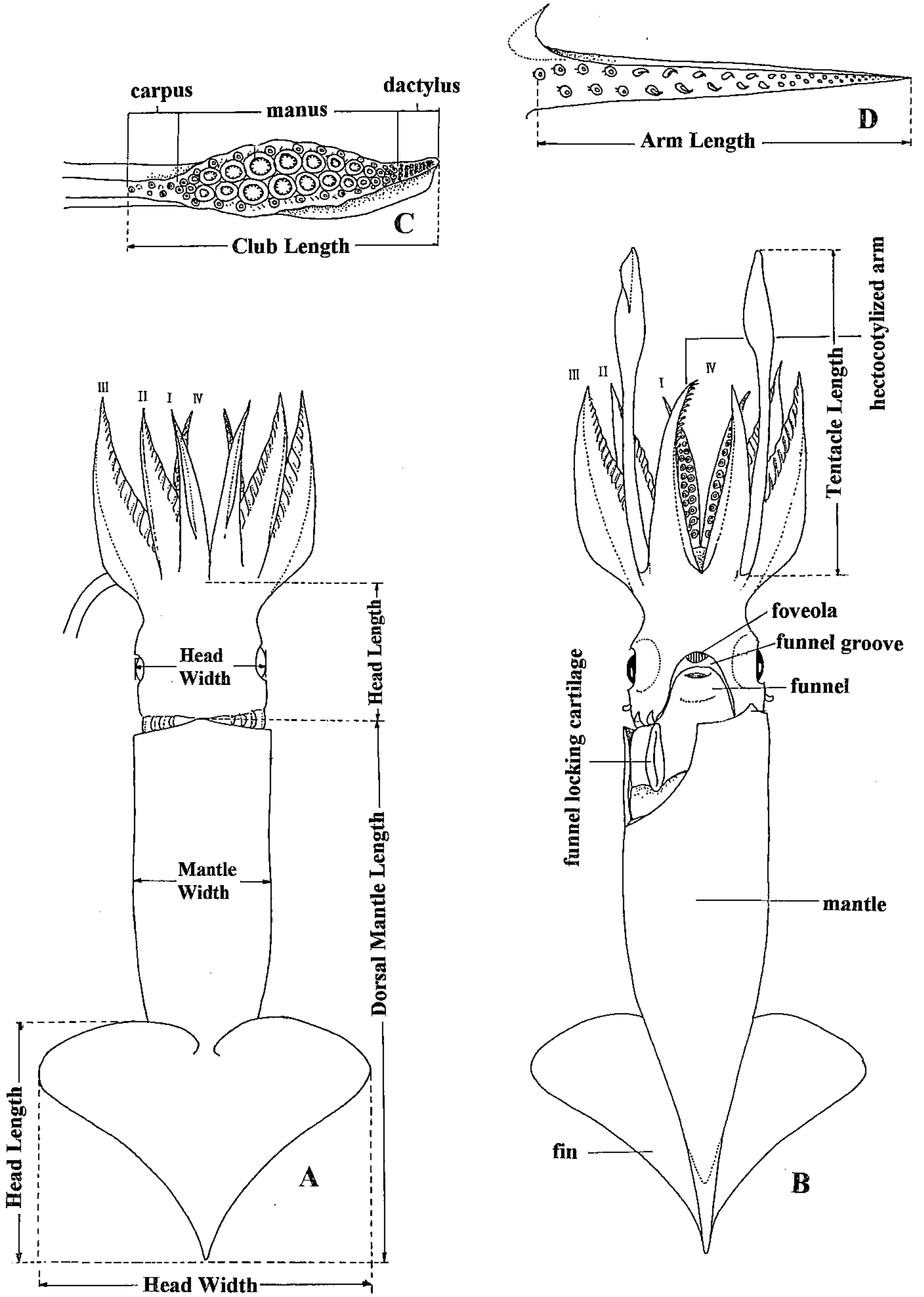

Fig. II-1. Terminology and measurements of squid revised from Okutani *et al*, (1987). A: dorsal view, B: ventral view, C: oral view of tentacular club , and D: oral view of an arm.

The geographical distributions of these Todarodinae squids around New Zealand and the adjacent waters are also presented. The mixing of two *Nototodarus* species around New Zealand is described using the results of identification from 1981/82 to 1991/92 Fishing years.

1. Materials and methods

(1) Detailed morphological measurements

Detailed morphological measurements, following Roper and Voss (1983), were made on each six adult specimens of *Nototodarus gouldi, N. sloanii, Todarodes filippovae, T. angolensis*, and *Martialia hyadesi*. The specimens of former four species were collected from the New Zealand waters, but the specimens of *M. hyadesi* were collected from Argentine waters (40° 47'S, 61° 00'W) by bottom trawl, because no adult specimen of this species was obtained from the New Zealand waters. Terminology and measurements used in the present study are shown in Fig. II-1.

(2) Electrophoresis

The enzymes, 6-Phosphogluconate (6-PGD, Enzyme Commission Number 1.1.1.44) and α - Glycerophosphate dehydrogenase (α-GDH, Enzyme Commission Number 1.1.1.8) were used for the species identification by electrophoresis. Processing of samples and electrophoretic methods followed those of May *et al.* (1979). Gels were run in an amine citrate buffer, PH 6.5 (Clayton and Tretiak, 1972). Gel-phenotypes of the five ommastrephid (Todarodinae) squids occurring in New Zealand waters were shown in Fig. II-2.

(3) Counts of suckers in Arm I for juvenile squids

The specimens of juvenile squids ranged 10- 220 mm DML (dorsal mantle length) identified by electrophoresis were used for counts of suckers in Arm I. These juvenile squids were collected by fine mesh midwater trawl during the *Kaiyo Maru* surveys in 1985 (Uozumi *et al.*, 1991). Counts were carried out successfully for 54, 50, 50, and 39 specimens of *N. gouldi*, *N. sloanii*, *Todarodes* spp., and *M. hyadesi*, respectively.

(4) Measurement of club length and count of suckers on hectocotylus in *N. sloanii*

Measurements of club length and count of suckers on hectocotylus were carried out for 1,038 specimens of *N. sloanii*. The maturity stage was also observed for these specimens and criteria used for the determination of maturity stages are shown in Table II-1. Localities of the samples and summary of the samples used in this section are shown in Fig. II-3 and Table II-2. Club length was measured from proximal-most carpal sucker to distal tip of club (Roper and Voss, 1983). Number of suckers on hectocotylus was counted by three parts, distal, middle, and proximal parts, as shown in Fig. II-4. The number of suckers ranged from 0 to 98 in the distal part. For the convenient to observe many specimens as possible, the exact number of suckers was not counted for the specimens which had more than 20 suckers in the distal part and just recorded that these squid had more than 20 suckers.

(5) Mixing ratio of *N. gouldi* and *N. sloanii*

Since 1981, species identification has been carried out correctly for the specimens of biological measurements and size composition. The samples for the biological measurements and size composition were collected from the catch of the Japanese trawlers and squid jiggers including the research vessels chartered by the Japan Marine Resource Research Center. These samples were collected from the catch irrespective of species. A total of 61,041 specimens were identified during 1981/82-1991/92 Fishing years. These specimens were pooled by fishing year and the fine biological sampling area which was constructed for the detailed observation on mixing of the two species (Fig. II-5).

2. Todarodinae squids occurred around New Zealand

Before 1976, only one species of Todarodinae, *Nototodarus sloanii*, was known from the New Zealand waters (Dell, 1970). Kawakami (1976) listed two species, *N. sloanii* and *Todarodes filippovae*. Saito (1976) pointed out the possibility on the existence of two subspecific groups of *Nototodarus* based on the two types of hectocotylus. Roberts (1978 and 1979) and Tung (1978) recognized the two types of *Nototodarus* in New Zealand. Smith *et al.* (1987) concluded that there are two *Nototodarus* species, *N. gouldi* and *N. sloanii* around New Zealand.

Forch (1986) suggested that there are four species of *Todarodinae, N. gouldi, N. sloanii, T. filippovae*, and *T. angolensis* as unpublished information. Uozumi *et al.* (1991) showed the distribution of immature *Martialia hyadesi* in the southern waters of New Zealand. Uozumi (1990) showed there is one unknown species of *Todarodes* and it is very similar to *T. sagittatus* and *T. angolensis*. This species must be identical to "*T. s. angolensis*" in Forch (1986). The specimens of unknown *Todarodes* species examined in Uozumi *et al.* (1990) were identified to be *T. angolensis* on the basis of morphological characters (Dunning, personal com.).[1] Now it is known that there are five Todarodinae squids (Table II-3).

Three Ommastrephinae squids, *Ommastrephes bartrami, Symplectoteuthis oualaniensis*, and *Eucleoteuthis luminosa* are known around New Zealand (Saito, 1976; Forch, 1986). But no Illicinae squid is known in this area.

3. Nomenclaturative review of *Nototodarus* squids around New Zealand

Smith *et al.* (1981) revealed that there are two species of *Nototodarus* based on the results of electrophoresis, morphology of the hectocotylus, and prevalence of parasites. Kawakami and Okutani (1981) also pointed out that *Nototodarus* squid exploited in New Zealand waters are divided into two

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[1] : M.Dunning, Queensland Department of Primary Indastries, Fisheries Divisien, Queensland, Australia.

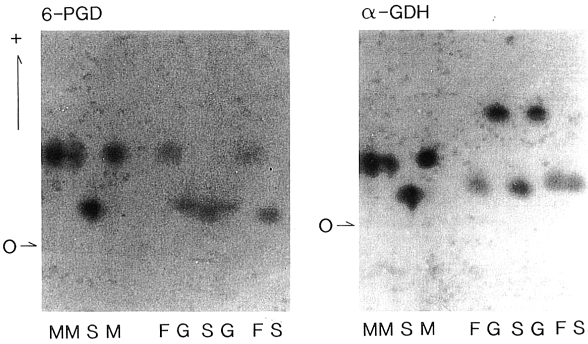


Fig. II-2. Starch gel-phenotypes of enzyme variants in five Todarodinae squids. G, *Nototodarus gouldi; S. N. sloanii*; F, *Todarodes filippovae*; M, *Martialia hyadesi*.

types, Types I and II, based on the morphological characters of hectocotylus and sucker counts of arms I-III. Type I was further divided into two subtypes. They concluded that Type Ib is identical to be *N. sloanii*, Type II is identical to *N. gouldi*, and Type Ia is an unnamed species.

Roberts (1983) agreed the existence of two *Nototodarus* species around New Zealand, but he showed that the locality of the type specimens for *N. sloanii* was out of its distribution area and the type specimen of *N. sloanii* was identical to *N. gouldi*. Then one species, which is distributed in the southern area, was an unnamed species.

Smith *et al.* (1987) reviewed the historical changes on the recognition about the *Nototodarus* species around New Zealand and clarified the nomenclaturative confusion. Holotype specimens of *N. sloanii* was identical to the squid recognized as *N. sloanii* by the authors, though the locality of holotype was out of the present geographical distribution area of *N. sloanii*. They concluded that there are two *Nototodarus* species, *N. gouldi* and *N. sloanii* around New Zealand, and the Type Ia in Kawakami and Okutani (1981) is identical to be immature *N. sloanii*.

Before the clarification by Smith *et al.* (1987), the various names were used for these two *Nototodarus* species. Names used for the two species in New Zealand waters are listed in Table II-4.

Table II-1. The criteria used for the determination of maturity stages in arrow squids.

Maturity stage	Male	Female
Immature	Testis thin or small; spermatophore sac empty	Ovary thin or granular; nidamental gland thin or small
Maturing	Testis large; spermatophore sac contains a few spermatophores and/or whitish particles	Egg forming; nidamental gland opaque
Mature	Testis large; spermatophore sac contains many spermatophores	Egg in oviduct; nidamental gland white
Spent	Spermatophores released and spermatophore sac empty	Oviduct large but contains a few eggs; nidamental gland large

Table II-2. Summary of the samples for measurement of club length and count of suckers on hectocotylus in *N. sloanii*.

Area	Males		Females	
	Number of specimens	Range of DML(mm)	Number of specimens	Range of DML(mm)
West Coast of Mainland	51	120-293	19	120-290
East Coast of South Island	204	114-323	138	110-385
Snares Shelf	156	150-340	168	153-386
Auckland Islands Shelf and Southern waters	147	168-398	155	129-447
Total	558	114-398	480	110-447

DML: dorsal mantle length

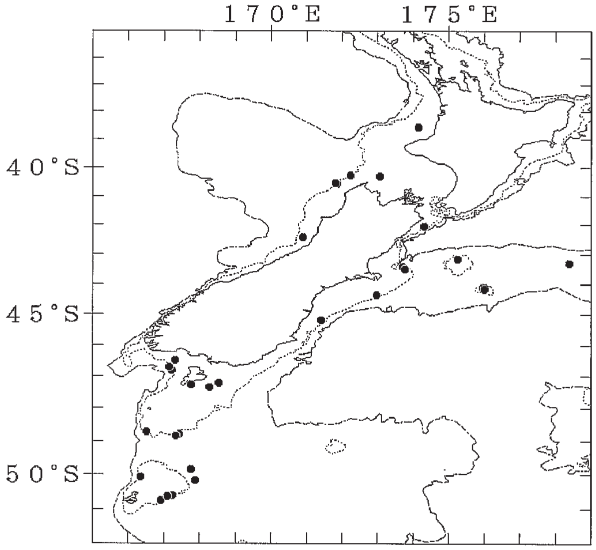


Fig. II-3. Localities of samples for the measurement of club length and counts of suckers on hectocotylus for *N. sloanii*.

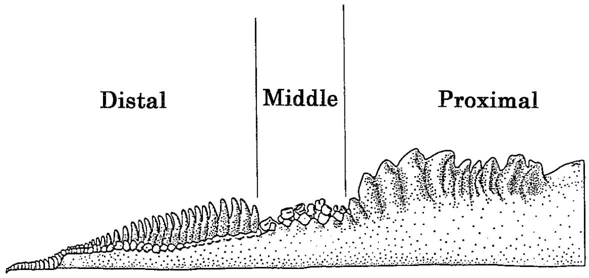


Fig. II-4. Hectocotylus of *N. sloanii* cited from Smith *et al.* (1981). The three parts, proximal, middle, and distal parts, are used for the counting of suckers.

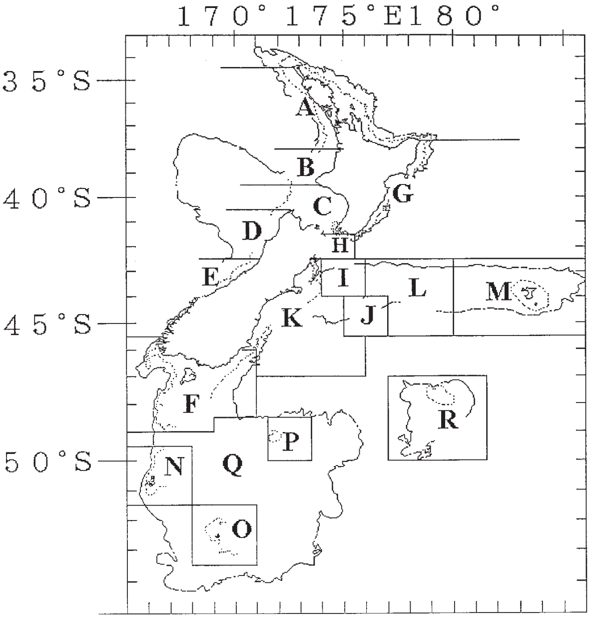


Fig. II-5. Fine biological sampling area for the detailed observation of mixing of the two *Nototodarus* species.

Table II-3. Species list of Todarodinae around New Zealand and corresponding English and Japanese common name.

Scientific Name	FAO English Name*	Common Name in New Zealand**	Japanese Name***
Nototodarus gouldi (McCoy, 1888)	Gould's flying squid	New Zealand northern arrow squid	Australia Surumeika
Nototodarus. sloanii (Gray, 1849)	Wellington flying squid	New Zealand southern arrow squid	New Zealand Surumeika
Todarodes filippovae Adam, 1975	Antarctic flying squid	_	Minami Surumeika
Todarodes angolensis Adam, 1962	Angora flying squid	_	Angora Surumeika
Martialia hyadesi Rochebrune et Mabille, 1889	Sevenstar flying squid	_	Aka Surumeika

*: Roper *et al*. (1984), **: Smith *et al*. (1987), ***: Uozumi (1990).

Table II-4. List of species names used for *N. gouldi* and *N. sloanii* around New Zealand in the literatures.

Literature	*Nototodarus gouldi*	*Nototodarus sloanii*
Saito *et al*. (1974) Kawakami (1976)	*N. sloani sloani* New Zealand Minami Surumeika	*N. sloani sloani* New Zealand Minami Surumeika
Saito (1976)	*N. sloani sloani* New Zealand Minami Surume	? New Zealand Oki Surume
Kawakami and Okutani (1981)	*N. gouldi* =Type II	*N. s. sloani* =Type Ib Type Ia (unknown species)
Smith *et al*. (1981)	*Nototodarus* sp. Western arrow squid	*Nototodarus* sp. Eastern and southern arrow squid
Roberts (1983)	*N. sloani*	*Nototodarus* sp.
Mattlin *et al*. (1985)	*Nototodarus* species 1	*Nototodarus* species 2
Smith (1985)	*Nototodarus* Northern species	*Nototodarus* Southern species

4. Identification of Todarodinae squids around New Zealand

A. Identification by morphological characters

Young and adult

It is very easy to identify the family Ommastrephidae, because this family has a very clear morphological key character, inverse T shape of funnel locking cartilage (Roper *et al*., 1984).

There are three subfamilies in Ommastrephidae, i.e., Ommastrephinae, Todarodinae, and Illicinae, but no Illicinae squid is known in New Zealand waters and this subfamily is omitted from consideration in the later sections. The Ommastrephinae squids have several side pockets on funnel groove, but Todarodinae has none. Then it is possible to identify Todarodinae based on these key characters (Roper *et al*., 1984).

It is known that there are three genera and five species of Todarodinae, *Todarodes, Nototodarus*, and *Martialia*, in New Zealand waters as mentioned in the section II-2. The results of counts and measurements for these five species are shown in Table II-5. The genus *Martialia*, which has a single species, *M. hyadesi*, has two clearly different morphological characters in arms and tentacles, well developed trabeculae and particular tentacular club which occupy almost entire length of tentacles (Rodhouse and Yeatman, 1990). There is a little difference between tentacle and club length indices as shown in Table II-5 and this means that club occupies almost area of tentacle. Based on these characters, it is possible to identify *M. hyadesi* certainly.

The key character to identify *Nototodarus* and *Todarodes* is hectocotylized arm (Roper *et al*., 1984). But it is impossible to identify female squid by this character. Table II-5 showed that the number of suckers in Arm I-III may be a key character to separate these two genera occur in New Zealand waters. Number of suckers in Arm I-III is less than about 60 in *Todarodes* and more than about 80 in *Nototodarus*.

In *Nototodarus*, Wormuth (1976) showed a clear difference in number of suckers in Arm I between *N. gouldi* and *N. sloanii*, but this difference was not emphasized, because of single specimen of *N. gouldi*. It was believed that it is very difficult to identify *N. gouldi* and *N. sloanii* by the morphological characters (Okutani, 1980). Smith and Hurst (1981), however, showed it is easy to distinguish the two species based on the morphology of hectocotylus. After Smith and Hurst (1981), it has become possible to identify the two

Table II-5. Means of the counts and indices for the five Todarodinae species around New Zealand. The specimens of *M. hyadesi* were obtained form the Argentine waters. R and L denote right and left, respectively. Morphological indices were followed after Roper and Voss(1983).

		N. gouldi	*N. sloanii*	*T. filippovae*	*T. angolensis*	*M. hyadesi*
Dorsal Mantle Length		268.8	310.7	406.8	452.8	306.5
Mantle Width Index		28.2	23.2	22.6	23.8	23.7
Head Length Index		23.7	20.2	21.4	18.8	18.9
Head Width Index		18.4	16.8	17.7	15.5	14.3
Funnel Length Index		15.6	14.5	12.9	12.6	11.6
Free Funnel Index		10.6	9.3	9.7	10.6	9.1
Foveolar Fold Count		9.8	10.0	10.0	9.0	7.7
Side Pocket Count		0	0	0	0	0
Fin Length Index		42.3	45.0	52.8	52.2	44.0
Fin Width Index		56.4	56.5	59.3	61.5	58.1
Fin Angle		48.2	48.0	37.6	41.5	46.0
Arm Length Index	1st R	46.8	45.4	39.4	38.9	39.9
	1st L	46.4	45.6	39.7	39.9	39.4
	2nd R	58.4	56.2	46.8	47.4	44.0
	2nd L	58.5	55.8	46.1	48.4	44.7
	3rd R	56.7	55.2	45.4	47.7	44.7
	3rd L	55.3	54.4	43.7	45.4	44.0
	4th R	46.9	45.4	36.9	36.5	39.0
	4th L	50.1	48.0	38.9	36.3	38.2
Arm Sucker Count	1st R	78.0	184.3	57.0	58.0	73.6
	1st L	82.0	190.4	55.0	61.7	74.7
	2nd R	82.0	180.7	59.5	60.7	73.2
	2nd L	84.8	180.7	59.5	60.7	74.4
	3rd R	84.7	188.0	57.3	60.3	73.3
	3rd L	84.3	193.6	59.0	58.0	71.0
	4th R	55.3	92.8	55.0	63.5	76.7
	4th L	83.2	143.0	59.0	65.0	75.5
Sucker Diameter Index	1st R	1.6	1.2	1.4	1.2	1.0
	1st L	1.6	1.2	1.4	1.3	1.0
	2nd R	2.0	1.8	1.6	1.4	1.2
	2nd L	1.9	1.8	1.6	1.4	1.1
	3rd R	1.9	1.7	1.5	1.4	1.2
	3rd L	1.9	1.7	1.6	1.4	1.2
	4th R	1.2	1.1	1.4	1.0	0.9
	4th L	1.2	1.1	1.4	1.1	0.9
Tentacle Length Index	R	102.9	89.1	87.9	78.3	63.7
	L	100.5	85.7	92.6	69.4	60.5
Club Length Index	R	62.7	49.6	63.3	62.0	58.5
	L	62.9	49.1	67.7	56.9	56.6
Dactylus Length Index		10.7	12.4	9.8	9.9	9.4
Manus Length Index		41.0	31.9	38.0	42.7	41.9
Carpus Length Index		9.7	7.7	7.3	6.3	7.4
Sucker Count of Dactylus	R	70.0	94.7	77.3	76.0	79.7
Sucker Count of Manus	R	50.4	52.0	53.3	62.0	79.2
Sucker Count of Carpus	R	5.0	5.0	5.0	6.0	4.3
Manus Sucker Index	R	2.9	2.6	3.8	2.3	1.7
Mean Number of Manus Teeth		15.9	13.1	11.2	15.4	14.6
Mean Number of 3rd Arm Teeth		11.0	9.8	7.5	6.8	5.9

species easily for males.

Smith *et al.* (1987) clarified the morphological differences between *N. gouldi* and *N. sloanii*. Table II-5 also shows clear difference in the number of suckers in Arm I-III between *N. gouldi* and *N. sloanii*. Based on the number of suckers in Arm I-III, it is easy to identify the two species of *Nototodarus*.

National Research Institute of Far Seas Fisheries (NRIFSF) started to collect the biological data by species for males since 1981 using the morphological character of hectocotylus (Sato, 1985). Using the differences in number of suckers in Arm I (Wormuth, 1976; Kawakami and Okutani, 1981), the NRIFSF started to collect the biological data by species for females since 1982.

Larvae and juveniles

Larvae of Ommastrephidae are known as rhynchoteuthions in which both tentacles are fused into a rod-like "proboscis" ant it is very easy to identify this family even in the larval stage (Okutani, 1987). Nesis (1979) described the morphological characters of the larvae and juveniles of *O. bartrami, S. oualaniensis, E. luminosa, T. sagittatus, T. angolensis*, and *Nototodarus* sp.. Forch (1986) also described the rhynchoteuthion larvae of *Nototodarus* spp. collected from the shallower waters around New Zealand. However there is no description on the larvae and juvenile of *T. filippovae* and *M. hyadesi*, except for the juvenile *M. hyadesi* (Uozumi *et al.*, 1991).

Based on the descriptions mentioned above, Ommastrephinae larvae can be identified by the presence of photophores and/or the shape of suckers at the tip of proboscis (Nesis, 1979; Wormuth *et al.*, 1992). But it is impossible at present to identify the larvae of Todarodinae by species using the morphological characters, because there is no description of *T. filippovae* and *M. hyadesi*, and there is no diagnostic character to identify *N. gouldi* and *N. sloanii* (Forch, 1986).

B. Identification by electrophoresis

Smith (1985) showed that there are two *Nototodarus* species which have different gel phenotypes in α-Glycerophosphotase dehydrogenase. Uozumi *et al.* (1991) applied the electrophoresis for the identification of larvae and juvenile Todarodinae squids around New Zealand and revealed that the gel-phenotypes of two enzymes, 6-Phosphogluconate dehydrogenase (6-PGD) and α-Glycerophosphotase dehydrogenase (α-GDH), make it possible to identify the four Todarodinae squids (*N. gouldi, N. sloanii, T. filippovae*, and *M. hyadesi*) even in the larval stage. Yokawa (1994) showed the Gel phenotypes of *T. angolensis* for the enzymes used in Uozumi *et al.* (1991) are same as those of *T. filippovae*.

Among the five species, *N. gouldi, N. sloanii, T. filippovae, T. angolensis*, and *M. hyadesi*, two gel-phenotypes were observed in 6-PGD and three Gel-phenotypes in α-GDH. Based on combination of these two enzyme gel-phenotypes, it is possible to identify *N. gouldi, N. sloanii, M. hyadesi*, and *Todarodes* spp. among the six Todarodinae species occur in New Zealand waters (Fig. II-2 and Table II-6), though the two species of *Todarodes* can not be identified into species by this combination of gel-phenotypes.

Table II-6. Gel-phenotypes of 6-PGD and α-GDH for Todarodinae squids occur in the New Zealand waters.

Species	6-PGD	α-GDH
N. gouldi	Slow	Fast
N. sloanii	Slow	Slow
T. filippovae	Fast	Slow
T. angolensis	Fast	Slow
M. hyadesi	Fast	Medium

C. Change in number of suckers in Arm I with growth

The most practical key character for identification of the five species is the number of suckers in Arm I, especially for identification of two *Nototodarus* species (Table II-5) in adult stage. Fig. II-6 shows the change of number of suckers in Arm I with DML for the specimens identified by the electrophoresis, though the specimens of *Todarodes* could not be identified into the species level. The semilogarithmic curves were fitted to the relationship between DML and number of suckers in Arm I by species. The resultant equations are as follows,

N. gouldi : $No=21.3\ln(DML)-15.2$ $(N=54,\ R^2=0.78)$

N. sloanii : $No=59.4\ln(DML)-112.1$ $(N=50,\ R^2=0.86)$

Todarodes spp. : $No=13.8\ln(DML)-10.5$ $(N=50,\ R^2=0.74)$

M. hyadesi : $No=17.6\ln(DML)-14.3$ $(N=39,\ R^2=0.74)$

where No; number of suckers in Arm I, N; number of specimens, and R^2; r-square.

The rate of increase of suckers was higher in smaller squid than larger ones as shown in Fig. II-6. The

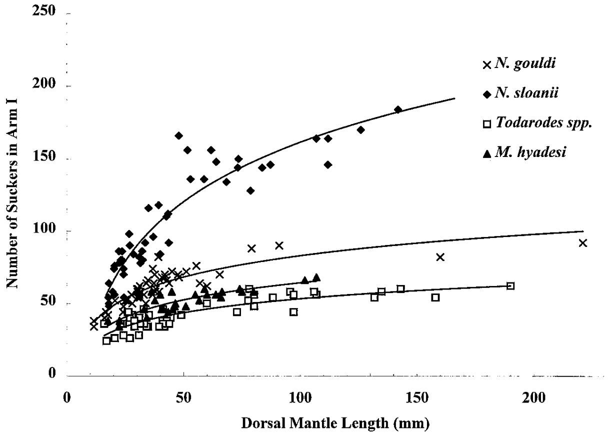


Fig. II-6. Relationship between dorsal mantle length and number of suckers in Arm I for *N. gouldi, N. sloanii, Todarodes* spp., and *M. hyadesi*. The curve shows the estimated semilogarithmic one for each species (or species group).

number of suckers attained to the mean number of suckers observed in the adult specimens shown in Table II-5 at about 80 mm DML for *N. gouldi*, 150 mm DML for *N. sloanii*, 143 mm for *Todarodes* spp., and 150 mm for *M. hyadesi*, respectively. These results indicate that it is very difficult to identify these species less than about 150 mm DML based on the number of suckers in Arms without information on the relationship between DML and number of suckers. Based on the relationship, it is possible to identify these species less than 150 mm DML, but it is still uncertain to identify the specimens less than about 40 mm DML, because the range of sucker number is considerably overlapped among the species. Therefore, usage of this key character should be limited in the size larger than about 40 mm DML even with the consideration of the relationship between DML and number of suckers.

5. Two types of *N. sloanii*

Kawakami and Okutani (1981) subdivided *N. sloanii* into two types (Type Ia and Ib) based on the number of suckers on the modified portion of right arm IV in males and on the club length index (club length/DML; CLI) in males and females. Type Ia males had 6-13 small suckers and a CLI larger than 50%, while Type Ib males had 49-95 suckers and a CLI less than 50%. Females were separated on the basis of CLI. Smith *et al.* (1987) suggested that the club length index is not reliable character for separating the two types and the number of suckers decrease with size. They concluded that no taxonomic status should be attached to the type Ia and Ib of *N. sloanii*. In the present study, the relationships between number of suckers on hectocotylus and DML and between club length and DML were analyzed to reconsider the status of the two types presented by Kawakami and Okutani (1981).

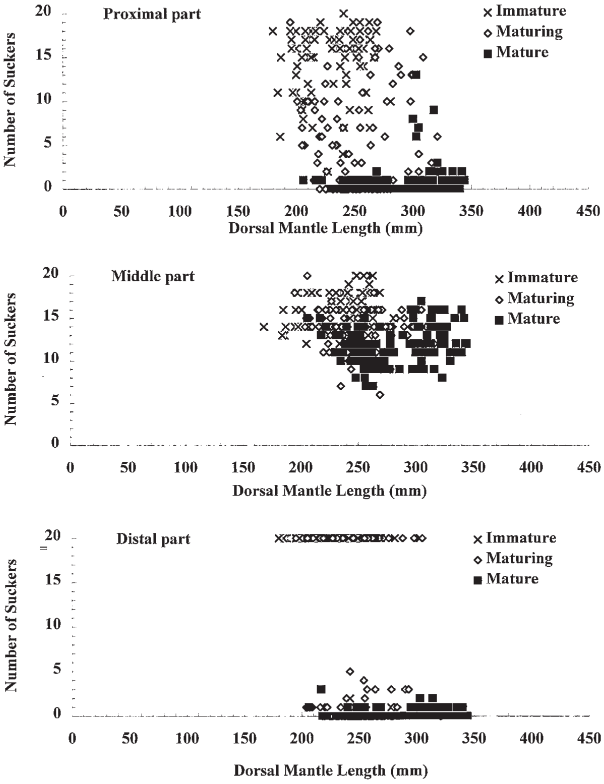


Fig. II-7. Relationship between dorsal mantle length and number of suckers on hectocotylus of *N. sloanii*.

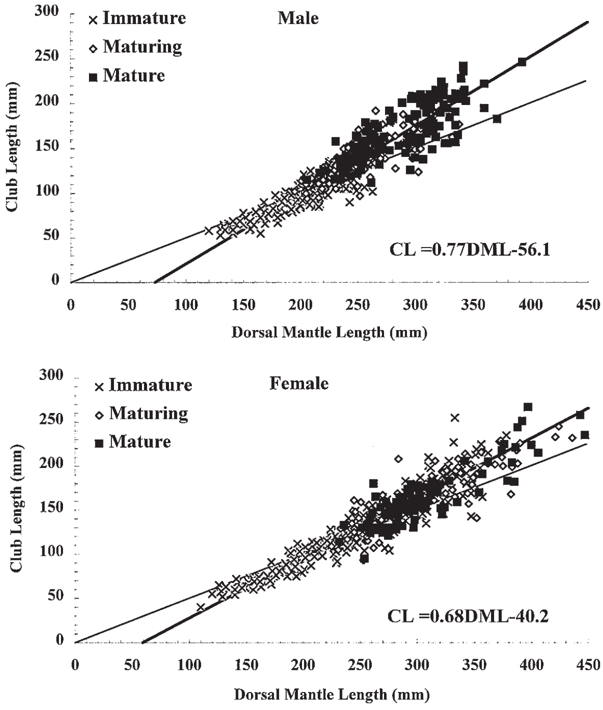


Fig. II-8. Relationship between dorsal mantle length and club length in *N. sloanii*. A thin line shows the 50% level of club length (CL) to dorsal mantle length (DML). A thick line shows GM regression line.

A. Suckers on hectocotylus

Fig. II-7 shows the relationship between number of suckers and DML in the three parts of hectocotylus by maturity stage. In proximal part immature squid had 14.1 small suckers on average at each tip of proximal tubercles and maturing squid had 4.8 suckers on average. The mean number of suckers for mature males was 0.8. In the middle part of hectocotylus the mean number of suckers for three stages were 16.4, 13.7, and 11.8, respectively. In distal part of hectocotylus the mean number of suckers was 18.0, if the number for the specimens which had more than 20 suckers was substituted by 20. The mean values for maturing and matured squid were 5.8 and 0.2, respectively.

The relationship between DML and number of suckers were negatively correlated, but the correlation coefficients were low, and -0.38, -0.25, and -0.44 for proximal, middle, and distal parts, respectively. Almost all of suckers in the proximal and distal parts of hectocotylus were lost at mature stage and only 6- 15 suckers remained at the middle part.

B. Club length

Fig. II-8 showed the relationship between DML and Club length (CL) by sex. It was observed that there was linear relationship between DML and CL for each sex. Fig II-8 suggested that there is no clear difference in the relationship between DML and CL among the

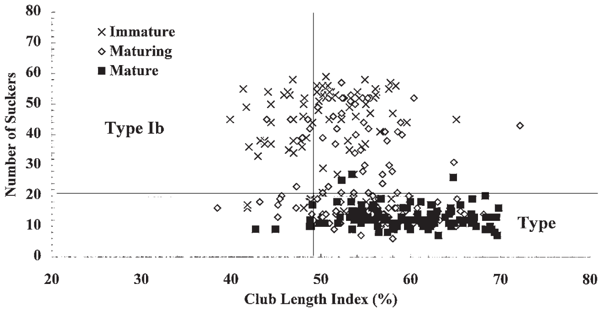


Fig. II-9. Relationship between club length index (CL/DML) and number of suckers on hectocotylus of *N. sloanii*. dotted lines show the borders between the two types, Types Ia and Ib, in Kawakami and Okutani (1981). CL and DML represent club length and dorsal mantle length, respectively.

maturity stages. The GM linear equations were estimated by sexes. The resultant equations are as follows,

Male: $CL=0.77DML-56.1$ (N=529, r=0.93)
Female: $CL=0.68DML-40.2$ (N=535, r=0.93),

N is number of specimens and r is correlation coefficient. These equations showed that the CL index (CL/DML) is less than 50% for squid smaller than about 208 mm DML in male and about 223 mm DML in female. For squid larger than these sizes, the CL index is more than 50%.

C. Reconsideration on the two types

Kawakami and Okutani (1981) proposed the number of suckers on hectocotylus and CL index as key morphological characters in dividing the two types of *N. sloanii*. But the present results showed that the number of suckers on hectocotylus decreases drastically with maturation and CL index increases from less than 50% to more than 50% with DML. Fig. II-9 shows the relationship between CL index and number of suckers on hectocotylus, though the number of suckers larger than 20 must be much higher value (number of suckers in distal part was not counted when there was more than 20 suckers in this part). There was no clear segregation in this relationship between the two types, while there was a relatively clear segregation among maturity stages.

The present results, the decrease of suckers on hectocotylus with the maturation and increase of CL index with DML, suggests that these characters are not appropriate ones for dividing the two types. Figs. II-5-9 show that the continuous changes in these two characters with maturation and growth. On the basis of these results, it is conclude that Type Ib represents the immature and/or maturing smaller *N. sloanii* and Type Ia represents mature and larger one, respectively.

6. Geographical distribution of Todarodinae squids around New Zealand and its adjacent waters

The geographical distributions of five Todarodinae squids were reviewed on the basis of the literatures. As for the two species of *Todarodes*, there is not yet sufficient information to describe the distribution of each species correctly, especially in New Zealand waters.

The distribution of *Todarodes* spp., which may combine the distribution patterns of the two species of *Todarodes*, is presented. A survey report presented the distribution of *T. filippovae* based on the bottom trawl operations (Hatanaka *et al*., 1989), but there is high possibility that the identification in *Todarodes* was not adequate. During the surveys, the squids caught were sorted into *N. sloanii, N. gouldi, Todarodes, Moroteuthis*, and other squid, but there might be no consideration to identify squid of *Todarodes* into the species level, because most of researchers on board believed that there was single species in *Todarodes* around New Zealand. Therefore, there was a possibility that *T. angolensis* might be included in the catch of *T. filippovae* during these surveys. Furthermore, Dunning (1988) suggested that Soviet biologists have confused the literature by referring all *Todarodes* caught in southern hemisphere waters to *T. angolensis*.

Fig. II-10 showed the geographical distributions of *N. gouldi* and *N. sloanii* on the basis of the literature (Sato, 1985; Smith 1985; Japan Fisheries Agency 1986; Yamada and Kattoh, 1987; Uozumi *et al*., 1987; Fenaughty and Uozumi, 1989; Hatanaka *et al*., 1989; Kailola et al., 1993), and these of *Todarodes* spp. and *M. hyadesi* after Dunning and Brandt (1985), and Dunning (1988 and 1993).

N. gouldi is distributed on the continental shelves of the southern Australia and northern New Zealand, while *N. sloanii* is an endemic species in New Zealand waters and distributed mainly on the shelves of the southern New Zealand. The distribution areas of the two species are overlapped in the middle part of New Zealand as shown in Fig. II-10. Both of them are mainly distributed in the waters shallower than 200 m depth, though some of them are caught in slope waters.

Todarodes spp. are distributed offshore waters in the wide range of latitudinal zone, though the north and south boundaries are not yet clear. Furthermore, the succession of the species may occur in this wide distribution zone from *T. filippovae* to *T. angolensis*. *M. hyadesi* is limited to the Subtropical Convergence Zone (SCZ) and southward. It is probable that this species may be rare on the island shelves where the squid fisheries have been operated in the southern waters of SCZ, because there was no report of this species in logbooks. Information on these three species have not yet sufficient to draw the clear figures of distribution at present.

7. Mixing ratio of *N. gouldi* and *N. sloanii* around New Zealand

The mixing ratios of *N. gouldi* and *N. sloanii* by fine biological sampling area from 1981 to 1992 are shown in Fig. II-11 and yearly variation of mixing ratios by area are also shown in Table II-7. *N. gouldi* is dominant around the North Island and more than 90% of arrow squid in this area were *N. gouldi*. In the waters off west coast of the North and South Islands, the mixing ratio changed gradually from 100% of *N.*

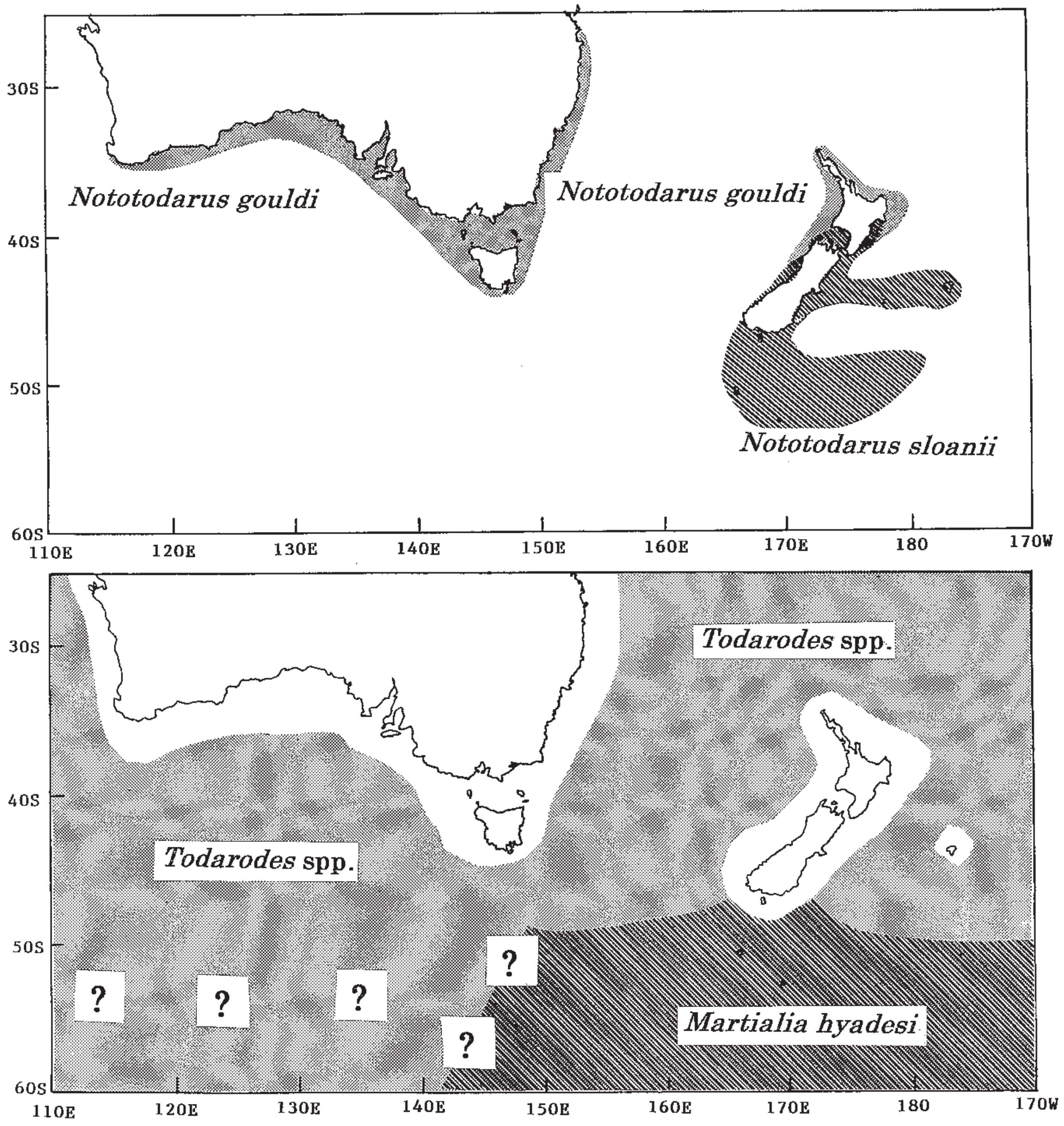


Fig. II-10. Geographical distributions of *N. gouldi*, *N. sloanii* (top), *Todarodes* spp., and *M. hyadesi* (bottom) around New Zealand and its adjacent waters.

gouldi in the northernmost area (Area A) to about 60% in the southernmost area (Area E). On the contrary the ratio changed abruptly from about 95% of *N. gouldi* off the east coast of North Island (Areas G and H) to nearly 0% in the east coast of the South Island. In the waters off east and south coasts of the South Island and on the Chatham rise (Areas F, I, J, K, L, and M), *N. gouldi* was very rare. On the Campbell Plateau and the Bounty Platform, no *N. gouldi* was observed.

The mixing ratio has been stable through the fishing years observed in Areas A, B, and C where *N. gouldi* is very dominated (Table II-7). On the contrary it fluctuated largely in Areas D and E where *N. sloanii* occupied a significant part.

N. gouldi is dominant around the North Island and its domination extend into the waters off west coast of the South Island, though the mixing ratio of *N. gouldi* gradually decreases southerly. In the waters off east and south coasts of the South Island, on the Chatham Rise, the Campbell Plateau, and on the Bounty Platform, *N. sloanii* is dominated exclusively through the fishing years observed. Based on these results, it could be assumed that the occurrence of *N. sloanii* around the North Island is negligible and also the occurrence of *N. gouldi* in the eastern and southern area of the South Island is negligible, but in the waters off west coast of the South Island, the mixing ratio of these two species is highly variable.

III. Age and growth based on daily increments counts in statoliths

Growth of arrow squids used to be estimated from the progressive changes of modes in length composition (Mattlin *et al.*, 1986; Uozumi and Kuroiwa, 1990). Recent attention has been focused on the use of statoliths to determine age. A number of studies have demonstrated the usefulness of statoliths for ageing (Rodhouse and Hatfield,1990). The results of ageing research suggested that the estimation by length-based method using the seasonal progression of modes in size composition may be biased, because of gradual replacement of older squid by younger squid (Uozumi and Shiba, 1993).

In this chapter the age and growth of arrow squids are estimated by ageing using the daily increment counts in the statoliths.

1. Materials and methods

(1) Samples and data

Most of the samples for ageing were collected by Japanese squid jiggers and trawlers (Tables III-1 and 2). Samples of juvenile squid were collected by a fine mesh mid-water trawl (KMT mid-water trawl net with 10 mm mesh cod-end) during a joint Japan-New Zealand squid survey by R/V *Kaiyo Maru* in July-September, 1985 (Anon., 1986). Localities of samples are shown in Fig. III-1. The samples of statoliths for *N. gouldi* were collected from off the west coast of the mainland which is the main area of distribution. Some 85% of the statolith samples for *N. sloanii* were collected on the Snares Shelf where is the one of the important fishery grounds for the squid jigging and trawl fisheries. Samples from the other areas were insufficient for the analyses.

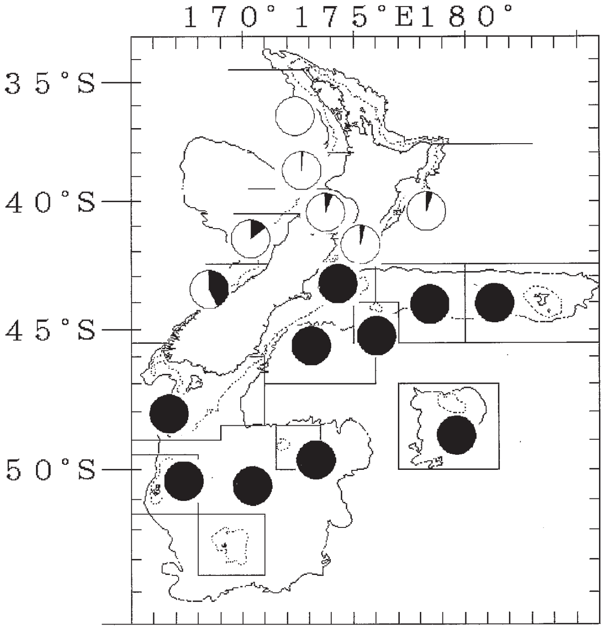


Fig. II-11. Mixing ratio of *N. gouldi* and *N. sloanii* by the fine biological sampling area from 1981/82 to 1991/92 fishing years. Open and dark parts show the percentage of *N. gouldi* and *N. sloanii*, respectively.

(2) Statolith processing and count of increments

Twelve detailed measurements were made in the laboratory: dorsal mantle length (DML), whole body weight, gonad weight, Needham's sac or nidamental gland weight, spermatophore sac or oviduct weight, nidamental gland length and stomach content weight. Observations were also recorded for whether copulation had occurred, sex, gonad maturity stage, fullness of stomach and composition of stomach contents. The statoliths were removed with fine-pointed forceps. After washing in 99% ethanol, the statoliths were stored in liquid paraffin. Ageing was carried out using these statolith samples. Preparation of the statoliths from squid smaller than about 10 cm DML is very easy, because the small statoliths are so transparent that there is no necessity of grinding. Such statoliths were mounted in liquid paraffin, posterior convex side upward, in the depression in a glass slide.

Grinding was necessary for larger statoliths to facilitate the counting of all rings. The statoliths were first washed in 99% xylene to remove the liquid paraffin, then dipped in 5% sodium hypochlorite to remove the adhering tissue and other debris. Each statolith was then washed in 99% ethanol, air-dried and mounted individually with anterior concave side down on a glass slide by single drop of super glue (cyanoacrylate adhesive). The statoliths were then ground by hand on fine waterproof sandpaper (Japanese Industrial Standard Nos. 1500) and finally polished with a buff using 1.0-0.05 μ alumina polish. It was necessary to make frequent stops in order to check progress under a microscope.

A microscope equipped with a color TV camera system was used during the grinding procedure and for viewing the increments in the statoliths. Counting was carried out on a 15-inch color TV monitor at 920x magnification.

The increments were most discernible in the dorsal dome, especially along the wing attachment area (Fig. III-2). Increments were usually counted in this area from the core to the edge region. Since the increments in the terminal-most portion of the statoliths could not be counted in most samples, the number of increments in this area was derived by extrapolation based on those counted in the nearest area where counting was possible. The proportion of the estimated number of increments to the total was about 5%, regardless of the size of statolith.

(3) Back-calculation

The number of juvenile samples was insufficient to derive the appropriate growth curve in this study. Therefore, a back-calculation method which estimates the length at the time when the rings were formed was applied to estimate length at younger ages. This method has been used commonly in studies on the growth of fishes (Carlender, 1987).

This method needs the relationship between statolith radius and DML, and each monthly radius. Measurements of statolith radius and monthly radii (radius of each 30 increments) were carried out on a

Table II-7. Mixing percentages of *N. gouldi* and *N. sloanii* by the fine biological sampling areas from 81/82 to 91/92 Fishing Years. Numerals in the upper two lines in each Area show the number of specimens observed.

Fine Biological Sampling Area	**Fishing Year**	**81/82**	**82/83**	**83/84**	**84/85**	**85/86**	**86/87**	**87/88**	**88/89**	**89/90**	**90/91**	**91/92**	**Total**
A	*N. gouldi*	0	0	0	8	211	0	0	0	0	0	0	219
	N. sloanii	0	0	0	0	0	0	0	0	0	0	0	0
	% of *N. gouldi*	–	–	–	100.0	100.0	–	–	–	–	–	–	100.0
B	*N. gouldi*	0	642	568	58	863	578	0	0	0	35	95	2839
	N. sloanii	0	6	0	0	20	0	0	0	0	0	0	26
	% of *N. gouldi*	–	99.1	100.0	100.0	97.7	100.0	–	–	–	100.0	100.0	99.1
C	*N. gouldi*	13	466	217	54	287	2325	0	0	0	351	124	3837
	N. sloanii	0	120	74	0	6	60	0	0	0	0	0	260
	% of *N. gouldi*	100.0	79.5	74.6	100.0	98.0	97.5	–	–	–	100.0	100.0	93.7
D	*N. gouldi*	0	233	1951	257	459	611	0	0	0	175	0	3686
	N. sloanii	31	264	59	191	39	19	0	0	0	12	0	615
	% of *N. gouldi*	0.0	46.9	97.1	57.4	92.2	97.0	–	–	–	93.6	–	85.7
E	*N. gouldi*	0	0	0	0	0	1471	0	0	0	0	0	1471
	N. sloanii	0	0	0	9	0	1088	0	0	0	0	0	1097
	% of *N. gouldi*	–	–	–	0.0	–	57.5	–	–	–	–	–	57.3
F	*N. gouldi*	0	0	7	0	2	0	0	0	0	0	0	9
	N. sloanii	514	785	7502	1004	3541	4606	0	0	88	1004	0	19044
	% of *N. gouldi*	0.0	0.0	0.1	0.0	0.1	0.0	–	–	0.0	0.0	–	0.0
G	*N. gouldi*	0	0	202	0	0	0	0	0	0	0	0	202
	N. sloanii	0	0	11	0	0	0	0	0	0	0	0	11
	% of *N. gouldi*	–	–	94.8	–	–	–	–	–	–	–	–	94.8
H	*N. gouldi*	0	56	0	0	0	0	0	0	0	0	0	56
	N. sloanii	0	2	0	0	0	0	0	0	0	0	0	2
	% of *N. gouldi*	–	96.6	–	–	–	–	–	–	–	–	–	96.6
I	*N. gouldi*	0	0	0	0	0	0	0	0	0	0	0	0
	N. sloanii	0	42	0	41	51	174	0	0	0	0	0	308
	% of *N. gouldi*	–	0.0	–	0.0	0.0	0.0	–	–	–	–	–	0.0
J	*N. gouldi*	0	1	0	0	0	0	0	0	0	0	0	1
	N. sloanii	25	506	433	354	873	95	0	0	0	0	0	2286
	% of *N. gouldi*	0.0	0.2	0.0	0.0	0.0	0.0	–	–	–	–	–	0.0
K	*N. gouldi*	0	13	11	4	0	0	0	0	0	0	0	28
	N. sloanii	85	574	3524	1227	1939	461	0	0	51	72	0	7933
	% of *N. gouldi*	0.0	2.2	0.3	0.3	0.0	0.0	–	–	0.0	0.0	–	0.4
L	*N. gouldi*	0	0	0	0	0	0	0	0	0	0	0	0
	N. sloanii	0	49	20	0	96	0	0	0	0	0	0	165
	% of *N. gouldi*	–	0.0	0.0	–	0.0	–	–	–	–	–	–	0.0
M	*N. gouldi*	0	0	0	0	1	0	0	0	0	0	0	1
	N. sloanii	0	117	0	44	248	0	0	0	0	0	0	409
	% of *N. gouldi*	–	0.0	–	0.0	0.4	–	–	–	–	–	–	0.2
N	*N. gouldi*	0	0	0	0	0	0	0	0	0	0	0	0
	N. sloanii	439	790	1766	7983	1568	3598	0	0	0	0	0	16144
	% of *N. gouldi*	0.0	0.0	0.0	0.0	0.0	0.0	–	–	–	–	–	0.0
O	*N. gouldi*	0	0	0	0	0	0	0	0	0	0	0	0
	N. sloanii	0	0	0	0	0	0	0	0	0	0	0	0
	% of *N. gouldi*	–	–	–	–	–	–	–	–	–	–	–	–
P	*N. gouldi*	0	0	0	0	0	0	0	0	0	0	0	0
	N. sloanii	0	0	20	64	67	0	0	0	0	0	0	151
	% of *N. gouldi*	–	–	0.0	0.0	0.0	–	–	–	–	–	–	0.0
Q	*N. gouldi*	0	0	0	0	0	0	0	0	0	0	0	0
	N. sloanii	0	20	0	21	0	0	0	0	0	0	0	41
	% of *N. gouldi*	–	0.0	–	0.0	–	–	–	–	–	–	–	0.0
R	*N. gouldi*	0	0	0	0	0	0	0	0	0	0	0	0
	N. sloanii	0	0	117	36	26	0	0	0	21	0	0	200
	% of *N. gouldi*	–	–	0.0	0.0	0.0	–	–	–	0.0	–	–	0.0

Table III-1. Data collection for the statoliths of *N. gouldi*.

Year	Month	Bottom Depth (m)	Number of Specimens	Range of Size (mm DML)
1985	AUG	?	7	15 - 90
91	JAN	?	103	166 - 296
91	MAR	60-91	263	101 - 380
91	APR	92-92	15	198 - 388
91	OCT	190-210	41	201 - 310
91	NOV	145-162	40	168 - 316
91	DEC	137-137	25	116 - 332
92	JAN	?	46	204 - 380
92	FEB	?	19	224 - 266
92	MAR	?	62	138 - 380
92	APR	?	29	262 - 366
92	MAY	?	12	252 - 305
		Total	**662**	**15 - 388**

Table III-2. Data collection for the statoliths of *N. sloanii*.

Year	Month	Bottom Depth (m)	Number of Specimens	Range of Size (mm DML)
1985	AUG	46-380	29	15 - 220
85	SEP	65-65	3	48 - 60
90	JAN	149-149	12	213 - 277
90	MAR	?	25	140 - 342
90	APR	?	9	300 - 340
90	NOV	470-507	26	268 - 398
91	JAN	115-185	184	98 - 280
91	FEB	117-180	296	114 - 272
91	MAR	?	31	208 - 272
91	APR	532-532	54	108 - 342
91	DEC	279-279	27	256 - 330
92	JAN	189-189	56	174 - 246
92	FEB	163-427	34	176 - 296
92	MAR	144-345	110	140 - 406
92	APR	249-277	64	140 - 376
92	MAY	365-458	47	230 - 370
		Total	**1,008**	**15 - 406**

TV monitor using a digital map meter (COMCURVE-5, Koizumi Sokki Mfg Co., Ltd) at 920x magnification. The statolith radius and monthly radii were measured from core to tip of the dorsal dome along the curved axis shown in Fig. III-3. Measurement of the statolith radius was carried out in almost all of the observed specimens which were not broken in the measurement area, while the measurement of monthly radii was carried out in 20 specimens hatched in the same month.

For estimation of the relationship between statolith radius and DML, some functional regression curves were fitted using the least square method. Akaike's Information Criterion (AIC), mentioned in III-1-(9), was used for selection of the optimal model among these functions.

(4) Validation of daily increment formation

For validation of the periodicity of increment formation, no direct methods such as the use of a chemical marker (Dawe *et al*., 1985; Lipinski, 1986; Nakamura and Sakurai, 1991) were carried out in this study. So another type of validation was tried which involved comparing the number of increments in the statoliths with the date of capture (Uozumi and Shiba, 1993).

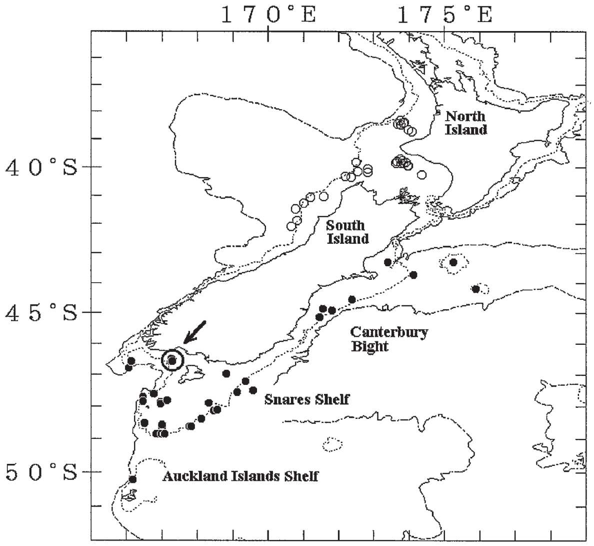


Fig. III-1. The localities of samples. Open and solid circles show the sampling sites for *N. gouldi* and *N. sloanii*, respectively. The Arrow and larger open circle show the sampling area which was used for the validation study for *N. sloanii*.

The data and specimens used in the validation were collected from a very restricted area of 8 square miles (shown by the arrow in Fig. III-1), during 29 days from 18th January to 15th February 1991. Length composition for each five-day period around the date on which each statolith sample was collected are shown in Fig. III-4. Statoliths were selected from the modal region of length compositions (shaded area of Fig. III-4), regardless of sex. This validation was only carried out for *N. sloanii*, because sufficient number of samples of *N. gouldi* were not obtained. A predictive regression model was applied to the analysis of the relationship between the number of increments and the sampling date.

(5) Month class

The term " month class " is used in the present study to express a group which comprises the individuals hatched in same month. Month class is an arbitrary category to analyze characteristics of the seasonal groups. This is one kind of micro-cohort which is the term used to refer to a group of animals born during the same short time interval (Caddy, 1991). This term corresponds to the term " year class " for the species which lives longer than one year. The term " month class " was used for the first time by Uozumi and Shiba (1993) who described the changes of age composition in monthly basis with the time for *Illex argentinus*.

(6) Estimation of growth rate for every 60 day old period by month class

For comparison of growth rate among the month classes, the growth rates (mm/day) for 60-day old intervals, 90-150, 120-180, 150-210, 180-240, 210-270, and 240-300 days, were estimated by sex and month class for both species. DMLs at age estimated from ageing and back-calculation were used for this estimation. It is assumed that 60-day periods age are short enough to be able to be approximate the growth

Fig. III-2. Photomicrograph of the posterior convex view of a ground statolith, from *N. gouldi* (left) with 205 mm DML and *N. sloanii* (right) with 200 mm DML.

pattern as linear. The GM regression, which is a model for data which have errors in both independent and dependent variables (Ricker, 1973), was applied to estimate the growth rate. The regression coefficient which is estimated by the length at age data in each 60-days period shows the growth rate (mm/day).

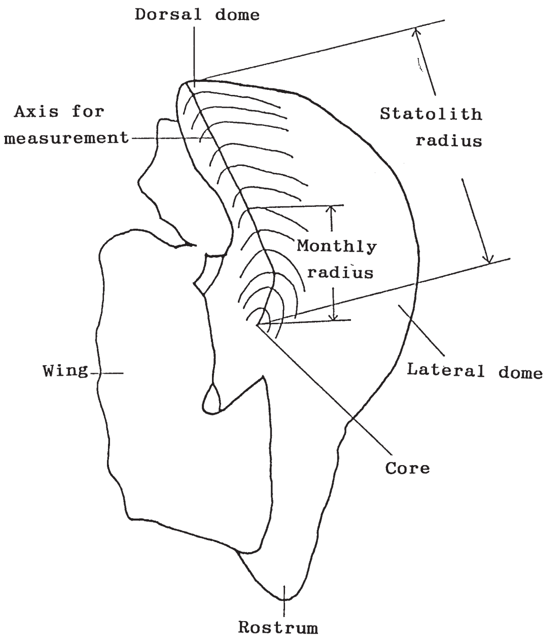


Fig. III-3. Schematic view of statolith showing the axis for the measurements.

(7) Estimation of the parameters for the logistic growth function by sex and month class

Mean DML at every 30-day old interval was estimated by back-calculation by sex and month class. The ageing results were also pooled for each month class and the mean DML at every ten-day interval was calculated. These mean DMLs were used for the estimation of the parameters of logistic curves. As the number of specimens were highly variable among the month classes for both species, the data for three successive month classes were used to estimate the parameters of a logistic curve for a month class which was a middle one. A logistic curve was fitted to express the growth of squid using a non-linear least square method, Marquardt's method (Akamine, 1986).

(8) Comparison of growth among the areas

There were insufficient number of samples for comparisons of growth among areas, because the samples were mainly collected from one of the major fishing grounds for each species (Fig. III-1). Based on the number of specimens by month class in the selected areas, the comparisons were carried out for the major month classes observed in the selected area. The areas for comparison were selected mainly on the geographical unit.

As for *N. gouldi*, the comparison was done in April-

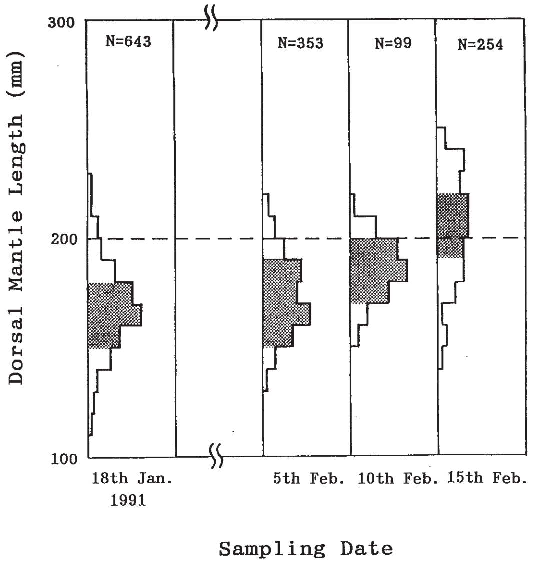


Fig. III-4. Length compositions of *N. sloanii* for each five-day period around the date on which each statolith sample was collected in January-February 1991. The shaded area shows the length range of specimens from which statoliths were extracted for the validation study.

June classes between the waters off the west coast of the North Island and the waters off the west coast of the South Island. The total number of specimens from the South Island was 127, and the number of the corresponding specimens from the North Island was 136.

As for *N. sloanii*, the comparison was done in July-August classes between the Canterbury Bight and the Snares Shelf, and in April-June classes between the Auckland Island and the Snares Shelves. The number of selected specimens from the Canterbury Bight was 54, and the number of the corresponding specimens from the Snares Shelf was 492. The number of specimens from the Auckland Island Shelf was only 21, and the number of the specimens from the Snares Shelf was 213.

(9) Akaike's Information Criterion (AIC)

Akaike's Information Criterion (AIC) was utilized as a criterion in the selection of models for the relationships between statolith radius and mantle length, and for the examination of difference in logistic growth between sexes, between month classes, and between the areas.

Five functional models were constructed for relationships between statolith radius and mantle length, but there is no useful conventional statistical criteria for the selection of the optimal model among the different type of models. In this regard, AIC is a useful criteria for comparison of fitness among the different type of the models (Sakamoto *et al.*, 1986). AIC for each model is given as follows,

$$AIC = N \cdot \ln(2\pi \cdot SS/N) + N + 2 \cdot NP$$

where N : number of specimens
ln : natural logarithm
SS : sum of squares
NP : number of parameters

It is known that the model with the lowest AIC gives the best selection (Sakamoto *et al.*, 1986).

Because the parameters of the logistic curves were estimated by a non-linear method, it is difficult to apply conventional statistical methods such as covariance analysis. The two models, sex (month class or area)-separated and sex (month class or area)-combined ones, were constructed for the logistic growth. Based on the values of AIC, the optimal model was selected.

The AIC for each model is expressed in equations as follows:

For the combined model, the equation is the same as one mentioned above.

For separated model,

$$AIC = N_1 \cdot \ln(2\pi \cdot SS_1/N_1) + N_1 + 2 \cdot NP + N_2 \cdot \ln(2\pi \cdot SS2/N_2) + N_2 + 2 \cdot NP$$

where subscripts refer to variables for male and female (month classes or areas), respectively.

2. Results

(1) Validation of daily increment formation of *N. sloanii* on the Snares Shelf

In sequential length composition, a gradual progression was observed in the modes from 160 mm DML on 18th January to 210 mm DML on 15th February (Fig. III-4). This progression suggested that all the samples were derived from the same cohort.

There was a linear relationship between the number of increments for these specimens and the sampling date (Fig. III-5). The equation for the regression of the number of increments on sampling date was;

$$Y = 1.1\,X + 149 \quad (r=0.6,\ n=97)$$

where Y = the number of increments observed in the statoliths,
X = catch date expressed as the number of days since 1st January 1989,
r = correlation coefficient, and
n = number of individuals observed.

Analysis of variance showed that this regression was significant at the 1% level (Table III-3) and the 95% confidence interval of the slope was 0.80 - 1.4. The estimated value of the slope was very close to 1, which means that the formation of each increment takes about one day.

Unfortunately daily increment formation for *N. gouldi* could not be validated, but it is assumed that an increment in the statolith of *N. gouldi* is formed daily in the following analysis.

Another problem related to the interpretation of the number of increments is determining the age (or stage) of initiation of increment formation. It is impossible to resolve this problem about these particular species until statoliths from reared larval squid can be obtained.

Therefore, it was assumed that increment formation begins at the time of hatching. Under this assumption, the number of increments signifies age in days after hatching.

(2) Hatching month

In total, 655 and 949 specimens of *N. gouldi* and *N. sloanii* were aged successfully. Following the validation, the day of hatching of each specimen can be estimated from age in days (number of increments) and the date of the sample. The number of specimens aged by hatching month are shown in Tables III-4 and 5. Hatching month ranged from January to December and the wide range of hatching month distribution suggested that spawning occurs throughout the year for both species, though the number of specimens and range of DML were highly variable among the hatching months. In other words, twelve month classes (hatching month groups) are observed for both species.

(3) Back-calculation

To analyze growth in the younger stages, back-calculation was applied. The relationships between statolith radius and DML for each species is shown in Fig. III-6 according to sex. Five regression curves were tried to fit this relationship by species using the sex-combined data and the AIC was calculated for each model (Table III-6). The AIC calculated for each model suggested that a power curve and cubical parabola were the optimal ones for *N. gouldi* and *N. sloanii*, respectively.

The power curves and cubical parabolas were estimated for the two models, i.e. sex-separated and sex-combined models, excluding the unsexed specimens. The AIC calculated for each model suggested that the sex-combined model was the optimal one for each species (Table III-7). The final equations were estimated using the sex-combined data including unsexed specimens. The resulting equations are as follows:

for *N. gouldi*

$$DML=0.000594.SR^{1.999} \qquad (n=445, R=0.92)$$

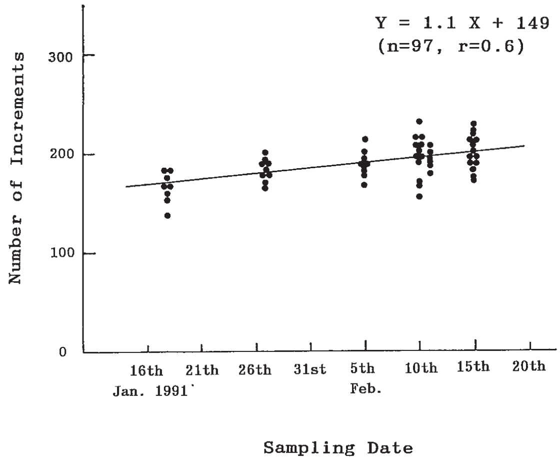


Fig. III-5. Relationship between the number of increments in the statoliths of *N. sloanii* and date on which the samples were collected in January-February 1991.

Table III-3. The result of analysis of variance for the relationship between number of increments and sampling date for *N. sloanii*.

Factor	SS	DF	MS	F-value	F-value at 1% level
Regression	10384.20	1	10384.20	55.5	6.91
Error	17784.50	95	187.21		
Total	28168.70	96			

for *N. sloanii*

$$DML=0.28-0.25.\,SR+0.00185.\,SR^{2}-0.00000114.SR^{3} \qquad (n=684, R=0.98)$$

where DML=dorsal mantle length in mm,
SR = statolith radius in μm,
n = number of specimens,
R = multiple correlation coefficient.

These equations were used for back-calculation of DML at the time when each monthly radius was formed. Because this equation expressed the relationship between 200 and 800 μm in statolith radius, application of back-calculation was limited in this range. Thus, the lower limit roughly corresponded to 90 days of age.

(4) Comparison of growth rate among month classes

The growth rates of DML (mm DML/day) by month class and sex for every 60-days period are shown in Fig III-7 for N. gouldi and in Fig. III-8 for *N. sloanii*. In these figures the austral summer and winter, when each month class spent the age range, are indicated.

In the 90-150 days old period, the growth rate ranged from 1.1 to 1.6 mm/day for *N. gouldi* and from 1.0 to 1.7 mm/day for *N. sloanii*. The difference in growth rate among month classes was wider in *N. sloanii* than it in *N. gouldi*. In this period the growth rates for females are faster than those for males for both species. There was no clear trend in the change of growth rate among the month classes for *N. gouldi*, but an increasing trend was observed from earlier to later month classes for *N. sloanii*. Namely the rates were lower in March, April, and May classes than those in September, October, and December classes. The former month classes spent their time in winter and latter ones spent in summer.

In the 120-180 days old period, the growth rate ranged from 1.4 to 1.9 mm/day for *N. gouldi* and from 1.3 to 2.1 mm/day for *N. sloanii*. The trend in the change of growth rate was similar in the 90-120 days old period for both species.

In the 150-210 days old period, the growth rate ranged from 1.4 to 2.2 mm/day for *N. gouldi* and from 1.6 to 2.3 mm/day for *N. sloanii*. The similar changing trend among the month classes was also observed very clearly for both species. The mean difference in growth rate among the two groups, one a group of month classes which spent the time in summer and the other spent in winter, is 0.3-0.5 mm/day for *N. gouldi* and 0.2-0.5 mm/day for *N. sloanii*.

In the other periods, there were insufficient data especially for the month classes which spent the time in winter, and the data were very variable as shown by

Table III-4. Number of specimens aged and back-calculated successfully by hatching month for *N. gouldi*.

	Male				**Female**			
Hatching Month	No. of Specimens Aged	Range of Age (day)	Range of Size (mm DML)	No. of Specimens Back-calculated	No. of Specimens Aged	Range of Age (day)	Range of Size (mm DML)	No. of Specimens Back-calculated
January	12	250-317	234-280	2	10	254-344	256-370	9
February	23	227-328	201-312	9	10	223-336	204-380	6
March	25	212-373	206-316	10	22	208-366	214-080	10
April	13	221-351	184-332	6	16	212-351	168-380	8
May	46	221-330	192-332	9	48	190-334	166-388	11
June	83	182-310	116-324	21	57	198-312	190-366	16
July	67	183-290	184-300	19	39	190-296	166-344	13
August	34	194-267	138-278	12	39	193-267	138-310	9
September	41	159-210	108-224	11	30	162-212	114-228	10
October	13	136-175	104-164	10	14	141-170	114-156	8
November	1	321-321	306-306	1	1	314-314	310-310	1
December	8	283-310	270-298	6	3	281-288	298-302	3
Total	366	136-373	104-332	116	289	141-366	114-388	104

Table III-5. Number of specimens aged and back-calculated successfully by hatching month for *N. sloanii*. Unsexed juveniles (32 specimens) are included in both sexes.

	Male				**Female**			
Hatching Month	No. of Specimens Aged	Range of Age (day)	Range of Size (mm DML)	No. of Specimens Back-calculated	No. of Specimens Aged	Range of Age (day)	Range of Size (mm DML)	No. of Specimens Back-calculated
January	4	284-309	322-350	2	4	194-306	158-398	4
February	5	253-273	304-348	3	2	252-277	310-336	2
March	8	233-359	268-314	4	4	241-374	225-406	4
April	35	100-360	23-346	10	32	100-349	23-384	11
May	47	88-330	15-325	16	39	88-330	15-386	12
June	43	200-319	180-348	18	38	202-315	174-376	18
July	105	172-299	112-334	25	101	171-296	130-340	16
August	155	142-281	98-342	21	185	148-287	118-370	22
September	52	155-261	140-312	22	44	136-261	140-318	15
October	17	150-226	140-300	11	24	162-230	108-322	9
November	2	191-194	230-272	2	0			0
December	1	235-235	220-220	0	2	318-320	356-386	2
Total	474	88-360	15-350	134	475	88-374	15-406	115

the wider confidence intervals. Therefore, a trend was not clear in these periods.

The mean growth rate increased rapidly from about 1.3 mm/day in the 90-150 days old period to about 1.9 mm/day in the 150-210 days old period. Then it decreased slightly in older periods, though the values were highly variable. In general, the rate in females were slightly greater than it in males and the difference in rate was about 0.1 mm/day for the periods younger than 210 days old. In older periods, the rates in females were generally greater than in males and the difference was about 0.2 mm/day.

(5) Growth by month class

The growth rates during some 60-days periods by month class suggested that there are some differences in growth rate among the month classes for both species. This difference in growth rate must affect the growth pattern of each month class. Therefore, the growth pattern of each month class by sex was analyzed and the logistic growth equation of each month class was estimated in this section.

The mean DML at each monthly radius was estimated starting from 90 days for each month class by sex using the relationship between statolith radius and DML estimated in section III-2-(3). The relationships between age and DML by month class are shown in Figs. III-9 and 10 for both species. The logistic curves were fitted to each month class (Figs. III-9 and 10) and the estimated parameters of logistic curve are shown in Table III-8.

Figs. III-9 and 10 indicate that the size at age estimated by the two methods, counting increments and back-calculation, are consistent with each other in each month class. Especially for March-May classes of *N. sloanii*, in which there were more than 20 juvenile

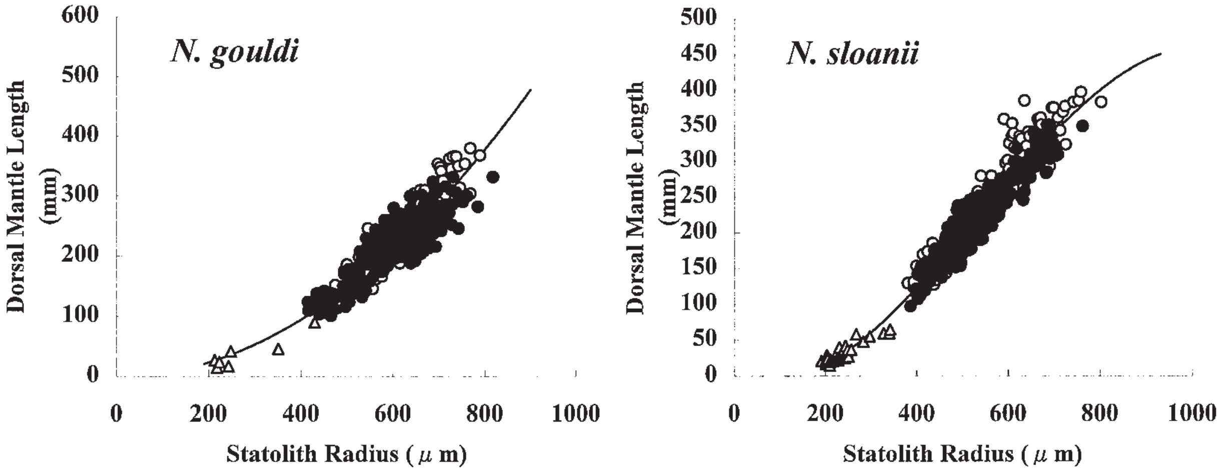


Fig. III-6. Relationship between statolith radius (SR) and dorsal mantle length (DML). Open and solid circles show female and male, respectively and triangles show unsexed specimens. Solid curve shows the final curve for sex combined model. Top figure is for *N. gouldi* and final curve is $DML=0.000594.SR^{1.999}$. Bottom figure for *N. sloanii* and final curve is $DML=0.28-0.255.SR+0.00185.SR^2-0.000114.SR^3$.

specimens whose statoliths were used for ageing, the mean DMLs estimated by back-calculation were closely consistent with the mean DMLs derived from counting increments.

The difference in growth between sexes is clear in most month classes for both species. The difference in DML at age was very little in younger stage than about 200 days old except for some month classes (October and November classes of *N. gouldi*, and November, December and January classes of *N. sloanii*) in which there were insufficient number of specimens, especially for the stages older than about 200 days old. The difference increased gradually from about 200 days old and peaked at the oldest age. The differences between sexes at 300 days old were calculated from the estimated curves by month class. The differences between sexes at 300 days old ranged from 35 to 53 mm for *N. gouldi* and from 20 to 40 mm for *N. sloanii*. The mean difference in 300 days old was 41 mm for *N. gouldi* and 32 mm for *N. sloanii*.

Figs. III-11 and 12 show the differences in growth among the month classes. These figures compare the growth between February and August classes which express the month classes hatched in mid-summer and mid-winter in the southern hemisphere, and between November and May classes which express the month classes hatched in mid-spring and mid-autumn. The AIC values for these pairs were calculated by month class-combined and month class-separated models and the results are shown in Table III-9. The resultant AIC values suggested that the month class-separated model was optimal for each pair, except for the pair of

Table III-6. *AIC* values for the various models in the relationship between statolith radius (SR) and dorsal mantle length (DML). The number of specimens used are 498 and 684 in *N. gouldi* and *N. sloanii*, respectively. * indicated the minimum value of *AIC* for each species.

	N. gouldi	***N. sloanii***
$DML=a+b.SR+c.SR^2$	4637.7	6028.4
$DML=a+b.SR+c.SR^2+d.SR^3$	4619.9	**5731.5***
$DML=a+b.SR+c.SR^2+d.SR^3+e.SR^4$	4709.5	5852.9
$DML=a+b.SR+c.SR^2+d.SR^3+e.SR^4+f.SR^5$	4074.4	6406.5
$DML=a.SR^b$	**4070.2***	6474.5

Table III-7. *AIC* values for the sex-separated and sex-combined models in relationship between statolith radius (SR) and dorsal mantle length (DML). The regression function for each species was selected by the *AIC* values in Table III-7.

N. gouldi		Number of Specimens	AIC
Sex-Separated		441	**3750.9**
	Male	251	(2166.7)
	Female	190	(1584.2)
Sex-Combined		441	**3644.3**

N. sloanii		Number of Specimens	AIC
Sex-Separated		606	**5557.1**
	Male	300	(2696.3)
	Female	306	(2863.8)
Sex-Combined		606	**5542.1**

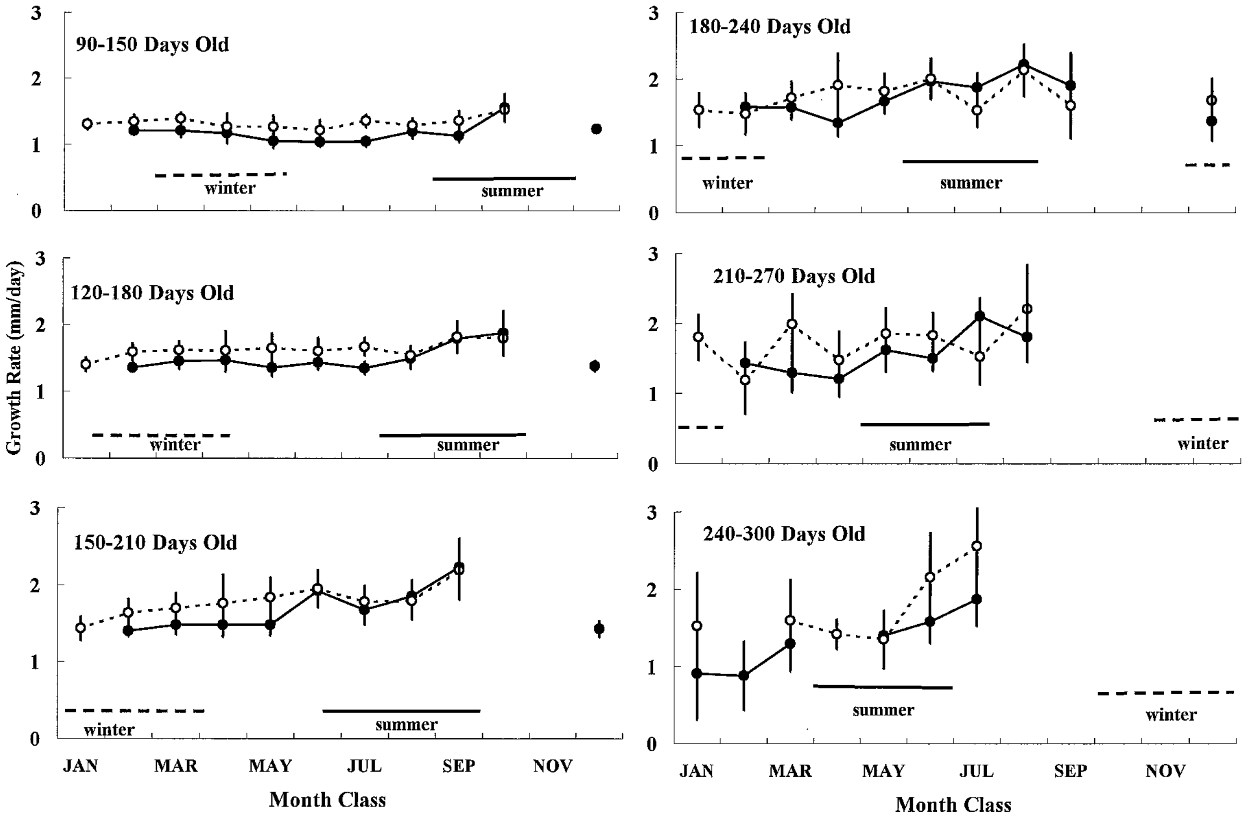


Fig. III-7. The growth rate of DMLs (mm/day) in every 60-days period by month class of *N. gouldi*. Solid and open circles show male and female, respectively. Vertical solid lines indicate 95% confidence intervals of growth rate. Summer (January to March) and winter (July to September) shown in each figure indicate the season when each month class spent the age period.

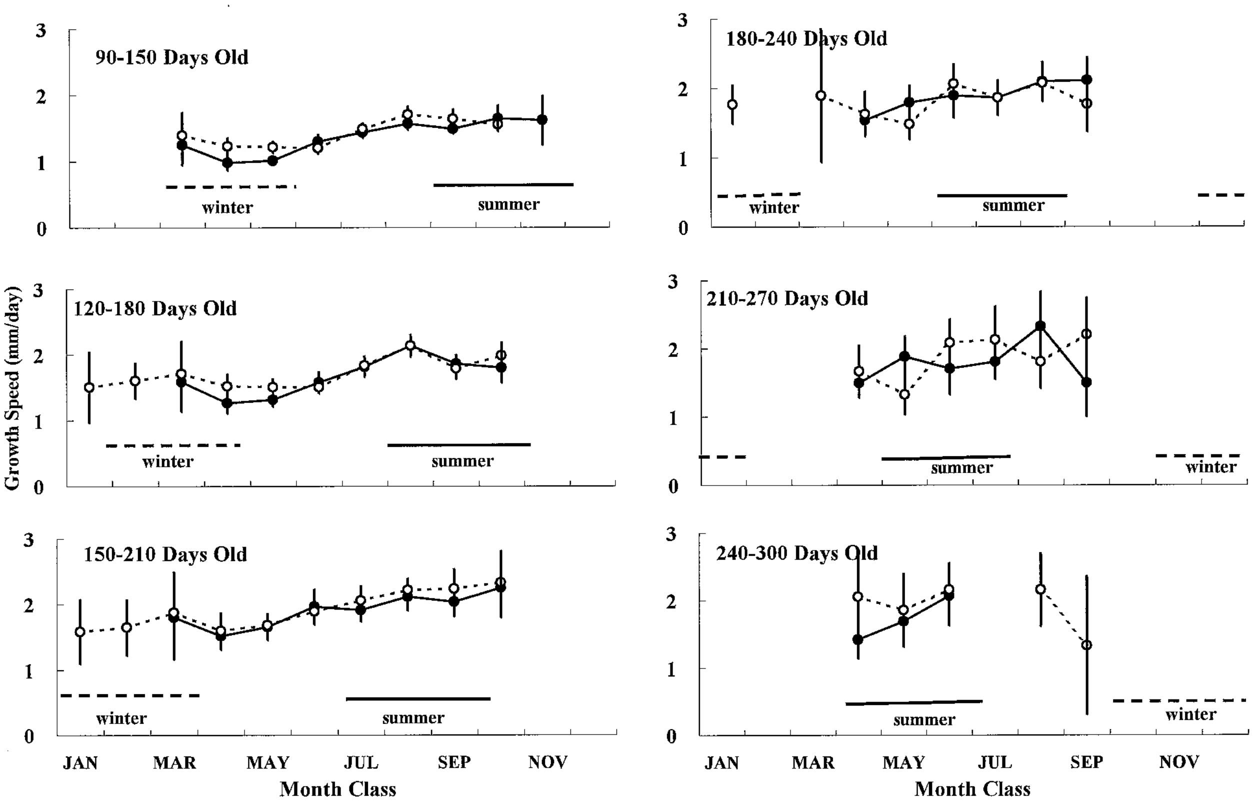


Fig. III-8. The growth rate of DMLs (mm/day) in every 60-days period by month class of *N. sloanii*. Solid and open circles show male and female, respectively. Vertical solid line indicates 95% confidence interval of growth rate. Summer (January to March) and winter (July to September) shown in each figure indicate the season when each month class spent the age period.

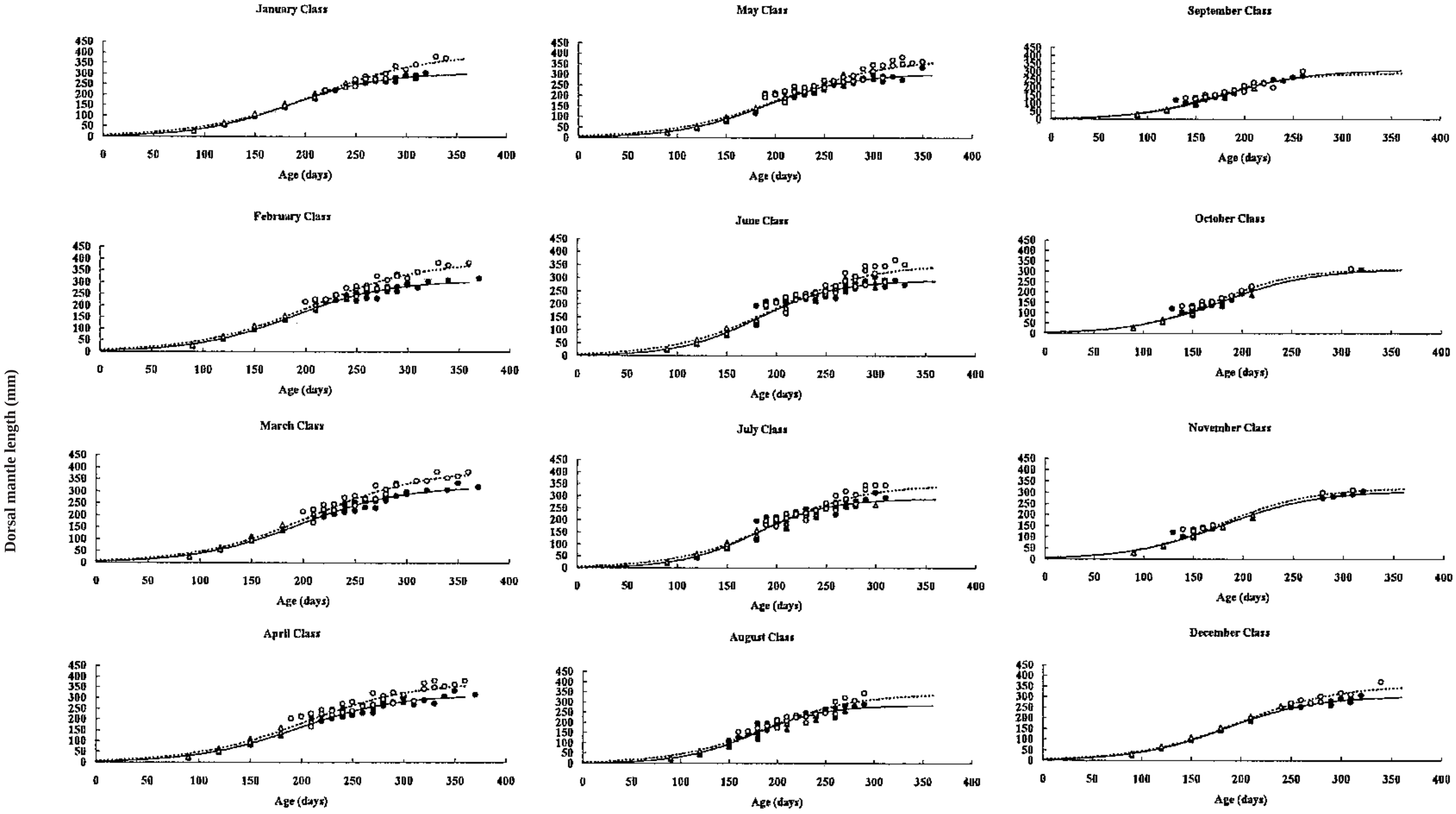


Fig. III-9. Relationship between age and dorsal mantle length for each month class of *N. gouldi*. Solid triangle and circle show male and open triangle and circle show female. Triangles show the means by back-calculation and circles show the mean by counting increments. Solid and dotted curves show the estimated logistic curves for male and female, respectively.

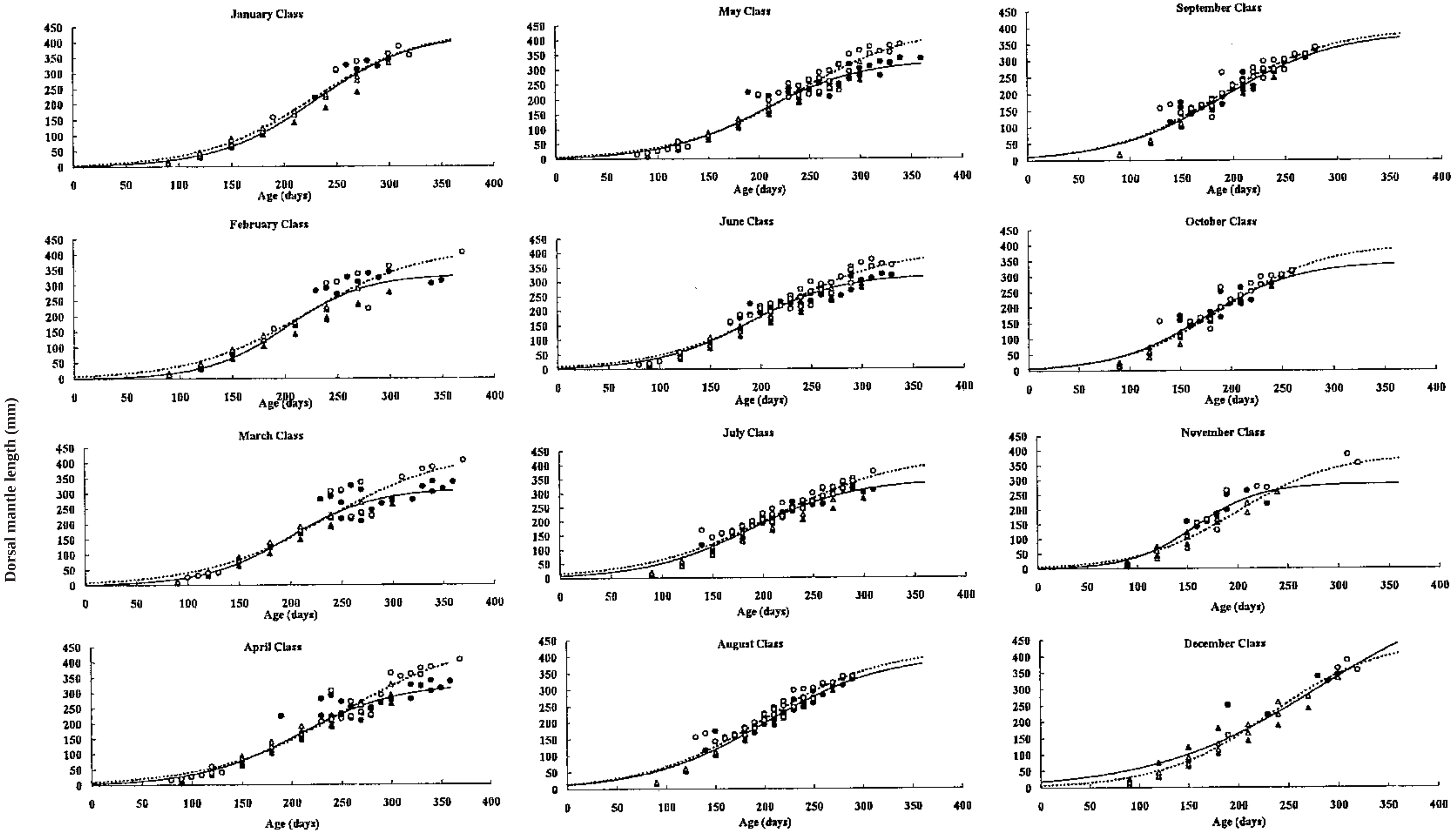


Fig. III-10. Relationship between age and dorsal mantle length for each month class of *N. sloanii*. Solid triangle and circle show male and open triangle and circle show female. Triangles show the means by back-calculation and circles show the mean by counting increments. Solid and dotted curves show the estimated logistic curves for male and female, respectively.

Table III-8. Estimated parameters of logistic curve for each month class.

N. gouldi						
Month Class	**Male**			**Female**		
	L infinity	K	T_0	L infinity	K	T_0
January	303.2	0.0224	185.3	395.8	0.0178	211.7
February	307.7	0.0216	188.6	389.5	0.0185	205.7
March	322.8	0.0202	196.7	390.8	0.0184	208.1
April	315.5	0.0207	196.3	376.4	0.0187	204.4
May	305.5	0.0227	190.0	374.2	0.0185	207.1
June	291.3	0.0254	181.8	352.1	0.0202	196.4
July	289.5	0.0271	178.5	349.2	0.0209	195.0
August	285.4	0.0272	175.2	342.0	0.0213	188.2
September	309.0	0.0232	178.6	289.9	0.0246	168.7
October	312.4	0.0221	180.4	312.1	0.0246	173.3
November	308.7	0.0214	180.0	321.6	0.0223	179.1
December	303.9	0.0223	184.9	355.7	0.0201	197.9

N. sloanii						
Month Class	**Male**			**Female**		
	L infinity	K	T_0	L infinity	K	T_0
January	427.3	0.0212	230.0	438.5	0.0192	228.6
February	333.3	0.0267	202.4	419.7	0.0184	221.8
March	315.5	0.0242	200.1	434.8	0.0168	235.2
April	327.2	0.0205	206.6	468.7	0.0156	250.3
May	331.8	0.0204	205.3	444.7	0.0170	237.5
June	325.2	0.0219	190.4	407.8	0.0177	214.5
July	348.0	0.0196	188.8	434.2	0.0157	211.0
August	403.6	0.0167	202.0	420.9	0.0167	199.9
September	385.1	0.0184	191.4	393.5	0.0188	188.6
October	345.4	0.0223	176.1	400.8	0.0205	193.9
November	287.8	0.0313	158.9	383.8	0.0209	200.1
December	601.4	0.0123	279.7	446.2	0.0183	232.8

February and August for female *N. gouldi* in which the AIC values for both models were very close to each other. These results suggested that the difference in the growth pattern between the month classes hatched in the opposite season, i.e. February class vs. August class, and November class vs. May class, may be significant.

The magnitude of the difference between month classes hatched in opposite seasons changed with age for all pairs of month classes for both species. The difference in DML at age increased gradually from 0 age and peaked at around 180 days old and then decreased gradually till about 270 days old. In several cases, the relationship in size between the pair of the month classes was reversed in ages older than about 270 days old. The magnitude of difference at 180 days old ranged 8 to 22 mm in *N. gouldi* and from 30 to 71 mm in *N. sloanii*. The magnitude of the difference in growth was smaller in *N. gouldi* than *N. sloanii*.

The relationship in size at age among the month classes may be closely related to the season in which the month classes spent time. The August class spends its life from 150 to 210 days old in the summer season. On the contrary the February class spends the same period in the winter season. The size of the August class at this period was larger than it of the February class for both species. For the period older than 210, the August class spends its life in autumn and winter, but the February class spends the period in spring and summer. The difference in size at age decreased in this period, and especially for *N. gouldi*, the relationship in size between February and August classes was reversed. Similar trends were also observed in the relationship between the November and May classes. These differences in growth trajectories among the month classes are consistent with the seasonal differences observed in the growth rate mentioned in section III-2-(4).

(6) Comparison on growth among the areas

The comparison of growth among the areas should be carried out, considering the sex and month class as mentioned in the previous sections. The comparisons were carried out between the specimens obtained from the west coasts of the North and south Islands for the pooled group of the April-June month classes in *N. gouldi* as mentioned in section III-1-(8). As for *N. sloanii*, the comparisons were done between the samples from the Canterbury Bight and the Snare Shelf for pooled group of July and August classes, and between the samples from the Auckland Island Shelf and the Snares Shelf for the pooled group of April and May classes.

The relationship between age and DML by areas and

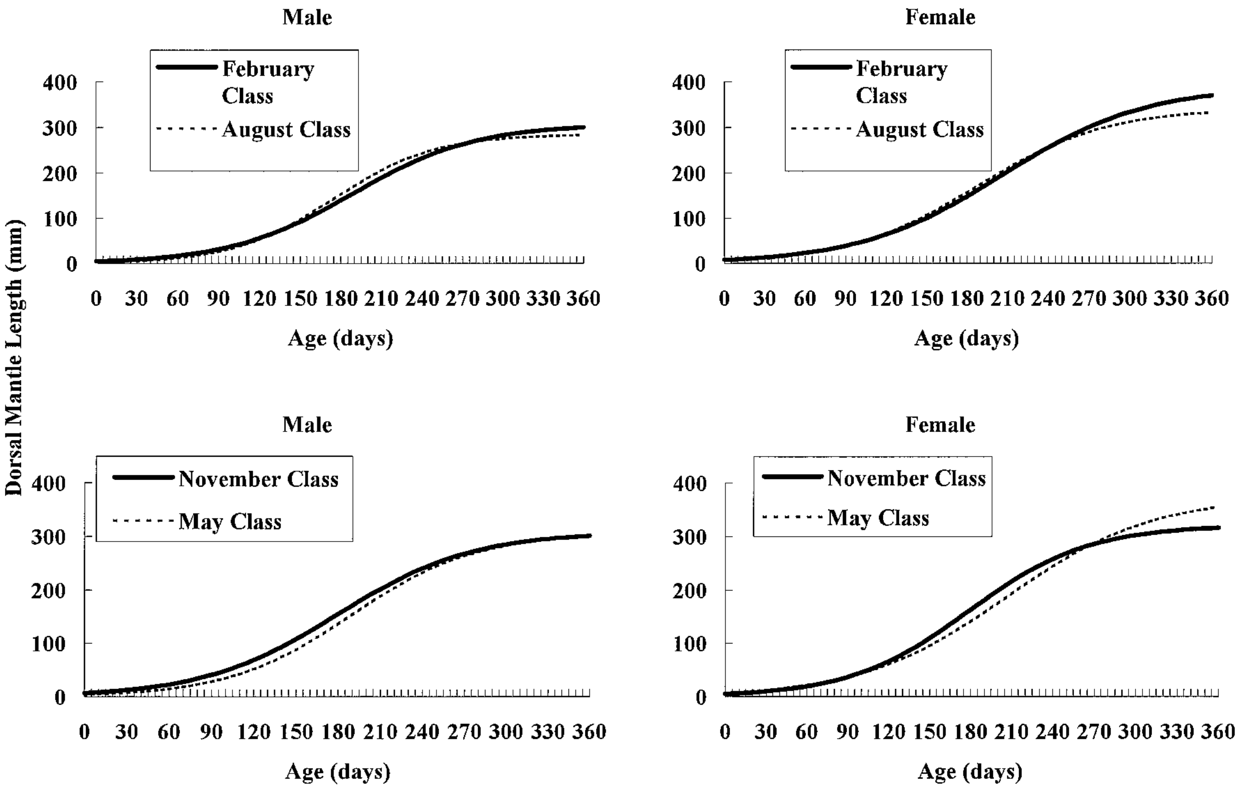


Fig. III-11. Comparisons of growth trajectories between the month classes which represent the month classes hatched in the opposite seasons for *N. gouldi*.

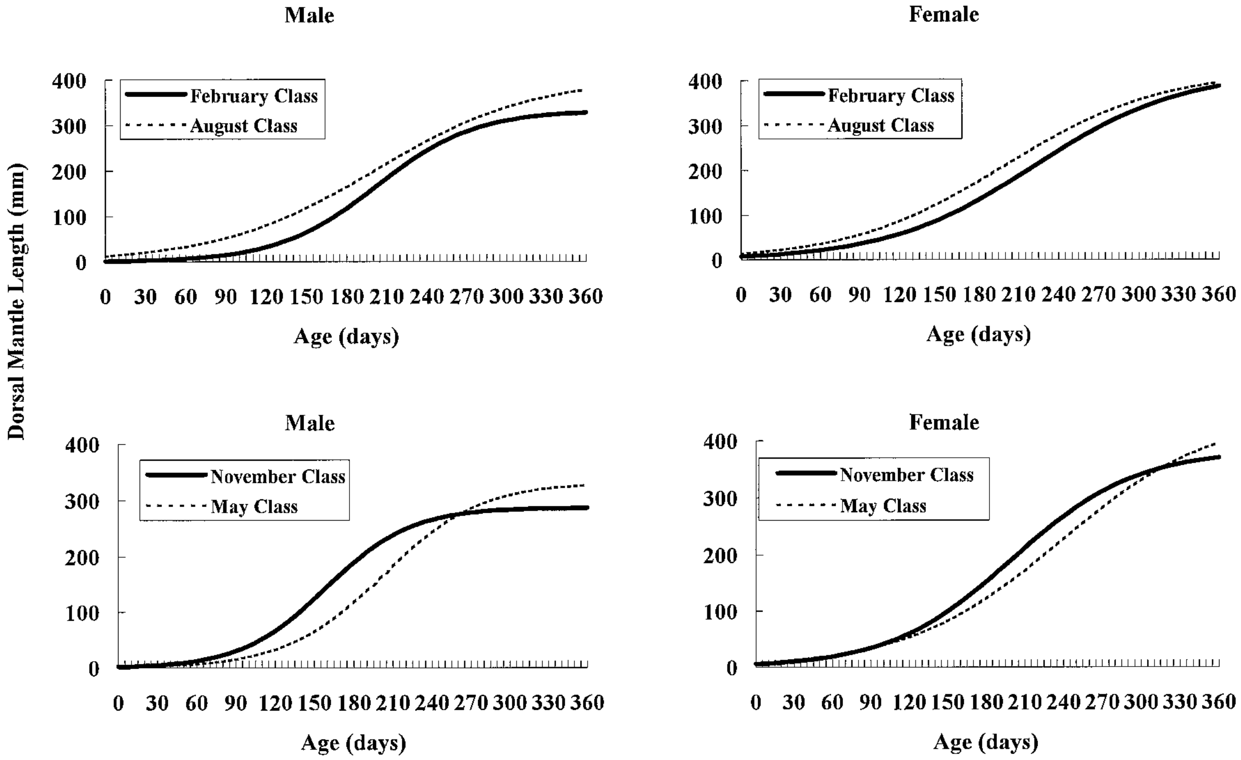


Fig. III-12. Comparisons of growth trajectories between the month classes which represent the month classes hatched in the opposite seasons for *N. sloanii*.

Table III-9. *AIC* values for the month class-separated and combined models in logistic growth curve equation.

February and August Classes		Model	
		Separated	Combined
Species	Sex	*AIC*	*AIC*
N. gouldi	Male	2077.0	2086.6
	Female	2003.2	2002.0
N. sloanii	Male	1872.6	1916.7
	Female	1695.0	1727.4

May and November Classes		Model	
		Separated	Combined
Species	Sex	*AIC*	*AIC*
N. gouldi	Male	1906.5	1912.8
	Female	2063.1	2075.2
N. sloanii	Male	1736.4	1770.0
	Female	1816.3	1831.0

sexes for *N. gouldi* are shown in Fig. III-13. Using the ageing data derived from both counting increments and back-calculation, the AICs for the two models, area-separated and area-combined models in logistic growth curve, were estimated for *N. gouldi*. The resultant AIC values are shown in Table III-10. The back-calculated DMLs at age were very similar among the samples from the North and South Islands, though most of the specimens from the South Island were larger than those from the North Island. As for the specimens, whose DMLs overlapped each other, the DMLs at age were similar to each other, though the range of DMLs overlapped was very narrow. The resultant AIC values suggested that the area-combined models for both sexes are optimal. These results suggested that there was no clear difference in the relationship between age and DML for April-June month classes between the waters off west coasts of the North and South Islands.

The number of *N. sloanii*'s samples obtained from the Canterbury Bight and from the Auckland Island Shelf were insufficient for the estimation of a growth equation. Therefore, the comparison between the Canterbury Bight and the Snares Shelf was done using the DMLs at age estimated from counting increments, because the DMLs were well overlapped between the areas (Fig. III-14). On the contrary, few DMLs at ages were overlapped between the samples from the Snares Shelf and the Auckland Island Shelf. Then the data from back-calculation were used for the comparison (Fig. III-15).

Fig. III-14 shows the relationship between DML and age for the Canterbury Bight and the Snares Shelf by sex. The mean DML values at each 10-days interval were very close to each other between the samples from the Canterbury Bight and the Snares Shelf. Namely, the mean values for the samples from the Canterbury Bight were located in the 95% confidence intervals of the means for the samples fro the Snares Shelf. Furthermore, the DML values at age for the samples fro the Canterbury Bight were larger than those from the Snares Shelf in some age intervals, but in the other age, the relationship became contrary for both sexes, especially for females. This result suggested that there was no clear difference in growth for July and August classes during 150-200 days old between the Canterbury Bight and the Snares Shelf.

Fig. III-15 shows the relationship between back-calculated DML and age of *N. sloanii* for the Snares and the Auckland Island Shelves by sex. For males, the back-calculated DMLs at age were very close to each other between the areas, but for females, the DMLs at ages were larger in the Auckland Island Shelf than those in the Snares Shelf and the difference became consistently larger with age. The back-calculated DML values at age were obtained from only 14 and 6 specimens for male and female, respectively. The mean DML values at each age interval were obtained from the same specimens, then it is probable that there may be some bias in the relationship between back-calculated DML and age for the samples from the Auckland Island Shelf mainly due to the insufficient number of samples.

(7) Comparison between the two species

Fig. III-16 shows comparison of the growth patterns between the two species by month classes which represent the four seasons. For the February class which represents the month classes hatched in austral summer, DML at age of male *N. gouldi* was larger than *N. sloanii* in the ages younger than about 220 days old, but in older ages DML at age of male *N. sloanii* became larger. For female February class, DML at age of *N. gouldi* was larger than *N. sloanii* throughout the range of age observed.

For the August class which represents the month classes hatched in austral winter, DMLs at age of male and female *N. sloanii* were larger than *N. gouldi* throughout the range of age observed. For November and May classes which represent the month classes hatched in austral spring and autumn, respectively, the relationship of DML at age between *N. gouldi* and *N. sloanii* were variable with age and sexes.

Although the relationships in growth pattern between the two species were different among the month classes, there was no large difference in DML at age between the two species.

(8) Life span of *N. gouldi* and *N. sloanii*

Length composition data showed that the maximum length reaches nearly 400 mm DML for both species (Kawakami, 1976; Mattlin *et al*., 1985; Uozumi and Kuroiwa, 1990). In this study the ages of the oldest specimens were 373 and 374 days old for *N. gouldi* and *N. sloanii*, respectively and the corresponding lengths were 376 and 406 mm DML (Tables III-4 and 5). These values suggested the life span may not exceed one year. The results indicate that the life span of the two species may be about one year, though the number of larger specimens was not sufficient to estimate the exact life span.

3. Discussion

By comparing the increase in the number of increments in statoliths with the number of days elapsed between sampling dates, the periodicity of increment formation was validated under the

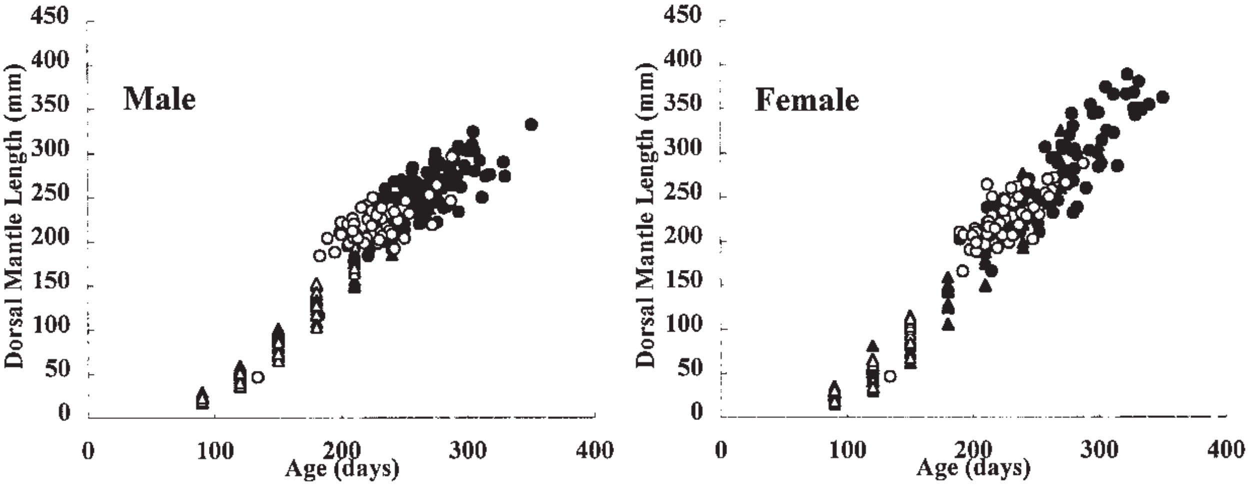


Fig. III-13. Comparisons of dorsal mantle length at age of April, May, and June classes between the specimens of *N. gouldi* obtained from the waters off west coast of North and South Islands. Open circles and triangles show the specimens from the North Island, and solid ones show the specimens from the South Island. Triangles show the data by back-calculation and circles show the data by counting increments.

Table III-10. *AIC* values for the area-separated and combined models in logistic growth curve equation for April-May classes of *N. gouldi*.

North and South		Model	
		Separated	Combined
Species	Sex	*AIC*	*AIC*
N. gouldi	Male	6387.2	6348.0
	Female	5398.0	5342.0

assumption that the samples were collected from the same cohort. The results indicate that the increments observed in the statoliths of *N. sloanii* are formed daily. In this study it was impossible to validate the periodicity of increment in *N. gouldi*, because there was no successive sample to analyze the relationship between sampling date and number of increments. Therefore, It was assumed that the increment in the statolith of *N. gouldi* forms daily as it in *N. sloanii*.

Daily formation of increments has been directly validated in other ommastrephid species (*Illex illecebrosus* and *Todarodes pacificus*) with a chemical marker (Dawe *et al.*, 1985; Nakamura and Sakurai, 1991). For other squid families, the daily formation of increment has been validated with a chemical marker in *Alloteuthis subulata* (Lipinski, 1986), *Abralia trigonura* (Bigelow, 1992), *Loligo chinensis* (Jackson, 1992), *Loliolus noctiluca* (Jackson, 1992), *Idiosepius pygmaeus* (Jackson, 1989a), and *Sepioteuthis lessoniana* (Jackson, 1989b). The relationship between the number of growth increments and the number of days elapsed since hatching in culture experiments indicates that the periodicity of formation is daily in the statolith of *Loligo opalescens* (Hixon and Villoch, 1983; Yang *et al.*, 1986). Furthermore, indirect validation such as comparison of growth estimates from statoliths with those available from mark-recapture studies was applied for *Photololigo edulis* (Nastukari *et al.*, 1988). The same method for validation as used in the present study was applied to *Illex argentinus* and the result showed daily formation of increments (Uozumi and Shiba, 1993). The periodicity of the increment in statoliths for all species mentioned here was validated to be daily. In fish, micro-increments are laid down daily in the otolith

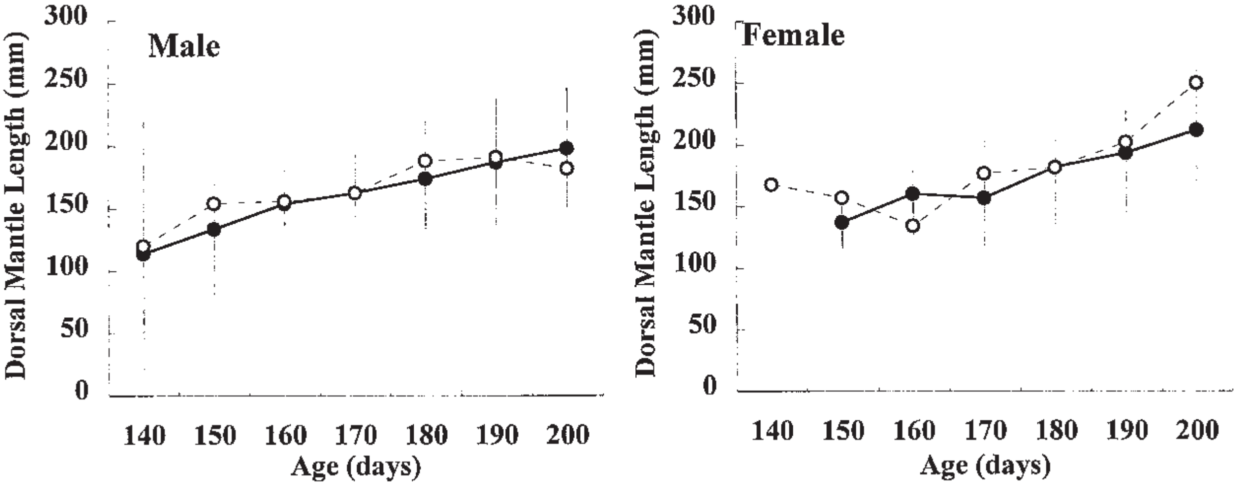


Fig. III-14. Comparisons of the mean dorsal mantle length by 10-days intervals for July and August classes of *N. sloanii* between the Canterbury Bight and the Snares Shelf. Open circles show the means of the specimens from the Canterbury Bight and solids ones show the means from the Snares Shelf. Vertical lines show the 95% confidence interval of the mean dorsal mantle length in the Snares Shelf.

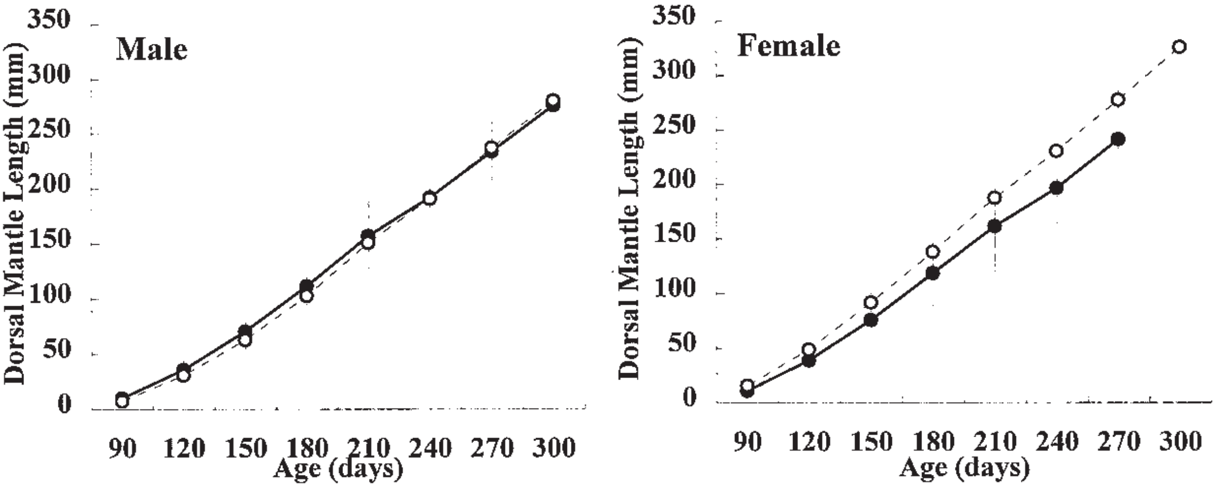


Fig. III-15. Comparison of the mean back-calculated dorsal mantle length for April and May classes of *N. sloanii* by 30-days intervals between the Snares and Auckland Island Shelves. Open circles show the means of the specimens from the Auckland Island Shelf and solid ones show the means from the Snares Shelf. Vertical lines show the 95% confidence interval of the mean back-calculated dorsal mantle length in the Snares Shelf.

(Brothers. *et al.*, 1976; Taubert and Coble, 1977). It has been observed that there is an endogenous circadian rhythm of increment formation in fish (Campana and Neilson, 1985).

Although there is some evidence that growth increments are formed daily in the squid statolith, the mechanism of the formation is not revealed yet. Yang *et al.* (1986) suggested that formation of increments is closely related to feeding. However, Dawe *et al.* (1985) showed that the formation of increments occurs without feeding in the absence of a tidal rhythm. Rodhouse and Hatfield (1990) pointed out that it therefore seems likely that, if growth increments are formed daily, there is a firmly entrained endogenous circadian rhythm of formation. These observations support the basic assumption for the daily formation of an increment for the present two species.

The period between formation of statocysts and hatching in *Todarodes pacificus* is short, about one day at 14-20° C (Hamabe, 1962). Immediate post-hatching paralarvae of *Illex illecebrosus* from the laboratory had only one or no increments in their statoliths (Balch *et al.*, 1988). These results suggest that the number of increments represents the number of days after hatching in ommastrephid squids. Therefore, there is a strong possibility that the number of increments signifies age in days after hatching in *N. gouldi* and *N. sloanii*.

Kawakami (1976) and Mattlin *et al.* (1985) suggested that the life span of *N. gouldi* and *N. sloanii* appeared to be about one year, based on length composition data. Based on the results of ageing in the present study, it concluded that the life span for both species is about one year. In ommastrephid squids, a one-year life span has been observed in many species, such as *Illex illecebrosus* (O'Dor, 1983), *Illex argentinus* (Hatanaka, 1986; Uozumi and Shiba, 1993), *Todarodes sagittatus* (Rosenberg *et al.*, 1981), *Todarodes pacificus* (Okutani, 1983), *Todarodes angolensis* (Villanueva, 1992), *Sthenoteuthis oualaniensis* (Arkhipkin and Bizikov, 1991) and *Sthenoteuthis pteropus* (Arkhipkin and Mikheev, 1992). Murata and Hayase (1993) suggested that there is a mixed life span representing a one-year group with good growth, and a two-year group with poor growth in female *Ommastrephes bartrami*. Nesis (1983) suggested that the life span of *Dosidicus gigas* may attain two years based on length composition data. Some *O. bartrami* grow up to more than 45 cm DML (Murata and Hayase, 1993) and *D. gigas* attains to 200-300 cm DML (Nesis, 1983). This evidence suggests that the life span of most ommastrephid squids is one-year, except for the species which attain more than 40 cm DML. The life span of the present two species is thus not exceptional in this respect.

Back-calculation was applied to compensate for the short sampling period (mainly from January to April) compared to squid life span. Campana and Neilson (1985) suggested the potential value of back-calculation using daily increments. The growth patterns of statolith length and mantle length were described by a smooth-monotonic curve in the present two species. This relationship suggested that daily increment width must reflect squid growth well. Applying back-calculation, it is easy to estimate the growth of smaller squid before recruitment to the fishery. There was little discrepancy between the results of back calculation and actual ageing (Figs. III-9 and 10).

In the present study the logistic curve was applied to the growth of the present two species, because this model is the most popular one for expressing growth which has one inflection point. The logistic curve expresses the growth of each month class very well through the range of ages observed. Figs. III-9 and 10 suggested that growth might not be asymptotic, though there was an insufficient number of samples larger than 300 mm ML. These results suggest that the parameter L infinity of the logistic model has little biological meaning.

There are clear seasonal differences in growth rate by 60-days periods (Figs. III-7 and 8) and in the trajectories of growth (Figs. III-9 and 10) in the two species and it was observed that the growth rate was

Fig. 16

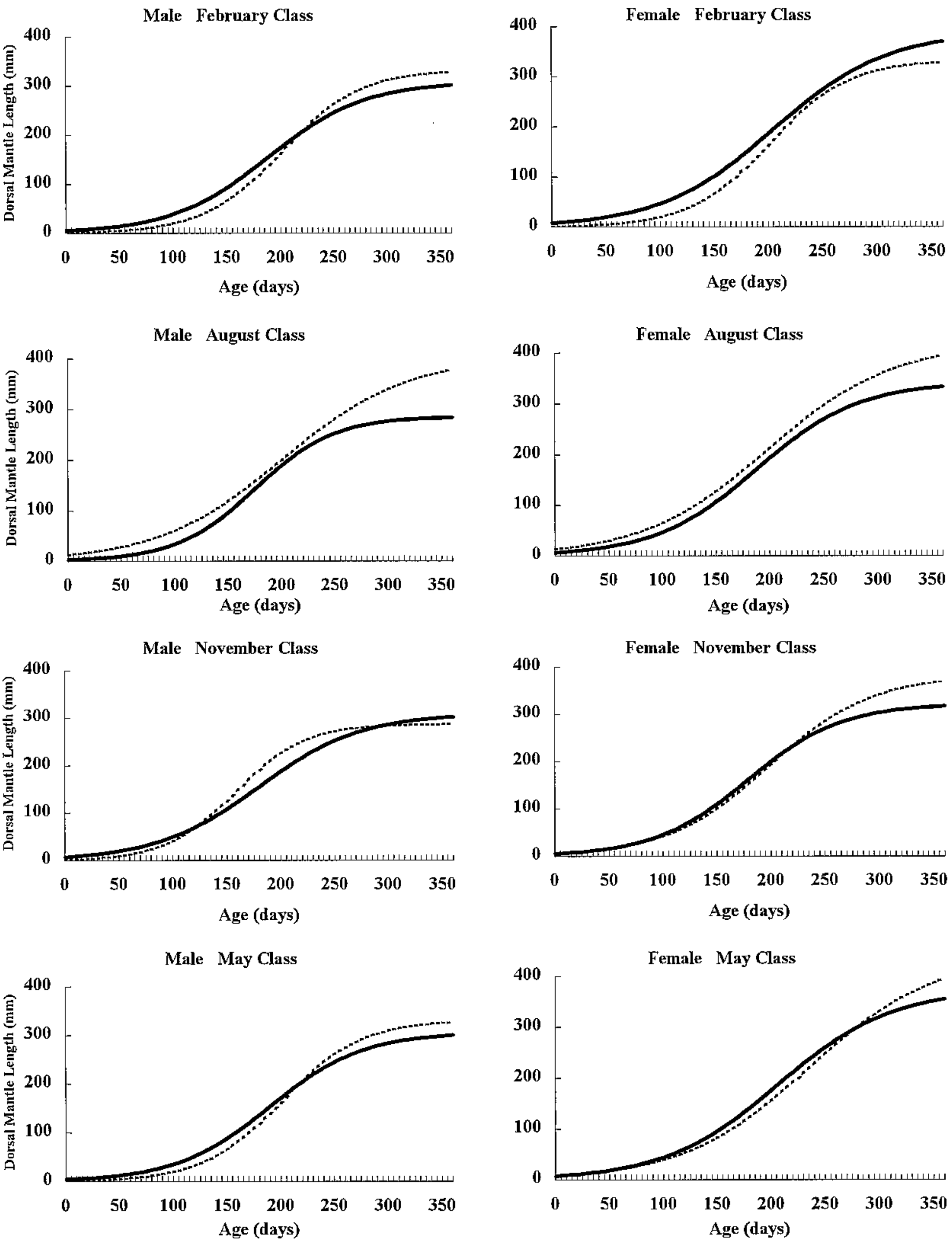


Fig. III-16. Comparisons of the growth trajectories for the month classes which represent the month classes hatched in the four seasons between *N. gouldi* and *N. sloanii*. Solid and broken lines show the growth trajectories of *N. gouldi* and *N. sloanii*, respectively

high in summer and low in winter for both species. These results suggest that growth is closely related to seasonal changes in the environment, such as temperature and food.

Water temperature in the area sampled shows clear seasonal changes. For offshore Shelf waters off west coast of North Island, temperature peaks at about 23°C at the surface and 16°C on bottom in January-March and reaches a minimum (about 14°C at surface and 12°C in bottom) in July (Robert and Paul, 1978). The

Table III-11. Water temperature in the Snares and Auckland Island Shelves.
*1:Kawahara and Tokusa, 1987, *2: Kono and Tokusa, 1986, *3: Uozumi *et al.*, 1987, *4: Annon. 1986, *5: Hatanaka *et al.*, 1989a.

		Feb.*1	Mar.*2	Apr.*3	Jul.*4	Aug.*4	Oct.*5
Snares Shelf	surface	12.2	12.3	11.0	11.0	10.5	10.5
	bottom	11.5	12.2	10.5	11.0	10.5	10.5
Auckland Is. Shlf	surface	10.3	11.2	9.5	8.5	8.5	8.5
	bottom	10.2	11.0	9.5	8.5	8.5	8.5

maximum difference in sea temperature between mid-summer and mid-winter is about 9°C at the surface and 4°C on bottom. Similar seasonal change in temperature has been observed in the Snares Shelf (Greig *et al.*, 1988). Temperature at surface nearshore waters peaks at about 18°C in February and is lowest (about 10°C) in August. The summer to winter range of long-term monthly mean temperature at the surface at the shore site on the Snares Shelf is about 8°C, which may be smaller in offshore waters.

Given an abundance of food, temperature is the main factor affecting the rate of growth at any given size and age prior to sexal maturity (Forsythe and Heukelem, 1987). A linear relationship between temperature and growth rate was observed in cultured *Loligo forbesi* (Forsythe and Hanlon, 1989). A mathematical simulation was carried out to show the effect of temperature on growth (Forsythe, 1993). This result indicated that accelerated growth of cohorts hatching in the warmer season allowed them to converge in size with cohorts hatched in cooler season in the older period. The present result was consistent with the result of this simulation.

The geographical differences in temperature between the waters off the west coast of North and South Islands was about 1°C in summer and in winter (Garners, 1961; Anon, 1986). Based on the various survey reports, the difference in temperature between the Snares and Auckland Island Shelves was about 2°C at the surface and 1°C on bottom throughout the year (Table III-11). There was no clear difference in temperature between the Canterbury Bight and Snares Shelf (Anon., 1986; Heath, 1975). It is probable that these geographical differences in temperature may affect the growth. However there was no clear difference in growth pattern observed among the areas, though there was not sufficient data to draw a firm conclusion (Figs. 13-15). One of the possible causes of this phenomenon may be that the differences in temperature between the areas were smaller than those between seasons (viz. 4-9°C between the season vs. 1-2°C between the areas).

The other main factor affecting growth is food. Without food there can be no growth. The quantity and quality of food will affect growth, and these must be changed seasonally and geographically. Unfortunately there are no available data on food organisms. Growth is a result of partitioning of dietary energy in an animal under prevailing environmental conditions. Therefore, it is very difficult to clarify the effect of temperature on growth directly from the field data. The growth of females in the Auckland Island Shelf was somewhat larger than in the Snares Shelf, though the temperature in the Auckland Island Shelf was lower than in the Snares. This discrepancy suggests that the factors other than temperature may affect growth.

Difference in growth among the seasonal groups is known to occur in *Todarodes pacificus* (Hamabe and Shimizu, 1966) and *Photololigo edulis* (Natsukari *et al.*, 1988). Modal analysis was applied to the first of these species, but the ageing by statolith was applied to the latter. In *T. pacificus*, the maximum DML is different among the summer, autumn, and winter groups (seasons in the northern hemisphere), the maximum DML of the autumn group is largest and followed by the winter group. In *P. edulis*, a warm season group (hatched in May- October) and a cool season one (hatched in November - April) are recognized. The growth rate of the warm season group is larger than the cool season group throughout the life span. The DML at one year old attains about 35 and 23 cm for male and female in warm season group, but it attains to only about 23 cm for both sexes in the cool season group. Natsukari *et al.* (1988) pointed out that the warm and cool season groups are not genetically discrete populations and Kubodera (1991) suggested that this phenomenon is one example to indicate the importance of environmental factors in the early life history for the growth through the life span. In the present two species, there is no clear difference in the maximum DML at the oldest ages observed among the month classes, though there is a clear difference in the growth trajectories among them. There is a clear discrepancy between the present result and Natsukari *et al.* (1988). It is suggested that the importance of environmental factors in the early life history may be different among taxonomic groups, such as between Myopsida and Oegopsida (*P. edulis* belongs to former sub-order and *Nototodarus* belongs to the latter), and/or other physiological characteristics such as maturation may play an important role in this discrepancy.

The length-based method has usually been applied to the study of squid growth (Uozumi and Kuroiwa, 1990; Hatanaka, 1986), on the assumption that the individuals which comprised the corresponding mode observed in the time series belong to the same cohort. However, it is difficult to validate this assumption without ageing studies. Uozumi and Shiba (1993) pointed out that this assumption may not hold in species which migrate with growth. Furthermore, there are difficulties in following the corresponding modes in a time series, especially for species such as the present two species which have a wide spawning season, several modes in the length composition, and a high growth rate. The ageing technique using statoliths makes it possible to validate the assumption of the length-based method and to easily follow the same cohort in a time series precisely even for species which have a complex stock structure.

IV. Sexual maturation

Sexual maturation of arrow squids has been analyzed based only on the relationship between some gonad somatic indices and size (DML) in the past, because there was no index of age. DML is one of the indices indicating somatic growth and the relationship between gonad somatic indices and DML indicates the sexual maturation with somatic growth. Age of each squid was estimated in Chapter III and the results showed that there is clear difference in growth between sexes, especially in age older than about 200 days old. In this Chapter, the process of sexual maturation was examined by the gonad somatic indices using ageing data. The general patterns of maturation with age are described for each sex of the two species.

1. Materials and methods

(1) Samples

The results of ageing, measurements, and observations on the same samples used in Chapter III were used in this Chapter. The four gonad maturity stages (immature, maturing, mature and spent) were used based on the appearance of the reproductive and accessory reproductive organs. Definitions of gonad maturation stages for *N. gouldi* and *N. sloanii* are given in Table II-1.

(2) Gonad somatic Index

The gonad somatic indices were calculated using the results of measurements for the specimens. The definition of each gonad somatic index is as follows,

$$\text{Testis Somatic Index (TSI)}=\frac{\text{Testis weight(g)}}{\text{Body Weight(g)}}\times 100$$

$$\text{Spermatophore sac Somatic Index (SSI)}=\frac{\text{Spermatophore sac weight(g)}}{\text{Body Weight(g)}}\times 100$$

$$\text{Ovary Somatic Index (OSI)}=\frac{\text{Ovary weight(g)}}{\text{Body Weight(g)}}\times 100$$

$$\text{Oviduct Somatic Index (ODSI)}=\frac{\text{Ovary weight(g)}}{\text{Body Weight(g)}}\times 100$$

$$\text{Nidamental Gland Length Index (NGLI)}=\frac{\text{Nidamental gland length(mm)}}{\text{DML(mm)}}\times 100$$

The Copulation Rate (CR) as a percentage for 10-day old intervals was calculated as the rate of number of copulated females to the total number of females observed for every 10-day interval.

CR denotes the accumulated rate of copulation activities, because signs of copulation in the buccal membrane remain after copulation. Therefore, the frequency of copulation activity at a particular age is shown by the differential coefficient in the copulation curve. To estimate the peak point of copulation activity, the logistic curve was fitted to the relationship between age and CR using Marquardt's method (Akamine, 1988). This estimation was only done for *N. gouldi*, because there were insufficient numbers of copulated female specimens of *N. sloanii*.

(3) Statistical analysis

Analysis of variance (ANOVA) was carried out in the comparisons on the maturation process between age and DML. In ANOVA, age and DML were treated as class variables and level of age was defined as 10-day interval and level of DML was defines as 10 mm interval. Generalized linear model (GLM) was applied for ANOVA. GLM procedure in SAS (release 6.10) was used in the present analysis.

2. Results

(1)Age and maturity stage

In *N. gouldi*, male of immature, maturing and mature stages comprised 37%, 17% and 46% of the total male samples, respectively. The females in each maturity stage comprised 74%, 7% and 20% of the total. In *N. sloanii*, 76% of the male specimens and 89% of female ones belonged to the immature stage. Only 11% of males and 4% of females belonged to the mature stage. No spent specimen of either species was found.

The proportions of each maturity stage in 10-day intervals by sex are shown in Fig. IV-1. All males younger than 170-180 days old were immature in both species and immature males were observed till 280-300 days old, though the proportion of immature males decreased clearly with age. Males in maturing stage were observed from 180-190 days old to 300-310 days old. Mature males were observed from around 200 days old for both species. The proportion in the mature stage increased constantly with age thereafter and attained to 100% at 310-320 days old.

All females younger than 190-200 days old were immature in both species and immature females were observed to 300-310 days old. The proportion of immature females deceased clearly with age as in males. Females in the maturing stage were observed from around 200 days old to 300-310 days old. Mature females were observed from 230-240 days old and the proportion of mature female increased with age. The proportion of mature females attained 100% at 320 days old for *N. gouldi*. Though the proportion of mature stage for female *N. sloanii* fluctuated mainly due to the insufficient number of samples, the trend of maturity stages appears to be similar to that of *N. gouldi*.

(2) Change of Testis Somatic Index (TSI) with age

Changes of TSI with age are shown in Fig. IV-2 for *N. gouldi* and *N. sloanii*. The value of TSI during the immature stage is low at around 0.5 for both species. There is no significant difference in the values of TSI between maturing and mature stages for either species, though the mean TSI in these stages are 1.5 for *N. gouldi* and 1.2 for *N. sloanii*. It was observed that some TSIs in the immature or maturing stages were higher than those in the mature stage for *N. sloanii*.

TSI of *N. gouldi* increased from around 200 days old and peaked at around 270 days old, then decreased gradually at older ages. TSI of *N. sloanii* increased also from around 200 days old, peaked at around 250 days old, then decreased gradually as in *N. gouldi* .

(3) Change of Spermatophore sac Somatic Index (SSI) with age

Changes of SSI with age are shown in Fig. IV-3. The mean increased clearly with the progress of maturity stage from 0.1-0.2 in the immature stage to 1.0-1.1 in the mature stage. These SSI changes are very similar for each species. SSI of *N. gouldi* began to increase at around 230 days old, peaked at 270 days old, then decreased gradually. The pattern of changes in SSI of *N. sloanii* is very similar to that in *N. gouldi*.

(4) Change of Ovary Somatic Index (OSI) with age

Changes of OSI with age is shown in Fig. IV-4. The mean OSI of immature and maturing females was 0.2 and 0.8-0.9, respectively for both species. The OSI in the mature stage was 3.4 for *N. gouldi* and 4.5 for *N. sloanii* and much higher than those in the immature and maturing stages. The OSI increased abruptly after 250 days old. In mature stage, OSI was highly variable and there was no clear trend of OSI with age. The OSI was discontinuous between immature/maturing and mature females in both species (Fig. IV-4), compared with the continuous changes in TSI (Fig. IV-2).

(5) Change of Oviduct Somatic Index (ODSI) with age

Changes of ODSI with age are shown in Fig. IV-5. The mean ODSI in the immature and maturing stages ranged from 0.1 to 0.3 for both species, but that in the mature stage was much higher than that in the immature and maturing stages. It increased from about 250 days old for both species, but was very variable in the mature stage.

(6) Change of Nidamental Gland Length Index (NGLI) with age

Changes of NGLI with age are shown in Fig. IV-6. The mean NGLI in the immature stage was 16.0 and 13.1 for *N. gouldi* and *N. sloanii*, respectively. The mean NGLI in the maturing stage was 21.9 and 22.3 for the two species. The mean values in the mature stage were 46.6 and 38.7 for the two species and were much higher than those in the immature and maturing stages. This index was more or less constant in each maturity stage for both species, but there are clear differences among the maturity stages, especially between the immature/maturing stages and mature stage, though there were insufficient numbers of mature specimens of *N. sloanii*.

(7) Change of Copulation Rate (CR) with age

Changes of CR with age are shown in Fig. IV-7. The youngest age when copulation was observed was 240 days old for *N. gouldi* and 190 days old for *N. sloanii*. CR increased consistently with age after 240 days old and attained 50 % at around 280 days old in *N. gouldi*. CR of *N. gouldi* attained 100% at 310 days old. Although CR of *N. sloanii* fluctuated largely, due to the insufficient number of specimens older than 240 days old, CR might begin to increase after around 230 days old.

The estimated parameters of the logistic curve, which model the relationship between age and CR, are as follows,

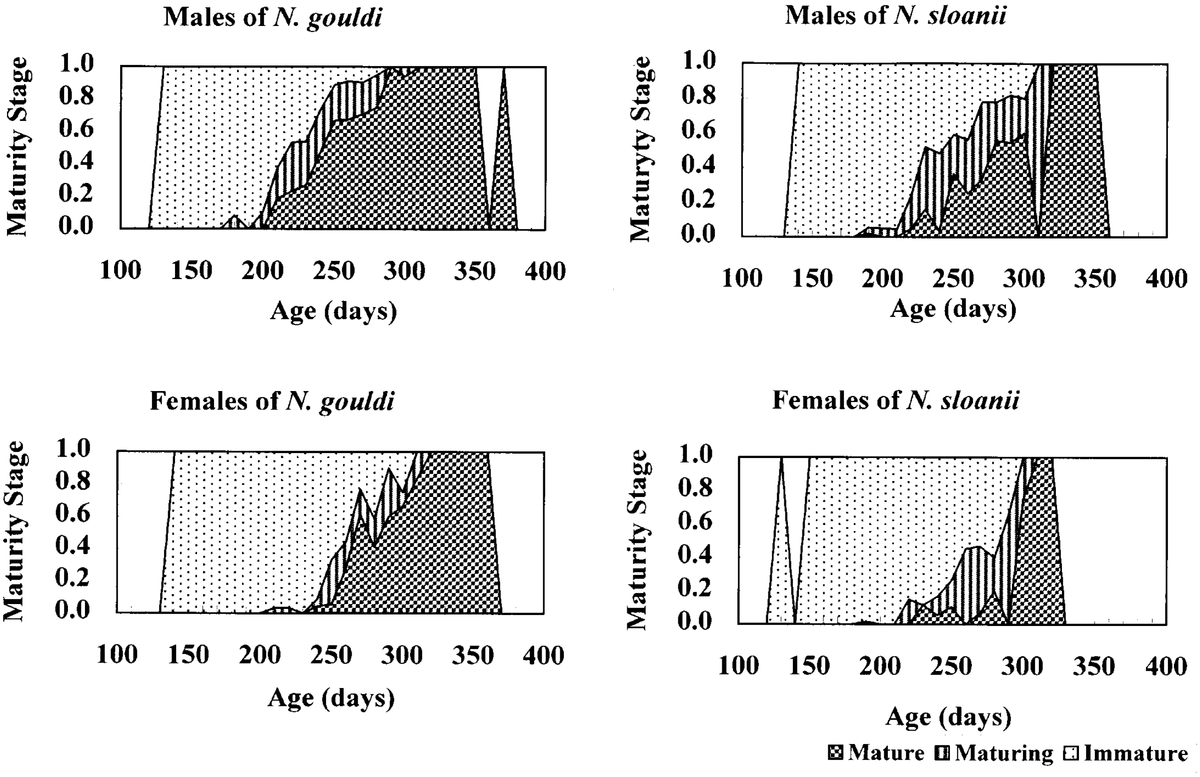


Fig. IV-1. Maturity stages of *N. gouldi* and *N. sloanii* by age in days. Definition of maturity stages are referred to Table II-1.

CR infinity = 1.00, K = 0.07, T_0 = 278.7

T_0 may indicate the age when copulation activity attains a maximum. The present results show that copulation activity in *N. gouldi* may peak at around 279 days old.

(8) Comparisons of the changes among the gonad somatic indices

The changes of mean values of gonad somatic indices with age are summarized in Figs. IV-8 and 9, which shows the ratio of the mean value of each index in every 10-day interval to the maximum value among the means of 10-day intervals.

The rapid increase in TSI started at around 200 days old and reached the maximum at around 260 days old. The rapid increase of SSI started more or less one month later than the rapid development of testis and reached the maximum at around 300 days old in *N. gouldi*. The start of rapid increase of SSI in *N. sloanii* was around 250 days old and later than in *N. gouldi*.

The rapid increase of OSI started at around 260 days old in *N. gouldi* and at around 290 days old in *N. sloanii* and reached the maximum at around 300 days old for both species. The changes of ODSI and NGLI coincided very clearly with the change of OSI in both species. Furthermore, the change of CR also coincided with the above indices.

(9) Comparison of the maturation process with age and DML

Results of ANOVA for gonad somatic indices with age and with DML are shown in Tables IV-1 and 2. In all gonad somatic indices in *N. gouldi*, the effect of DML was highly significant, but the effect of age was not significant in all indices except for ODSI. On the contrary, the effect of age in *N. sloanii* was highly significant. These results suggested that the gonad somatic indices were more closely related with DML than with age in *N. gouldi*, but in *N. sloanii*, the indices were closely related with both DML and age.

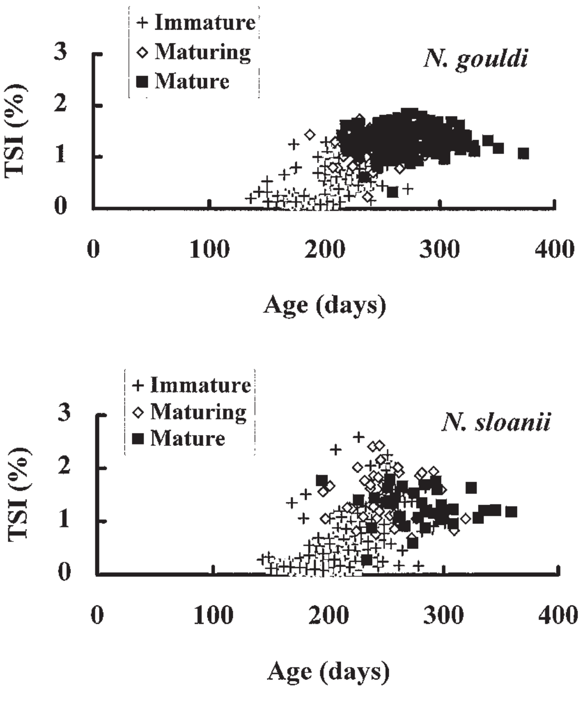


Fig. IV-2. Testis Somatic Index (TSI) of *N. gouldi* and *N. sloanii* by age.

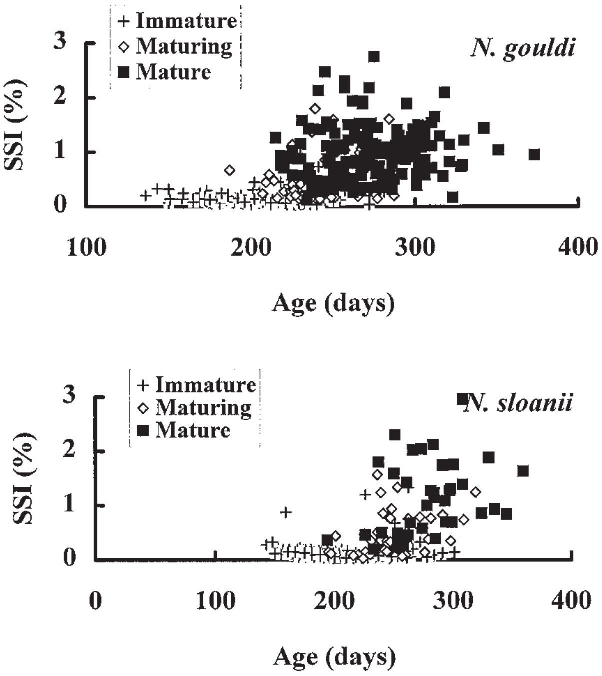


Fig. IV-3. Spermatophore sac Somatic Index (SSI) of *N. gouldi* and *N. sloanii* by age.

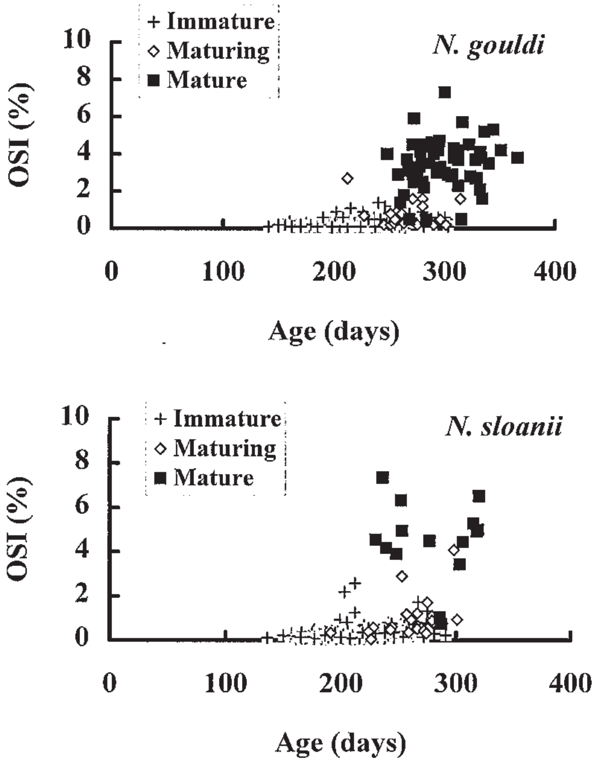


Fig. IV-4. Ovary Somatic Index (OSI) of *N. gouldi* and *N. sloanii* by age.

3. Discussions

SSI indicates the accumulation process of spermatophores in the spermatophoric sac. For *N. gouldi* and *N. sloanii* in the present study, the accumulation of spermatophores may start more or less one month later than the start of rapid testis development and the spermatophores begin to be produced after the testis develops to about 1% of body weight. The maturation patterns in males are very similar between the two species in the present study.

Based on the present results, it is clear that in both species, the rapid development of ovary, oviduct, and Nidamental gland starts almost simultaneously, though it is unknown which one promotes maturation in females. The development of ovary may be so rapid between immature/maturing stages and mature stage that it is difficult to observe the intermediate stage of the ovary. As the definition of maturity stage in the present study (Table II-1), ovulation occurs between maturing and mature stages. These results also suggest that ovulation may occur just after the start of the rapid development of ovary. The Nidamental gland develops very rapidly and there is also a discontinuity in the age/NGLI relationship between the immature/maturing stages and mature stage. This means that the changes of NGLI correspond very closely with the development of the ovary in the two species in the present study.

Amaratunga and Durward (1979) suggested that NGLI of *Illex illecebrosus* is one of the most useful indices of sexual maturation in females, because Nidamental gland length develops simultaneously with the development of ovary. As the present results suggest NGLI is very sensitive to the change in the situation of ovary and/or ovulation, NGLI is also one of the most useful tools to determine the maturity of *N. gouldi* and *N. sloanii*.

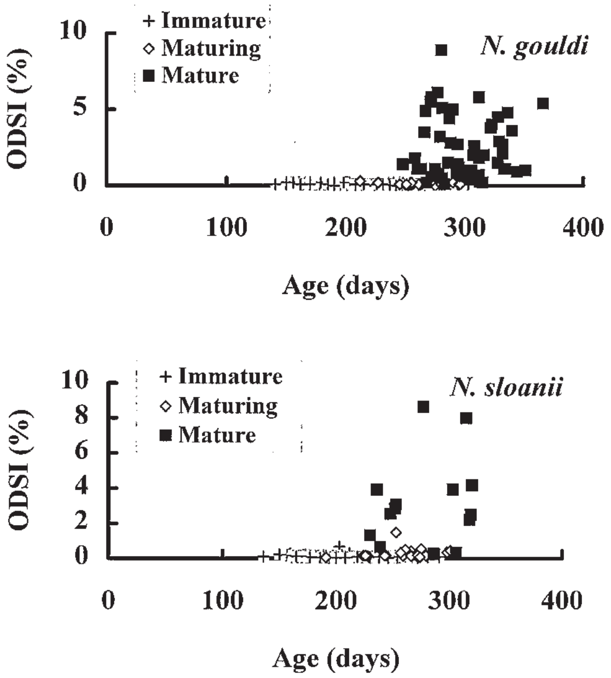


Fig. IV-5. Oviduct Somatic Index (ODSI) of *N. gouldi* and *N. sloanii* by age.

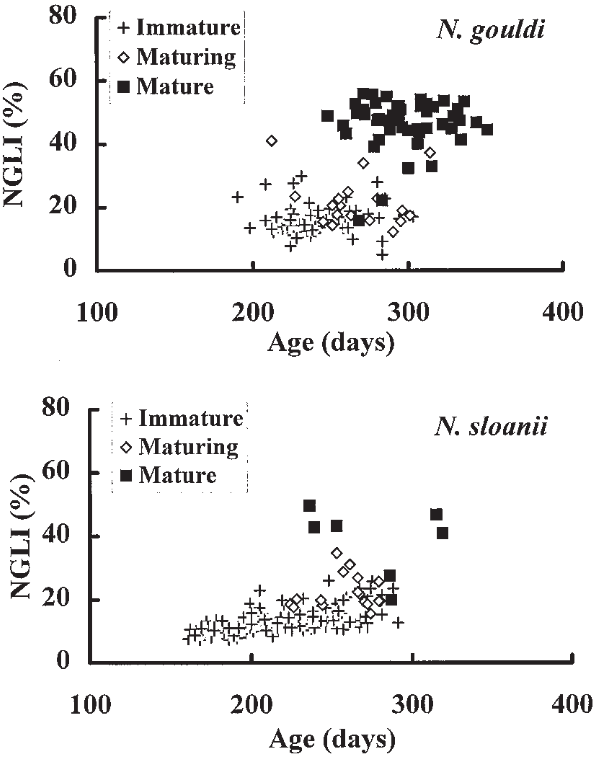


Fig. IV-6. Nidamental Gland Length Index (NGLI) of *N. gouldi* and *N. sloanii* by age.

In many cephalopods, males mate with immature females (Mangold, 1987). But, for the two species of *Nototodarus* in New Zealand waters, the peak of mating may coincide with the period of rapid maturation in females and the peak of TSI. This result suggests that the copulation occurs most frequently during the maturing and mature stages in females. The development of testis reached the maximum and the production of spermatophores also peak when females are at these stages.

There are some differences in maturation between the present two species, especially in females. The ovary and accessory organs develop rapidly, and copulation

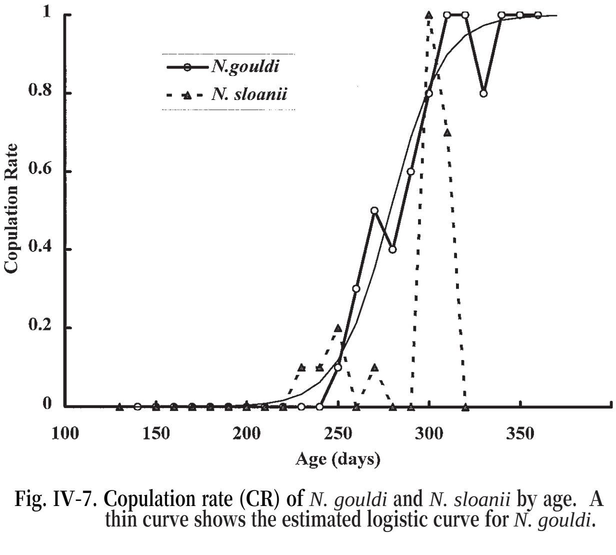


Fig. IV-7. Copulation rate (CR) of *N. gouldi* and *N. sloanii* by age. A thin curve shows the estimated logistic curve for *N. gouldi*.

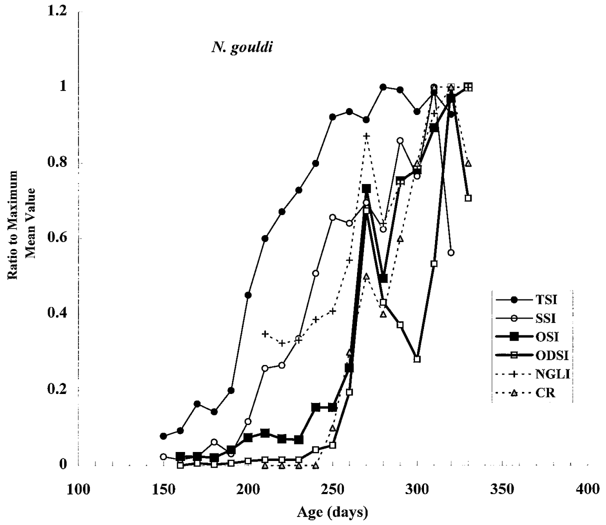


Fig. IV-8. Mean gonad somatic indices of *N. gouldi* by 10-day old intervals. The values of each index by interval are expressed in the rate to the maximum value of each index.

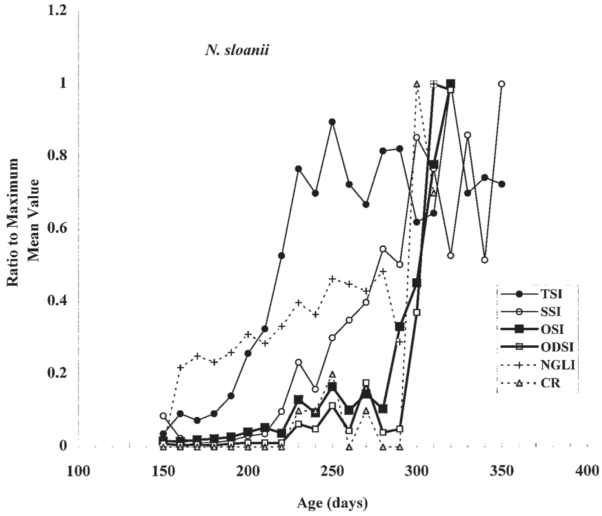


Fig. IV-9. Mean gonad somatic indices of *N. sloanii* by 10-day old intervals. The values of each index by interval are expressed in the rate to the maximum value of each index.

begins about 30-40 days earlier in *N. gouldi* than *N. sloanii*. Furthermore, the spermatophores start to accumulate earlier in *N. gouldi* than in *N. sloanii*. This means *N. gouldi* matures earlier than *N. sloanii*.

It is often observed in squid species such as *Todarodes pacificus* that males mature at a smaller size than females. Sexual maturation takes place in males 3-6 months earlier than in female *Todarodes pacificus* (Hamabe,1962). In the present two species a similar tendency was observed, namely, development of the testis started about 2-3 months earlier than the rapid development of ovary. Although there is no direct evidence to indicate when spawning occurs, it may occur within two months after copulation, considering the season of copulation (the peak of copulation) and the single year life span as shown in Chapter III.

Spent squid were not observed in the present study. One possible reason is that it is difficult to observe the spent condition as defined in this study and specimens in the spent condition were misidentified as the other

Table IV-1. Results of ANOVA for gonad somatic indices in *N. gouldi*. DML is a class variable and has 23 levels from 150 mm to 370 mm by 10 mm interval. Age is also a class variable and has 17 levels from 150 days to 330 days old by 10 days interval.**: significant at 99% level, *: significant at 95% level.

TSI

Source	Degree of Freedom	Sum of Square	Mean Square	F Value
Model	115	42.74	0.37	3.8**
Error	215	21.02	0.10	
Corrected Total	330	63.76		

Source	Degree of Freedom	Sum of Square	Mean Square	F Value
DML	18	8.75	0.49	4.97**
Age	21	1.19	0.06	0.57
DML*Age	76	5.84	0.08	0.79

SSI

Source	Degree of Freedom	Sum of Square	Mean Square	F Value
Model	115	57.64	0.50	2.66**
Error	215	40.50	0.19	
Corrected Total	330	97.14		

Source	Degree of Freedom	Sum of Square	Mean Square	F Value
DML	18	9.86	0.55	2.91**
Age	21	2.95	0.14	0.74
DML*Age	76	14.55	0.19	1.02

OSI

Source	Degree of Freedom	Sum of Square	Mean Square	F Value
Model	115	419.80	3.65	6.64**
Error	145	79.72	0.55	
Corrected Total	260	499.52		

Source	Degree of Freedom	Sum of Square	Mean Square	F Value
DML	22	94.55	4.30	7.82**
Age	19	7.57	0.40	0.73
DML*Age	74	61.98	0.84	1.52*

ODSI

Source	Degree of Freedom	Sum of Square	Mean Square	F Value
Model	115	264.50	3.17	8.64**
Error	145	53.22	0.37	
Corrected Total	260	417.72		

Source	Degree of Freedom	Sum of Square	Mean Square	F Value
DML	22	138.99	6.32	17.21**
Age	19	35.80	1.88	5.13**
DML*Age	74	82.90	1.12	3.05**

Table IV-2. Results of ANOVA for gonad somatic indices in *N. sloanii*. DML is a class variable and has 21 levels from 150 mm to 350 mm by 10 mm interval. Age is also a class variable and has 19 levels from 150 days to 350 days old by 10 days interval.**: significant at 99% level, *: significant at 95% level.

TSI

Source	Degree of Freedom	Sum of Square	Mean Square	F Value
Model	137	128.15	0.94	6.23**
Error	259	8.89	0.15	
Corrected Total	396	167.05		

Source	Degree of Freedom	Sum of Square	Mean Square	F Value
DML	20	15.99	0.80	5.32**
Age	21	3.38	0.40	2.66**
DML*Age	96	22.05	0.23	1.53*

SSI

Source	Degree of Freedom	Sum of Square	Mean Square	F Value
Model	137	61.10	0.47	11.61**
Error	259	10.44	0.04	
Corrected Total	396	74.54		

Source	Degree of Freedom	Sum of Square	Mean Square	F Value
DML	20	11.08	0.55	13.75**
Age	21	6.22	0.30	7.35**
DML*Age	96	17.34	0.18	4.48**

OSI

Source	Degree of Freedom	Sum of Square	Mean Square	F Value
Model	133	175.72	1.32	2.21**
Error	252	150.99	0.60	
Corrected Total	385	326.70		

Source	Degree of Freedom	Sum of Square	Mean Square	F Value
DML	22	58.29	2.65	4.42**
Age	18	17.80	0.99	1.65*
DML*Age	93	55.61	0.60	1.00

ODSI

Source	Degree of Freedom	Sum of Square	Mean Square	F Value
Model	133	59.16	0.44	1.34**
Error	252	83.75	0.33	
Corrected Total	385	142.92		

Source	Degree of Freedom	Sum of Square	Mean Square	F Value
DML	22	22.66	1.03	3.10**
Age	18	6.48	0.36	1.08
DML*Age	93	19.94	0.21	0.65

categories. Another reason is that all of the samples were obtained from out of the spawning area. The size distribution with depth suggested that spawning may occur in the waters shallower than 100 m (Mattlin *et al*., 1985) and all samples in the present study were collected from the waters deeper than about 100 m. It is desired to observe the condition of spent squid by the rearing experiments.

The estimated inflection point in a growth curve for each species was about 180 days old for males and around 200 days old for females. This tendency was very similar between the two species. The rate of growth decreases gradually after the inflection point (Figs. III-9 and 10). The growth of each sex is very similar to each other until the inflection point, after which the difference in growth between sexes becomes clear. The difference in the age of inflection point between sexes may be correlated closely to the sexual difference in the time of commencement of the rapid maturation. Namely, the maturation starts in males about two months earlier than in females.

The maturation process of both species was described by the relationship between some gonad somatic indices and age. But it is probable that the maturation process is not restrained only by age (time), but also by somatic growth. It is very difficult to assess the effect of each factor on maturation, because the age and growth are closely correlated with each other as shown in Chapter III. Richard *et al*. (1990) and Mayo *et. al*. (1990) discussed about relationship in maturation between age and growth. Richards *et al*. (1990) pointed out based on the analyses of lingcod (*Ophiodon elongatus*) that both length and age are useful maturity attributes, whose joint contribution to the model gives significantly better predictions of percentage maturation than either attribute alone. Roff (1982) showed that growth and age were linked to maturation, but the dominant factor varied by species and even stocks of the same species. Mayo *et al*. (1990) also showed by the results of two-factor analyses that maturation of male acadian redfish (*Sebastes fasciatus*) in the shore region was primary age-driven and not related to size; for females inshore and for both sexes offshore, however, size and age effects operated concurrently on the maturation process. Alm (1959) showed that faster growth typically resulted in earlier maturation, but several studies showed the contrary results which suggested that the earlier maturation was associated with poorer growth (Shaffer and Elson, 1975). These studies show there are some variations in the relationships among the maturation, age, and growth in fishes. But there was few description on relationship among maturation, size and age in cephalopods. In the past, the maturation process was analyzed only by the relationship between gonad somatic indices and DML which may reflect age indirectly, because there was no direct ageing for each individual.

The comparisons of the maturation process between size and age using the ageing data showed that the maturation of *N. gouldi* is more closely related with size than with age, but there was no clear difference in the maturation of *N. sloanii*. As there is strong correlation between age and DML as shown in Chapter III, it is very difficult to extract pure effect of each age and DML on the maturation. The present results suggested that the maturation is not only related with age, but also with DML (somatic growth). Furthermore, there are some differences in these relationships between the two species. As shown in Chapter III, there are clear differences in growth pattern among the month classes for both species, but the present analysis ignored these differences. Then these differences should affect the present results. Therefore, further investigations are desirable on the relationship between maturation and age/DML.

V. Month class-length key and Iterative month class-length key

The ageing results showed that the spawning occurs throughout the year and there are some differences in growth among the month classes. It is important to analyze the data on the basis of cohort such as month class when there are some seasonal cohorts which may have some different biological parameters. Generally, the size composition is decomposed to age composition by age-length key, but it is well known that an age-length key is capable of providing biased estimates of age distributions, when size distributions are applied to age-length key constructed from sampling in a different year from that in which the length data were collected (Kimura and Chikuni, 1987). In the present study, the ageing was carried out for the specimens in the particular years, though there are many biological data in the other years. Then iterative age-length key method is applied to overcome the problems mentioned above (Kimura and Chikuni, 1987).

In this chapter, the standard age-length key and the iterative age-length key methods were applied to the same size composition to consider the potential usefulness of iterative age-length key method in the present study. The term "age-length key" is usually used for estimation of age composition from size composition. In the present study, the month class composition is estimated from size composition by the age-length key method. Then the name of key must be called as month class-length key.

1. Material and methods

(1) Data for month class-length key

Ageing data shown in the Chapter III were used. Considering the number of samples, the data of *N. gouldi* in January and March 1991 are used for the construction of month class-length keys, and as for *N. sloanii* the data in January and February 1991 were used.

(2) Size composition data

The size composition data from January to March 1991, when the samples for ageing were mainly collected, were used in this chapter. The data were voluntarily collected by the fishermen of the Japanese squid jigging vessels. A hundred squid were sampled randomly from the catch in every 10-days and measured by sex after species identification.

(3) Iterative month class- length key (IMLK)

Under the assumption that the size of individuals in each month class at every-10-days is normally distributed, the relative size composition of each month class at every 10-days is estimated by sex. These relative size composition are used for the IMLK method. The program which was originally coded by Kimura and Chikuni (1987) in FORTRAN was transformed to the one in BASIC and applied to the present analysis.

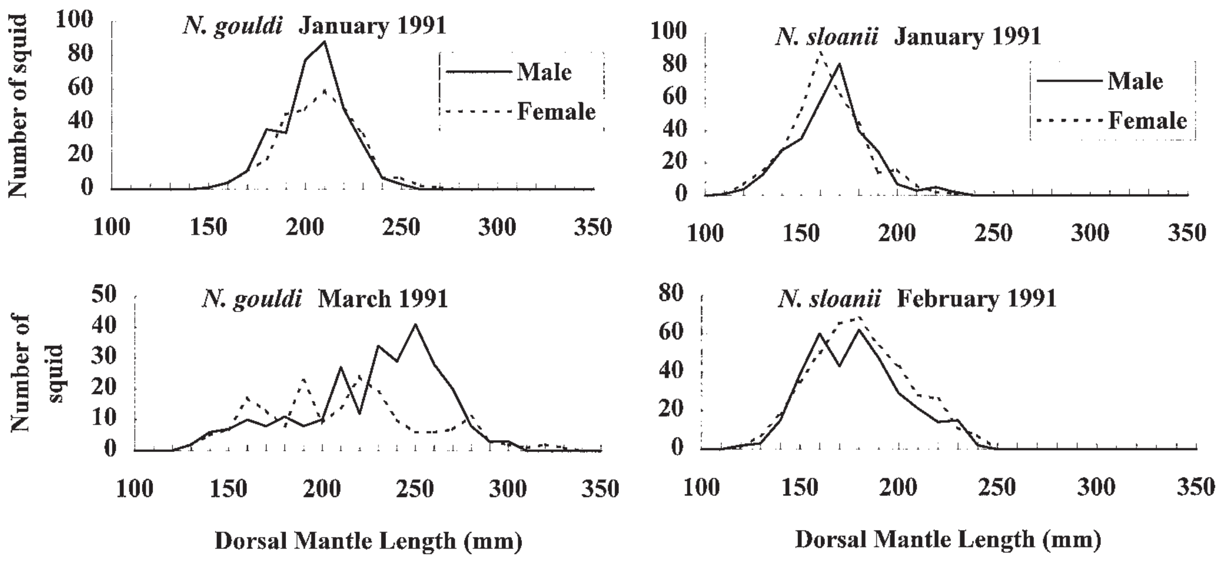


Fig. V-1 Monthly size compositions. The data for *N. gouldi* were collected from the waters off west coast of the North Island. The data for *N. sloanii* were from the Snares Shelf.

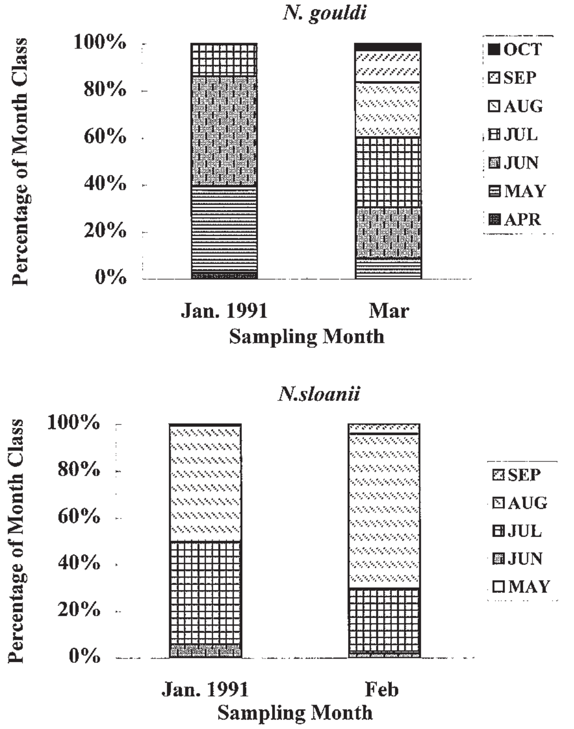


Fig. V-2 Month class compositions estimated from the size composition shown in Fig. V-1 by the month class- length key method.

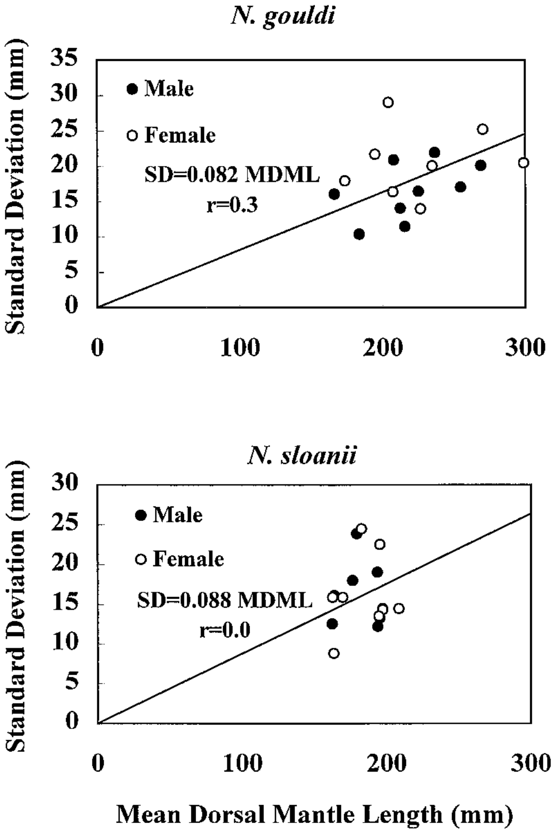


Fig. V-3 Relationship between mean dorsal mantle length and standard deviation of the size composition for the month classes shown in Fig. V-2.

2. Results

(1) Month class composition estimated by Month Class-Length Key

Using the results of ageing described in Chapter III, Month class-Length keys were constructed by month and sex (Appendix tables V-1 to 4). The samples in some length classes were sometimes lacked, though the size composition data were present in these length class. In such a case, the ratio which was observed in the adjoining length class was extrapolated arbitrarily. The size compositions were decomposed into month class compositions using these month class-length keys. This method is applicable, when both size composition and month class-length key are available in a same month-area stratum. Then, this method was applied for the monthly size compositions in January and March 1991 on the waters off west coasts of the Main Islands for *N. gouldi*, and those in January and February 1991 on the Snares Shelf for *N. sloanii*.

The monthly size composition and the resultant month class compositions are shown in Figs. V-1 and 2. There was one clear mode at 210 mm DML for both sexes of *N. gouldi* in January 1991. The range of size became wider in March and the clear mode was observed at 250 mm DML for males, though there was no clear mode for females. The month class composition estimated by month class-length key showed that the May and June classes occupied most part of the size composition in January 1991, but the percentage of these month classes decreased to about 30% in March and the percentage of July class increased. Furthermore, August-October classes appeared in March.

There was clear mode at 170 mm DML for males and at 160 mm for females in the size composition of January 1991 for *N. sloanii*. The size composition in February was similar to it in January (Fig. V-1). The month class compositions in these two months were similar and July and August classes occupied more than 90% of the size composition.

(2) Relationship between mean dorsal mantle length and standard deviation in each month class

The mean DMLs and correspond standard deviations (SDs) were calculated for the month classes obtained in the V-2-(1) in each month sampled. The relationship between mean DMLs and SDs are shown in Fig. V-3. The mean DMLs and SDs were calculated for the month classes' size compositions which had more than 10 individuals for each sex. The Mean DMLs and SDs were obtained from April-September classes and from May-September classes for male and female *N. gouldi*, respectively. Those were obtained from July-September and from June - September classes for male and female *N. sloanii*, respectively.

Fig. V-3 suggested that there is positive correlation between mean DML and SD for *N. gouldi*, though the correlation coefficient was not so high (0.3). Then it is postulated that SD is in direct proportion to mean DML. While there was no clear relationship was observed for *N. sloanii* mainly due to the narrow range

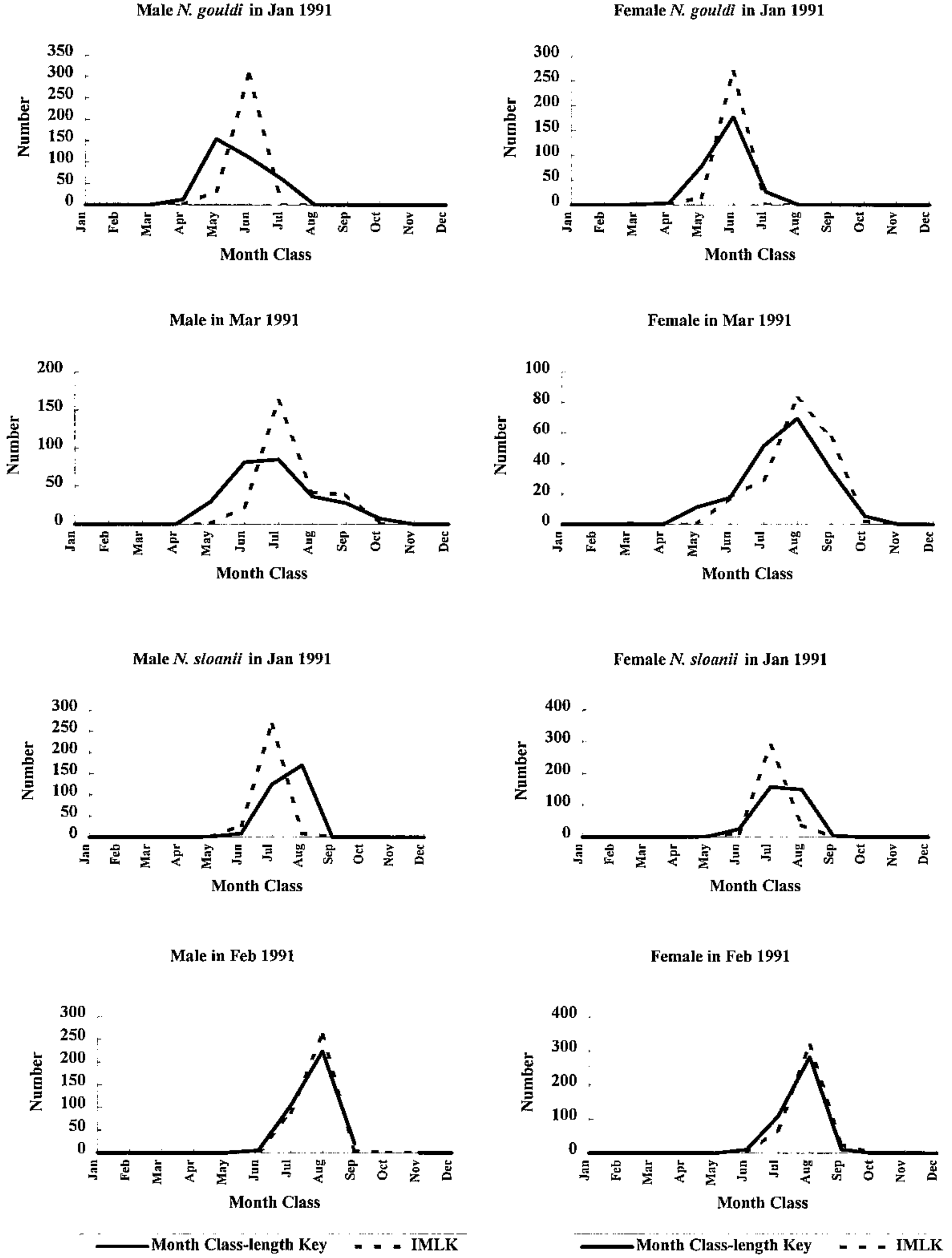


Fig. V-4 Comparison of the month class compositions between the two methods.

of mean DMLs obtained. The regression line from the origin was estimated for both species. The estimated lines are as follows,

N. gouldi : $SD=0.082MDML$,
N. sloanii : $SD=0.088MDML$,

where SD=standard deviation of DML (mm), MDML=mean dorsal mantle length (mm).

(3) Construction of length-at-age distribution for each month class at every 10-days

Mean DML at every 10 days old for each sex of each month class can be calculated by the growth equation estimated in Chapter III and the corresponded SD is estimated by the equation mentioned in V-2-(2). Under the assumption that the length-at-age is distributed normally, the length-at-age distribution can be constructed for every ten-days for each sex of each month class of two species. Then a total of 432 length-at-age distributions were estimated for each sex of each species.

(4) Month class composition estimated by Iterative Month class-Length Key (IMLK)

Using length-at-age distribution, iterative month class-length key method (IMLK), which is so-called "Kimura-Chikuni Method", was applied to decompose size composition into month class composition. In this section, iterative month class-length key was applied to the monthly size compositions which were decomposed by month class-length key in section V-2-(1) for comparison of the results between the two methods.

Fig. V-4 shows the month class compositions estimated by the two different methods, month class-length key and IMLK method. Generally, the results of the two methods were very similar to each other.

3. Discussions

The results of comparisons suggested the potential usefulness of the IMLK method and this method is applicable for estimation of month class composition from the size composition data. But this method have some assumptions such as the size is normally distributed and constant coefficient of variance, no interannual variation of growth for each month class. There are no sufficient data for validation of these assumptions. But the relationship between growth speed and temperature, which was observed in the Chapter III, suggested that there may be some annual changes in growth due to the some environmental changes. Furthermore, the month class is defined for convenience' sake as a micro-cohort for detailed analysis of seasonal cohorts and then the month class may not be in actual existence, but may be one arbitrary component of the seasonal cohort. Therefore, there are some possibilities that the size composition in each month class is far from normal one.

In the further analysis with IMLK method, it must be kept in mind that there is high possibility that the results obtained by this method may be biased. Therefore the result based on this method should be recognized as very rough one.

VI. Distribution and migration of *N. gouldi* and *N. sloanii* by development stage.

The geographical distributions of the two species, *N. gouldi* and *N. sloanii* were described in the Chapter II based on some bibliographies. In this chapter more detailed distribution of the two species in New Zealand waters were described by age from paralarva to mature stages based on the results of two larval surveys and ten bottom trawl surveys which were carried out during 1982 and 1986 (Uozumi and Forch 1995; Kono and Tokusa, 1985; Kawahara and Tokusa, 1987; Uozumi *et. al.*, 1987; Hatanaka *et. al.*, 1989; Fenaughty and Uozumi, 1989; Hatanaka *et. al.*, 1989; Hurst *et. al.*, 1990; Livingston *et. al.*, 1991; Roberston *et. al.*, 1981; Horn, 1991). Migrations with age and maturation were also analyzed by the distribution patterns in the some depth strata by age and distribution pattern by the maturation stages.

The distribution of paralarva and juvenile were described based on the results of the Bongo net sampling, larva-net attached to the bottom trawl, and fine mesh midwater trawl surveys. Bongo net and midwater trawl samplings were carried out in a Japan/New Zealand joint survey using Japanese R/V Kaiyo Maru in 1985. The larval net sampling was carried out during the two Japan/New Zealand joint bottom trawl surveys in 1986. These surveys were the first trials to collect the information on the larval and juvenile stage of arrow squid.

The ten Japan/New Zealand joint bottom trawl surveys using in this Chapter were planned to obtain abundance indices of several commercially important groundfishes including arrow squids and to collect biological information on these species. These surveys covered the distribution area of the present two species

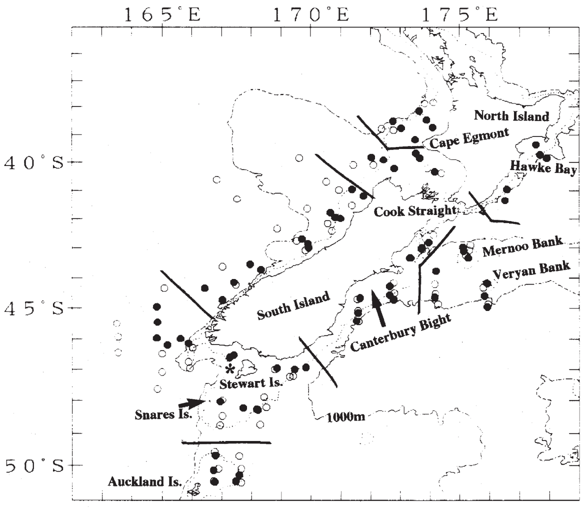


Fig. VI-1. Localities of the stations of bongo net and fine mesh midwater trawl during the *Kaiyo Maru* survey in 1985. Open circles denote the bongo net and fine mesh midwater trawl stations in the 1st period and solid ones denote those in the 2nd period. An asterisk shows the station where depth stratified sampling by bongo net was done. The solid lines show the boundaries of the areas used in the size composition analyses for juveniles.

in the areas such as the Snares Shelf, Auckland Island Shelf, Chatham Rise, and the west coast of the North Island very well and the depth coverage (about 100-1,000m depth) was wide enough to collect information on squids from full range of their distribution area.

1. Materials and methods

The results of the surveys using the four kinds of sampling gears such as Bongo net, larva-net attached to bottom trawl gear, fine mesh midwater trawl, and bottom trawl were used in this chapter. The first two sampling gears were used to sample paralarval and juvenile squid, third one was to sample juvenile, and the last one was to catch adult squid.

(1) Bongo and larva-net survey for paralarva

A. Bongo net

A joint survey was conducted around New Zealand in 1985 to collect information on paralarva and juvenile arrow squids by Japanese and New Zealand scientists on board the Japanese research vessel *Kaiyo Maru* (2,640 gross tones) (Anon, 1986). The survey was repeated two times, from 17 July to 17 August and from 17 August to 25 September, respectively, in the area shown in Fig. VI-1. Thus sampling at each corresponding station in the 2nd period was undertaken about one month later the first period. In total, 133 paired bongo net tows were made. All samplings were undertaken at night.

The paired bongo net (0.335 mm mesh, 70 cm mouth diam. for both nets) was hauled obliquely from 200 m or from near the bottom (if shallower). Standard and Marine Monitoring Assessment and Prediction (MARMAP) program procedures were used (Posgay and Marak, 1980).

Depth stratified sampling by opening-closing bongo net (Bongo Net Model 1271) was carried out at the station in the western side area of the Stewart Island (Fig. VI-1) where paralarvae were more frequently caught than elsewhere. The bottom depth at the station was 128 m and depth strata were set as surface, 0-50 m, 50-100m, and 100-bottom. The entire set of depth stratified samples was undertaken once by day and once by night. On both occasions an additional tow was made at the 50-100 m depth range.

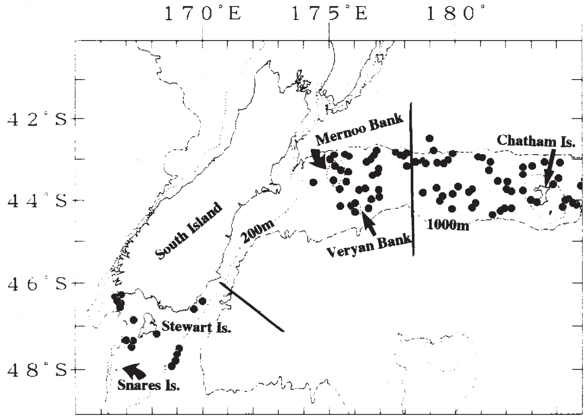


Fig. VI-2. Localities of the stations of a larva-net during the *Shinkai Maru* survey in 1986. The solid lines show the boundaries of the areas used in the size composition analyses.

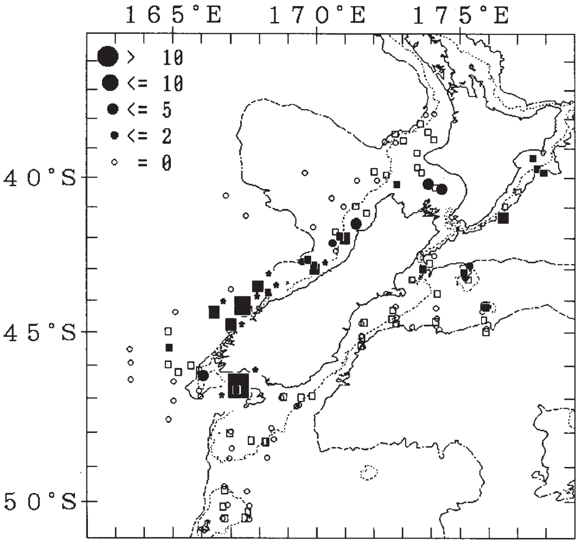


Fig. VI-4. Catch in number of paralarvae of *N. sloanii* per 2000 m^3 by bongo net at each station. Circles denote the stations sampled in the first period (17th July to 17th August, 1985). Squares denote the stations in the second period (17th August to 25th September, 1985). * denotes the stations where the specimens were identified as *N. sloanii* by electrophoresis.

The samples were sorted into taxonomic groups. Dorsal mantle length (DML) of paralarval and juvenile ommastrephid species was recorded for each station. A sub-sample was frozen for future electrophoretic analysis at stations where more than three ommastrephid paralarvae and juveniles were caught.

Catch at each station was expressed in this paper as number of squid per 2000 m^3, which is an average volume of water filtered per tow.

B. Larva-net

Another joint bottom trawl survey was conducted by Japanese and New Zealand scientists aboard the Japanese research vessel *Shinkai Maru* (3,396 gross tones), which is belonged to Japan Marine Research Resource Center, on the Chatham Rise and southern New Zealand in June/July 1986 (Hurst *et al.*, 1990; Livingston *et al.*, 1991). This survey had been primarily designed to estimate the relative abundance of groundfish by the stratified random sampling method.

During this survey, paralarvae and juveniles of squids were also sampled by a larva-net attached to the outside of the cod-end which filtered water emerging out from the cod-end. A 70 cm diameter net with a mesh size of 0.335 mm was used. During a total of 165 trawls, 100 were made with the larva-net. The stations are shown in Fig. VI-2.

The mean duration of bottom trawl tow from the gear reaching the bottom to the start of hauling was about one hour at an average speed of 3.5 knots (range from 2.6 to 4.4). Total time elapsed from shooting the gear to landing on the deck was about two hours. Thus the larva-net filtered water for about one hour at the bottom and for up to one hour at intermediate depths at unknown speeds.

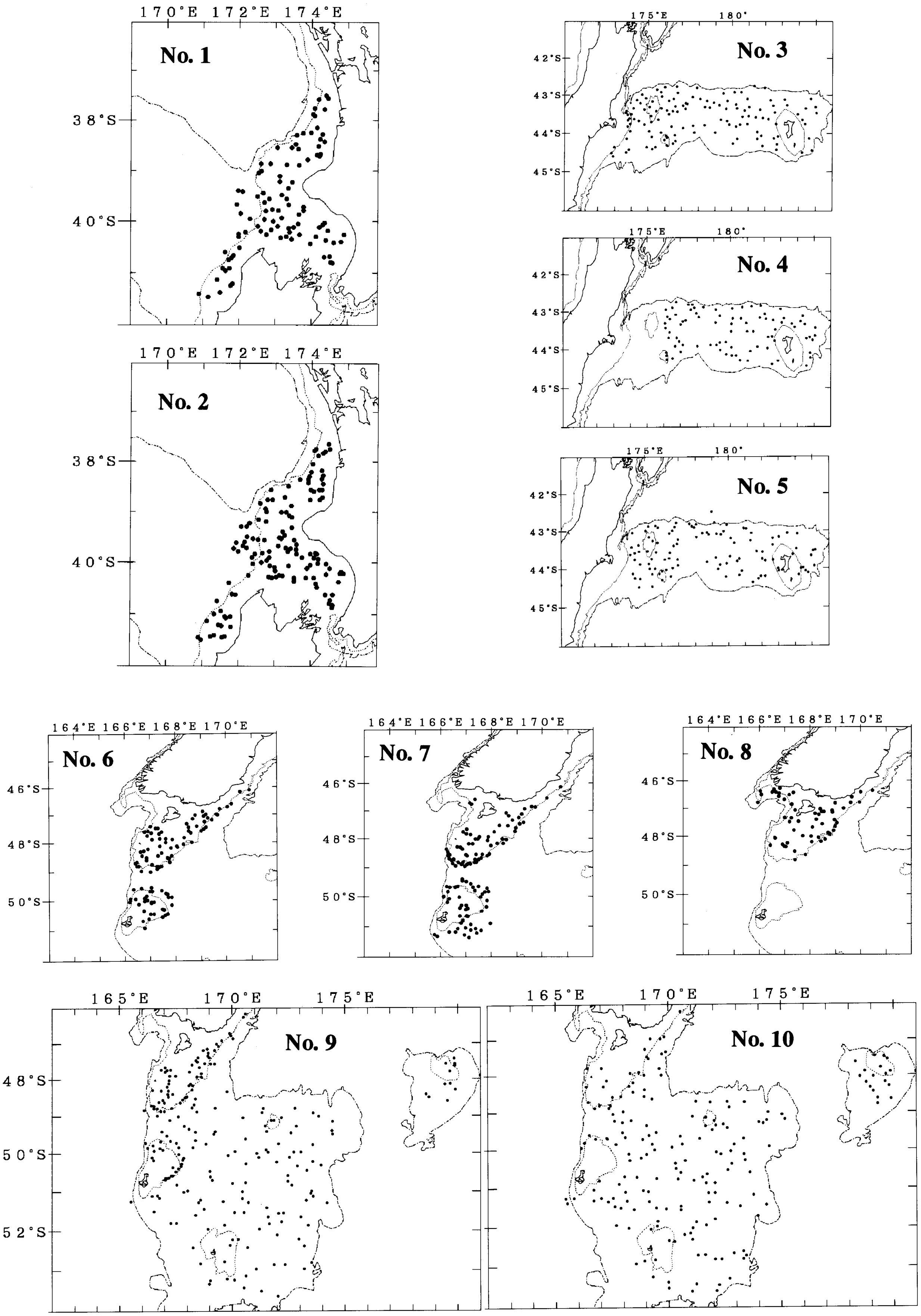


Fig. VI-3. Survey areas and bottom trawl stations of the Japan-New Zealand joint trawl surveys.

Table VI-1. Summary for the ten Japan-New Zealand joint bottom trawl surveys carried out in the New Zealand waters. A reference for each bottom trawl survey is as follows, Survey No.1: Roberston *et al*., (1981), No.2: Horn (1991), No. 3: Fenaughty and Uozumi (1989), No. 4:Hatanaka *et al*. (1989), No. 5: Livingston *et al*. (1991), No. 6: Kawahara and Tokusa (1987), No. 7: Uozumi *et al*. (1987), No. 8: Hurst *et al*. (1990), No. 9: Kono and Tokusa (1985), No. 10: Hatanaka *et al*. (1989).

Survey No.	Date and Period	Survey Area	Depth Range	No. of Strata	No. of Stations	No. of squid measured	Total Catch in number (Coverage of Sample)
1	23 Dec 1980-10 Feb 1981	off West coast North and South Islands	24-300m	30	98	2,941	4,500 (51%)
2	24 Oct-24 Nov 1981	off West coast North and South Islands	24-300m	30	131	1,326	17,100 (8%)
3	2-30 Mar 1983	Canterbury Bight and Chatham Rise	80-1000m	21	127	2,638	16,200 (16%)
4	22 Nov-12 Dec 1983	Chatham Rise	100-800m	12	84	1,541	1,900 (82%)
5	25 Jun-25 Jul 1986	Chatham Rise	50-800m	27	107	2,433	3,100 (76%)
6	25 Jan-2 Mar 1981	Snares and Auckland Island Shelves	80-600m	10	100	14,808	38,900 (38%)
7	31 Mar-29 Apr 1983	Snares and Auckland Island Shelves	80-600m	8	114	5,629	27,400 (37%)
8	5-23 Jun 1986	Snares Shelf	50-600m	11	52	4,049	19,700 (21%)
9	7 Mar-30 Apr 1982	Snares, Auckland Island Shelves and Campbell Plateau	100-800m	28	218	7,533	84,900 (9%)
10	6 Oct-19Nov 1983	Snares, Auckland Island Shelves and Campbell Plateau	80-800m	27	184	2,568	4,100 (62%)

The samples were sorted. Some randomly selected squid were frozen for the electrophoresis at all stations where ommastrephid squids were caught. DMLs of fresh specimens which were not badly damaged were also assessed for development stage (Roper and Lu, 1979).

(2) Fine mesh midwater trawl survey for juvenile

During the *Kaiyo Maru* survey in 1985 mentioned in the Bongo net sampling section, fine mesh midwater trawl sampling was also carried out. Weather permitting, a midwater trawl was made at each station as for Bongo net station (Fig. VI-1). All samplings were undertaken at night.

A double oblique tow of the midwater trawl (cod-end of 75 mm mesh with a liner of 10 mm mesh, headline height ca. 12 m) was generally made as close as practicable to the bottom or 500 m (whichever was least). Tow duration was half an hour at about 3 knots. The treatment of samples was same as those in the samples of bongo net. The catch at each station was expressed as number of squid per one hour tow.

(3) Bottom trawl survey for adult

Ten Japan-New Zealand joint bottom trawl surveys were carried out in New Zealand waters during 1981 and 1986 using the research vessels belonged to the Japan Marine Fishery Resource Research Center. The details on the surveys were presented in the published survey reports (Kono and Tokusa, 1985; Kawahara and Tokusa, 1987; Uozumi *et al*., 1987; Hatanaka *et al*., 1989; Fenaughty and Uozumi, 1989; Hatanaka *et al*., 1989; Hurst et. al., 1990; Livingston *et al*., 1991; Jones, 1990). The dates and areas of these surveys are shown in Table VI-1. Localities of bottom trawl stations in each survey are shown in Fig. VI-3. The general survey design and procedure of survey were described in this section.

These surveys were mainly designed to determine the distribution and abundance of the major shelf and slope species including arrow squid and to collect biological information (size composition, age, gonad condition, diet and so on) of the main commercial species. Each survey was designed as a stratified random trawl survey (Doubleday, 1973). Each survey area was divided into depth strata (shallower than 100 m, 100-200 m, 200-400m, 400-600m, 600-800 m), though depth range of each stratum was slightly different among the surveys. Trawl stations were allocated to each stratum in proportion to the size of each stratum. The positions of trawl stations were selected randomly within each stratum. Numbers of strata and trawl stations are shown in Table VI-1.

Tow duration was mainly set for 30 minutes on the bottom and towing speed was about 3 knots. Most of tows were made at daytime. The wingspreads of the bottom trawl in the surveys ranged from 27.3 m to 31.0 m, headline heights ranged from 6.2 m to 8.8 m, towing speeds ranged from 3.2 to 3.5 knot. Catch of each tow was sorted into species and weighted.

In the present study, the catch of squid was standardized to the catch per 0.028 square nautical mile (n mile^2) which is the overall mean of swept area among the ten trawl surveys. Furthermore, the results of trawl at night were eliminated, because CPUE and size composition are different between day and night (Kawahara and Tokusa, 1987).

In the present study, the original data obtained during these ten bottom trawl surveys were re-analyzed.

(4) Species Identification for paralarvae and juvenile, and catch estimation

After initial identification, a representative sub-sample of ommastrephid squids smaller than 100 mm in DML from bongo, larva-net, and midwater trawl tows were frozen for identification by the electrophoresis as shown in Section II-4-B. A portion of mantle tissue from specimens larger than 10 mm DML and the whole body of all specimens smaller than 10 mm DML were sacrificed for electrophoresis.

The results of electrophoresis suggested that the catches of both the bongo and larva-net comprised a single species, but that the catch of midwater trawl contained more than one species. Catch composition by species at each station was assumed to equate to that established by electrophoresis for the sub-sample.

(5) Definition of development stages

The classification for developmental stages of paralarvae and juveniles was based on Roper and Lu (1979). Namely there are two stages in paralarva, “ rhynchoteuthion ” having a complete rostrum-like tentacle (proboscis), “ transition ” having a split at the base of rostrum-like tentacle (though this stage is included into Rhynchoteuthion in *sensu lato*). In this study, transition stage has been divided into two stages, early-transition having a proboscis split for less than half its length, and late-transition having a proboscis split for more than half its length. A “ juvenile ” (post-rhynchoteuthion) has completely split tentacles.

There is no comprehensive definition of the boundary between juvenile and adult. Considering the size selectivity of gears used (fine mesh midwater trawl and bottom trawl with 60 mm mesh cod-end), It is defined arbitrarily that juvenile has completely split tentacles and smaller than 50 mm DML. Squid smaller than 50 mm DML is hardly caught by the bottom trawl with 60 mm mesh cod-end, and squid larger than 50 mm DML is rare in the samples of the fine mesh midwater trawl.

(6) Size composition and estimation of hatching month for juveniles

Size compositions were grouped by areas. The area of a fine mesh midwater trawl survey was divided into eight sub-areas as shown in Fig. VI-1 and the larva-net survey was into three sub-areas (Fig. VI-2).

Ageing of the juvenile *N. sloanii* was carried out using the statolith as shown in the Chapter III. Statoliths were collected from the frozen fine mesh midwater trawl specimens obtained during the *Kaiyo Maru* survey 1985.

A Geometric Mean functional regression (GM regression, Ricker, 1973) was applied as a linear growth model to express the relationship between age and DML. Hatching month was established by the estimated regression equation and sampling date at each station for the data from the fine mesh midwater trawl survey. The comparison of growth between the *N. gouldi* and *N. sloanii* in the Chapter III shows that there is not so larger difference in growth between the two species especially for younger age. It was assumed that the growth of juvenile *N. gouldi* is similar to *N. sloanii*. The estimated equation was also applied to the estimation of hatching month of *N. gouldi*.

(7) Size composition and estimation of age for adult caught during the bottom trawl surveys

At each trawl station, 100-200 squid were randomly sampled from the catch for size measurement. Specimens were separated by species and sex. Each sample weight was recorded. The size composition of a sample at each trawl station were converted into size composition in terms of CPUE (number per standard trawl haul), using the ratio of sample weight for size composition and CPUE (kg/ standard trawl haul) at each station as follows,

$$l_{ijk}=CPUE_{ik}/SW_{ik}.\ sl_{ijk}$$

l_{ijk} : number of squid per standard trawl haul (0.028 n mile^2) in k-th size class at j-th station in i-th stratum, sl_{ijk} : number of specimens in a sample in k-th size class at j-th station in i-th stratum,$CPUE_{ik}$: Catch weight (kg) per standard trawl haul at j-th station in i-th stratum.SW_{ik}: Sample weight (kg) at j-th station in i-th stratum.

Using the Iterative Month Class-Length Key (IMLK) as shown in the Chapter V, the corrected size composition at each station where more than 10 squid were caught was converted into month class composition, because it is very difficult to apply IMLK for the data which have less than 10 individuals. Considering the date of each survey, month class composition was converted into age composition. The age composition at each station was grouped into the three age groups such as 4-6, 7-9, and 10-12 months old. These age groups roughly correspond to sexual maturation process shown in the Chapter IV. Namely 4-6 months old group is immature with low value of gonad somatic indices (see Figs. IV-8 and 9). In 7-9 months old group, rapid development of gonad and accessory organs and copulation occur, and in 10-12 months old group the gonad somatic indices reach at highest level.

(8) Percentage of the squid distributed on the shelf

There were no sequential surveys which investigated the inshore-offshore migration process of a particular month class directly. But it may be possible to compare the distribution pattern by depth strata among the difference month classes in a survey to get some ideas on the inshore-offshore migration. For this comparison among the difference month classes, it is necessary to eliminate the effect derived from the differences in the recruitment level. To investigate the inshore-offshore migration with age, the percentage of squid distributed in the shallower water than 200 m depth to the total number of squid distributed by age in a survey area was estimated for each bottom trawl survey.

Mean size composition in each stratum ($ml_{i.k}$) was calculated based on l_{ijk} mentioned in the previous section as follows,

$$ml_{i.k} = 1/n_i \sum l_{ijk}$$

$ml_{i.k}$: number of squid per standard trawl haul in k-th size class in i-th stratum, n_i : number of stations in i-th stratum.

Weighted mean size composition in each depth range was calculated using $ml_{i.k}$ of corresponding strata for each depth range as follows,

$$Dl_{kd} = (1/\sum A_i) \cdot \sum A_i \, . \, ml_{i.k}$$

Dl_{kd} : number of squid per standard trawl haul in k-th size class in d-th depth range, A_i : area of i-th stratum which belongs to d-th depth range.

The size composition (Dl_{kd}) in terms of CPUE (number per standard trawl haul) in each depth range was converted into month class composition ($CPUE_{md}$) using the IMLK. Age of each month class in each bottom trawl survey can be known from the date of the survey.

The obtained CPUE by month class in each depth range was converted into abundance index which regards density (CPUE) and size (n. mile^2) of each depth range as follows,

$$AI_{md} = A_d \, . \, CPUE_{md}$$

AI_{md}: Abundance index of m-th month class in d-th depth range, A_d: size of d-th depth range, $CPUE_{md}$: number per standard trawl haul of m-th month class in d-th depth range.

Using this abundance index by depth rage, the percentage of squid distributed in the water shallower than 200 m depth to the total abundance of the squid in a area was calculated. This percentage was calculated for the west coast of the North Island for *N. gouldi*, Snares and Auckland Is. Shelves for *N. sloanii*, respectively.

(9) Distribution of fully matured squid

The geographical and vertical distributions of fully matured squid, which is expected to mate or spawn soon, were described using the data on biological measurements of squid specimens which obtained during the bottom trawl surveys.

In mature squid defined by category of maturation stage shown in Table II-1, fully matured squid was determined arbitrarily as mature male with Spermatophore sac Somatic Index (SSI) higher than 1.5 and mature female which is copulated with Oviduct Somatic Index (ODSI) higher than 4.0. The definitions of these indices are shown in Chapter IV. It was probable that SSI and ODSI may be related with spawning activity more closely than other gonad somatic indices such as testis and ovary somatic indices (TSI and OSI).

2. Results

(1) Species composition

A. Bongo net

A total of 90 paralarvae and two juveniles were caught by bongo nets. Forty-four specimens were tested by electrophoresis. The results showed that all of the paralarvae sampled were composed of a single species, *N. sloanii*. But these samples for electrophoresis were restricted to collections from the south west of the South Island and west of the Stewart Is. during the 2nd period of the bongo net survey (Fig. VI-4). Therefore, the paralarvae caught in the 1st period and those from other areas in the 2nd period have not been identified by electrophoresis.

B. Larva-net

A total of 461 paralarval and juvenile ommastrephid squids was caught by the larva-net attached to the cod end of the bottom trawl net. The catch of

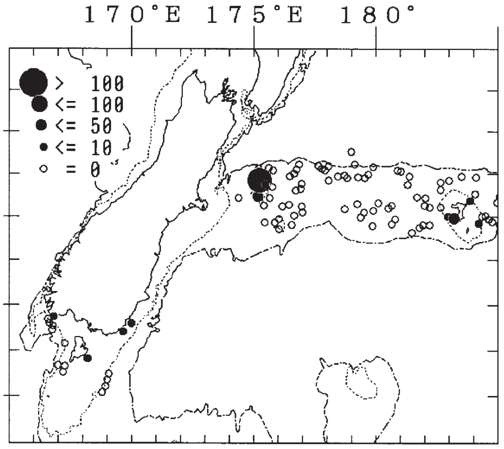


Fig. VI-5. Catch in number of *N. sloanii* paralarvae per one tow by larva-net at each station.

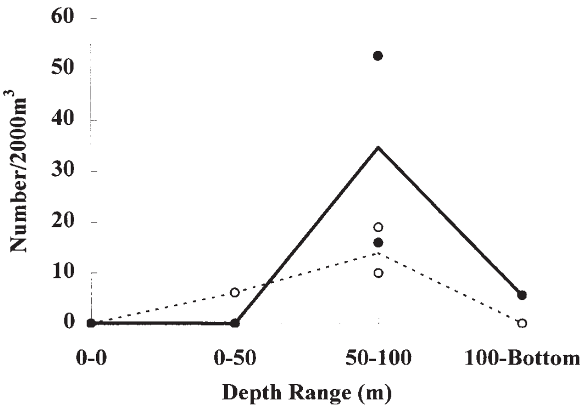


Fig. VI-6. Catch in number of *N. sloanii* paralarvae per 2000 m^3 by depth strata sampled by bongo net. Open circles and broken line show the samples for day. Solid circles and line show the samples for night.

ommastrephid squids was composed of 289 paralarvae and 172 juveniles. Among them 211 specimens were analyzed by electrophoresis. The results revealed that all specimens were *N. sloanii*.

C. Fine mesh midwater trawl

No paralarva was caught by midwater trawl net. A total of 1,462 juveniles of ommastrephid squids were caught. Mantle tissue of 536 juvenile specimens was analyzed by electrophoresis. The results revealed that the samples were composed of the four ommastrephid species, 237 individuals were *N. gouldi*, 162 were *N. sloanii*, 71 were *Todarodes* spp. and 66 were *Martialia hyadesi*. It was estimated based on the results of electrophoresis that the total catch in number of *N. gouldi*, *N. sloanii*, *Todarodes* spp. and *M. hyadesi* were 597, 640, 100, and 125, respectively.

D. Bottom trawl

The specimens, which were randomly sampled from the catch for length measurement, were identified by morphological characteristics mentioned in the section II-4-A. Number of specimens identified (equal to number of squid measured) are shown in Table VI-1 by the surveys.

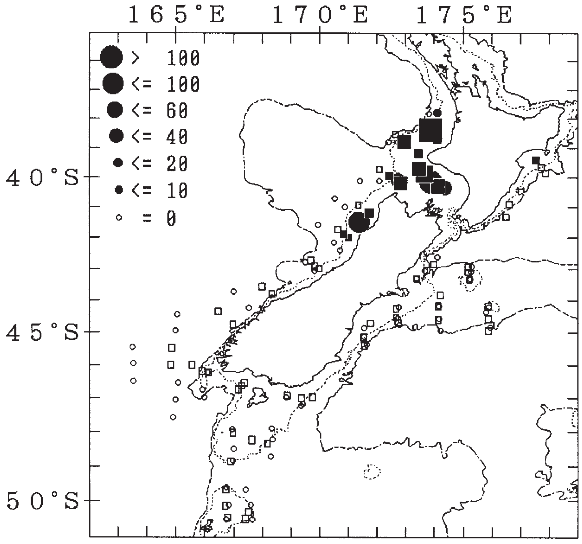


Fig. VI-7. Catch in number of juvenile *N. gouldi* per one hour tow of the fine mesh midwater trawl at each station. Circles denote the stations sampled in the first period (17th July to 17th August, 1985). Squares denote the stations in the second period (17th August to 25th September, 1985).

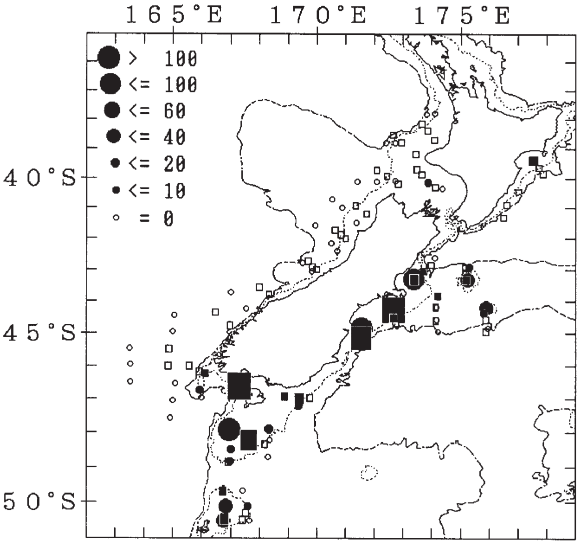


Fig. VI-8. Catch in number of juvenile *N. sloanii* per one hour tow of the fine mesh midwater trawl at each station. Circles denote the stations sampled in the first period (17th July to 17th August, 1985). Squares denote the stations in the second period (17th August to 25th September, 1985).

Unfortunately, all specimens in the Survey Nos. 1, 2, and 6 in Table VI-1 were identified as genus *Nototodarus*, but not identified into species, because key characters for the identification, number of suckers on Arm I and morphology of hectocotylus, were not confirmed before 1982 (see Section II-4-A).

The survey areas of the former two surveys (Survey Nos. 1 and 2) were off west coast of the North and South Islands. As shown in the section II-7, both of the two species coexist in this survey area. There is high possibility that both species were included in the specimens of these two surveys. Considering the result of observation on mixture rate of the present two species by fine biological sampling area shown in Fig. II-11, it can be assumed that the specimens from these two surveys obtained from the waters north of 40° 30 ’ N (Areas A, B, and C in Fig. II-5) were composed of a single species, *N. gouldi* in the following analyses.

The survey area of Survey No. 6 was the waters on the Snares and Auckland Island Shelves. As shown in the section II-7, the two species were observed on the Snares Shelf, but the occurrence of *N. gouldi* was negligible (see mixing percentage in fine biological sampling area F in Table II-7). Only a single species, *N. sloanii*, was observed on the Auckland Island Shelf (Table II-7). Based on these results shown in Chapter II, it was assumed that all *Nototodarus* squid caught during the survey No. 6 was *N. sloanii*.

As for the other seven surveys, all specimens were identified to species level and the results revealed that all samples were composed of a single species, *N. sloanii* in these bottom trawl surveys.

(2) Geographical distribution of paralarva

The distribution of paralarvae caught by bongo net is shown in Fig. VI-4. The maximum number caught was 16 individuals at the station off the west coast of Stewart Is. Generally the number of specimens caught ranged from 1 to 2 at the other positive-catch stations.

During the 1st period of the survey paralarvae were caught mainly in coastal waters off the west coast of the South Island (Fig. VI-4). In the 2nd period, the distribution pattern was very similar to one in 1st period with the good catch obtained at stations located on the west side of Stewart Is. Isolated paralarvae were caught on the Mernoo and Veryan Banks in both periods. None were caught around the Auckland Is. Paralarvae collected off south-west coast of South Island and west of the Stewart Is. in 2nd period were identified as *N. sloanii*, but low numbers prevented identification of the remaining paralarvae from other stations of bongo net.

The distribution of paralarvae caught by the larva-net is shown in Fig. VI-5. Electrophoresis revealed that all specimens of larva-net were *N. sloanii*. The maximum number caught by the larva-net was 215 at the station on the Mernoo Bank. Paralarvae were caught at almost of all stations shallower than 150 m depth (Fig. VI-5), including the area around the Chatham Is. No paralarva was caught at the stations deeper than 200 m.

(3) Vertical distribution of *N. sloanii* paralarva

A total of 41 paralarvae were caught during the depth stratified sampling by bongo net. Twenty specimens were analyzed by electrophoresis and all were confirmed as *N. sloanii*. The mean number of paralarvae per 2000 m^3 at each depth range is shown in Fig. VI-6. Catch in number peaked at 50-100 m. No paralarva was caught at the surface by day and night. The vertical distribution pattern was very similar between day and night.

(4) Geographical distribution of juveniles

The distribution of juveniles (expressed by the catch in number per one hour midwater trawl) obtained by a fine mesh midwater trawl are shown by species in Figs VI-7 and 8. The distribution of juvenile *N. sloanii* caught by a larva-net is shown in Fig. VI-9.

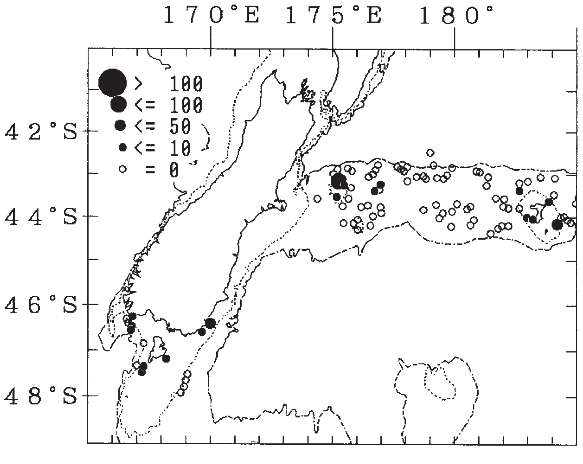


Fig. VI-9. The catch in number of juvenile *N. sloanii* per tow of the larva-net at each station.

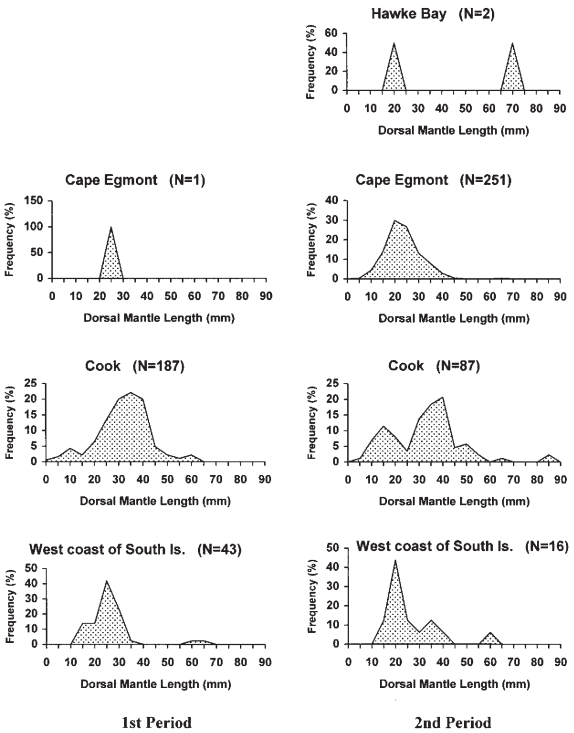


Fig. VI-10. The size composition of juvenile *N. gouldi* caught by the fine mesh midwater trawl. Size composition is shown by area (see Fig. VI-1). N denotes the number of individuals measured.

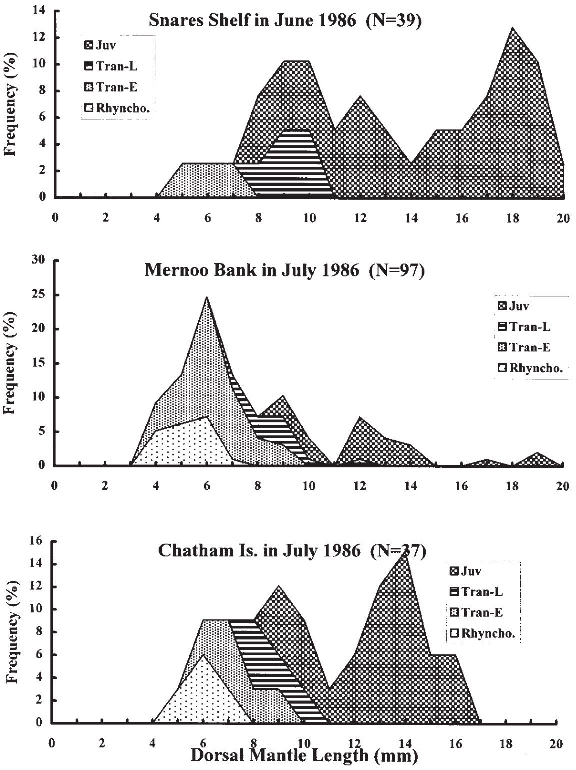


Fig. VI-11. Size composition of paralarvae and juveniles of *N. sloanii* caught by the larva-net. Size composition is presented by developmental stage and by area (see Fig. VI-2). Rhyncho.: rhynchoteuthion stage, Tran-E: early transition stage, Tran-L: late transition stage, and Juv: juvenile stage. N denotes the number of individuals measured.

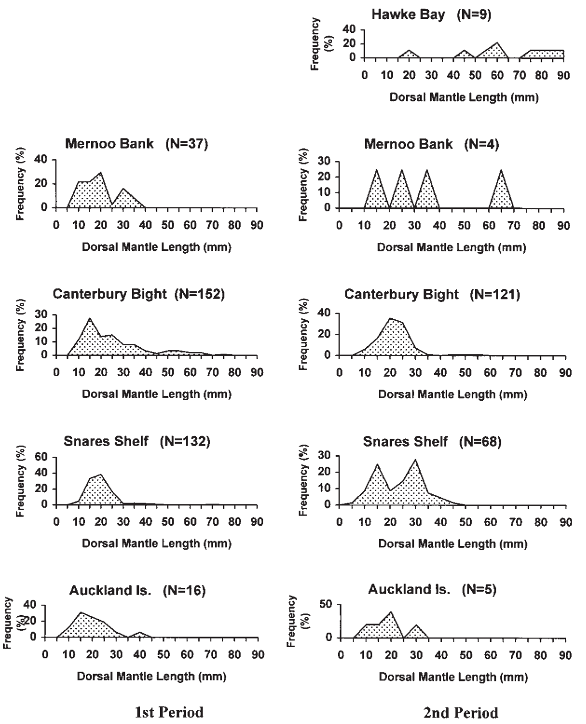


Fig. VI-12. Size composition of juvenile *N. sloanii* caught by the fine mesh midwater trawl. Size composition is presented by area (see Fig. VI-1). N denotes the number of individuals measured.

A. *N. gouldi*

The juveniles of *N. gouldi* were caught only by a fine mesh midwater trawl off the east and west coasts of the North Island, and north-west of the South Island (Fig. VI-7). There was no clear difference in the distribution pattern of juveniles between 1st and 2nd period of the fine mesh midwater trawl survey. High catch rates (more than 100 individuals /one hour tow) were obtained on the shelf off the west coast of the North Island. Along the east and south coasts of the South Island and around the Auckland Islands, no *N. gouldi* was caught. Almost all juveniles were caught on the shelf. There were few juveniles caught in offshore waters. These results show that the juveniles of *N. gouldi* are mainly distributed on the continental shelf in the west coast of the North and South Islands. The more southerly survey by a larva-net caught no paralarval or juvenile *N. gouldi*.

B. *N. sloanii*

N. sloanii was caught along the east and south coast of the South Island, east coast of the North Island, Mernoo Bank, Veryan Bank and around the Auckland Islands by a fine mesh midwater trawl (Fig. VI-8). There was no catch on the west coast of the North and South Islands except for the two positive stations in Cook Strait. There was no clear difference in the distribution pattern of juveniles between the 1st and 2nd periods by a fine mesh midwater trawl survey. Almost all juveniles were caught on the shelf, and few were caught off-shore waters. These results show that juveniles of *N. sloanii* are mainly distributed on the shelf, including the banks off the east coast of the South Island.

Juvenile *N. sloanii* was caught on the Snares Shelf, Mernoo Bank and around the Chatham Is. by a larva-net (Fig. VI-9). The catch in the waters deeper than 150 m depth was negligible, though a few juveniles were caught in the slope waters.

(5) Size composition of paralarvae and juveniles

A. Juvenile *N. gouldi*

The size composition of juvenile *N. gouldi* caught by the fine mesh midwater trawl is shown in Fig. VI-10. The DMLs of juvenile *N. gouldi* ranged from 5 mm to 95 mm. One or two clear modes were observed in the size composition by area in both periods. Modal peaks were observed at 35-40 mm in the Cook Area and at 25-30 mm in the west coast South Island Area during the 1st period. In the 2nd period modal peaks were observed at 20-25 mm in the Cape Egmont area, at 15-20 mm, and 40-45 mm in the Cook Area, and at 20-25 mm in the west coast South Island.

B. Paralarvae of *N. sloanii*

DMLs of paralarvae caught by a bongo net, which were identified as *N. sloanii* by electrophoresis, ranged from 1.5 mm to 8 mm. Transition stage was observed from 4 mm and all paralarvae larger than 6 mm belonged to transition stage.

Size compositions of paralarvae by the larva-net are shown in Fig. VI-11. The DMLs ranged from 3 to 12 mm. The ranges of DML corresponding to rhynchoteuthion, early-transition and late-transition stages were 3-8, 3-10 and 6-12 mm, respectively. A clear mode was observed at 6-7 mm on the Mernoo Bank where more than 200 paralarvae were caught. There was no clear difference in the range of DML between the areas.

C. Juvenile *N. sloanii*

The two juvenile *N. sloanii* were caught by a bongo net and these DMLs were 8 and 11 mm. The size compositions of juveniles caught by a fine mesh midwater trawl by areas are shown in Fig. VI-12. The DMLs of juvenile *N. sloanii* sampled ranged from 10

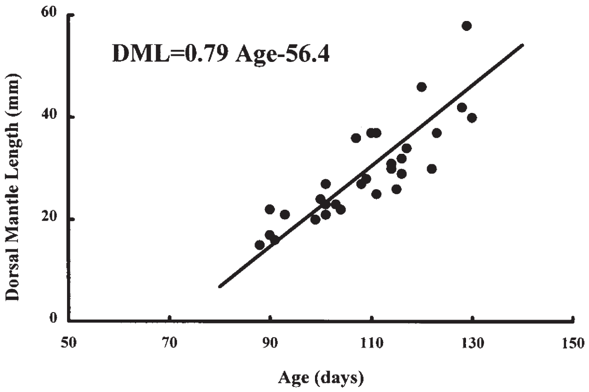


Fig. VI-13. The relationship between age and dorsal mantle length in juvenile *N. sloanii*.

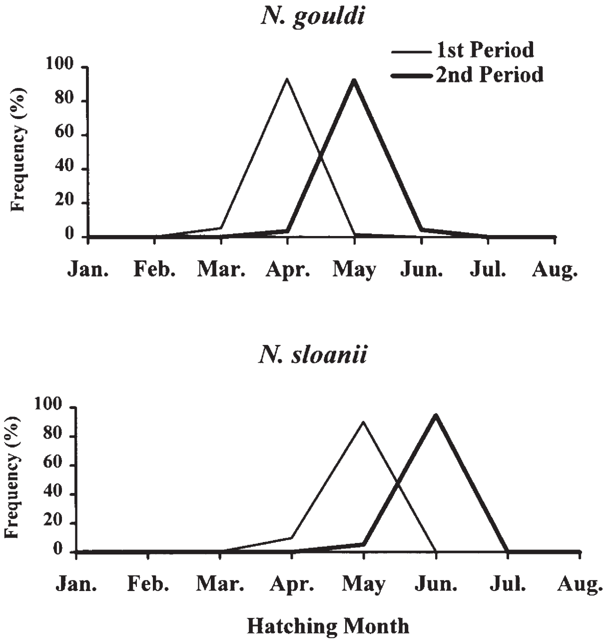


Fig. VI-14. Hatching month of juvenile *N. gouldi* and *N. sloanii* estimated by the relationship shown in Fig. VI-13 and size compositions shown in Figs. VI-10 and VI-12. Hatching month of *N. gouldi* was estimated under the assumption that the juvenile growths are similar between *N. gouldi* and *N. sloanii* .

mm to 100 mm. Either one or two clear modes were observed in the size composition of each area, and modal peaks occurred in the range from 20-40 mm. There was no clear difference in the size composition among the areas. In general, size compositions in both periods were very similar. In the Canterbury Bight, a clear mode was observed at 15-20 mm in the 1st period and at 20-25 mm in the 2nd period. On the Snares Shelf, a clear mode was observed at 20-25 mm in 1st period. Two modes were observed at 15-20 mm and at 30-35 mm in the 2nd period.

The size compositions of juveniles caught by the larva-net are shown in Fig. VI-11. The DML of juveniles ranged from 7 to 20 mm. Clear modes were observed at 18-19 mm on the Snares Shelf, at 12-13 mm on the Mernoo Bank, and at 14-15 mm around the Chatham Is.

(6) Hatching month of paralarvae and juveniles

A total of thirty two juvenile *N. sloanii* ranged from 15 to 58 mm DML were successfully aged (see Chapter III). Age ranged from 80 to 130 days old. The relationship between age and DML is shown in Fig. VI-13. The growth over 80-130 days old appeared linear. The estimated GM functional regression was as follows:

$$\text{DML (mm)} = 0.79 * \text{Age (days)} - 56.4$$
$$\text{correlation coefficient} = 0.85$$

Using the estimated equation between DML and age, hatching month was back calculated from size composition (Fig. VI-14). The equation was also applied to the size composition of *N. gouldi*. The equation may express the general Age-DML relationship in the range between 20-60 mm DML (Fig. VI-13).

Most juvenile *N. gouldi* in the 1st period of the fine mesh midwater trawl survey were estimated to be born in April. On the contrary, those in 2nd period were born in May. While for the juveniles of *N. sloanii*, it was estimated that most in the 1st period were born in May, but most in the 2nd period were born in June.

(7) Geographical distribution of adults

A. *N. gouldi* off west coast of the North Island (Survey Nos. 1 and 2)

The two bottom trawl surveys (Survey Nos. 1 and 2 in Table VI-1) were carried out in the waters off west coast of the North Island (Roberston *et al.*, 1981; Horn, 1991). The former one was carried out from 23rd December 1980 to 10th February 1981, and the latter was from 24th October to 24th November 1981. The main objective of both surveys was to obtain abundance indices of jack mackerels (*Trachurus declivis* and *T. novaezelandiae*). Therefore, the depth range of the survey area limited shallower than 300 m depth, where jack mackerels are mainly distributed. In the Survey No. 1, the specimens for size measurement

Table VI-2. Month classes correspond to three age groups in each bottom trawl survey. Survey Nos. are same as those shown in Table VI-1.

	Corresponded Month Classes to Each Age Group		
Survey No.	4-6 months old	7-9 months old	10-12 months old
1	July-September	April-June	January-March
2	May-July	February-April	January, November and December
3	September-November	June-August	March-May
4	June-August	March-May	January, February and December
5	January-March	October-December	July-September
6	August-October	May-July	February-April
7	October-December	July-September	April-June
8	January, February and December	September-November	June-August
9	September-November	June-August	March-May
10	April-June	January-March	October-December

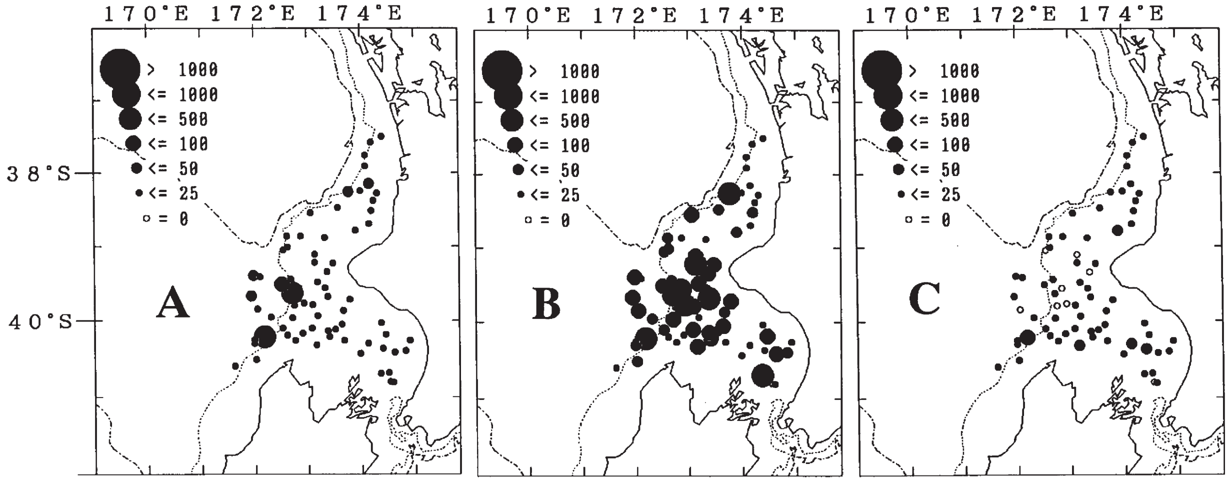


Fig. VI-15. Distribution and CPUEs (number/standard trawl haul, 0.028 n mile^2) of *N. gouldi* in the Survey No. 1 during 23rd December 1980 and 10th February 1981. A: 4-6 months old group, B: 7-9 months old group, and C: 10-12 months old group.

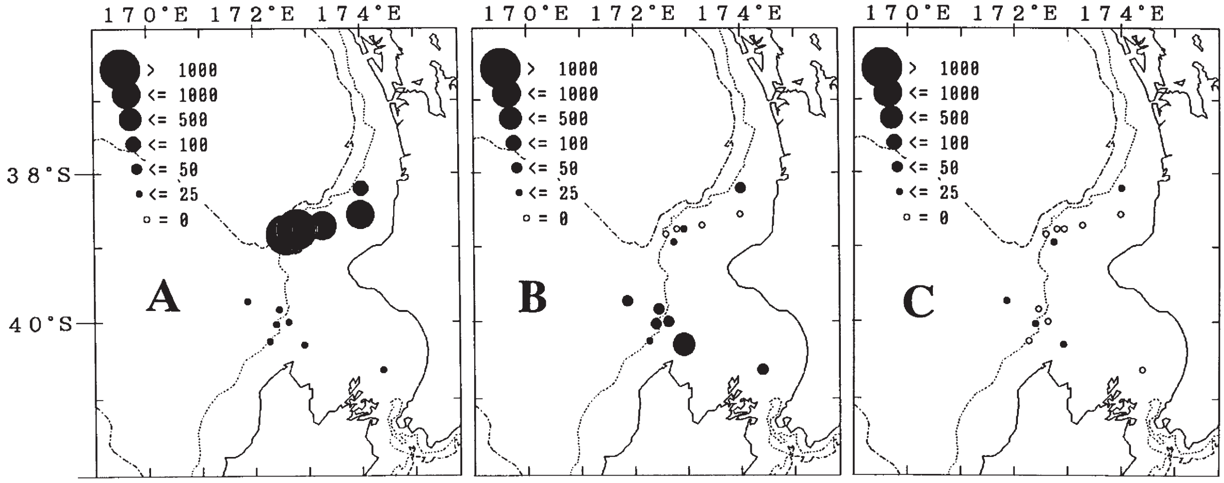


Fig. VI-16. Distribution and CPUEs (number/ standard trawl haul, 0.028 n mile^2) of *N. gouldi* in the Survey No. 2 during 24th October and 24th November 1981. A: 4-6 months old group, B: 7-9 months old group, and C: 10-12 months old group.

were obtained at almost positive-catch stations, but in the Survey No. 2 there were only 22 stations (18% of the positive-catch stations) where the size samples were collected, because the survey effort was heavily focused on jack mackerels.

Figs. VI-15 and 16 show the catch in number per standard trawl haul (catch per 0.028 n mile^2) at each bottom trawl station in Surrey Nos. 1 and 2 by age groups. The corresponded month classes to each age class by the surveys are shown in Table VI-2.

Squid of 4-6 months old group which roughly corresponded to July-September classes was widely distributed in the waters off west coast of the North Island in the Survey No. 1 (Fig. VI-15-A). Relatively higher CPUEs (more than 25 squid per standard haul) were observed on the edge of the shelf. Squid of 7-9 months old which roughly corresponded to April-June classes was also widely distributed on the shelf and the upper slope shallower than 300 m depth (Fig. VI-15-B). There was no clear difference in CPUE between the coastal waters and edge of the shelf. Squid of 10-12 months old which roughly corresponded to January-March classes was distributed uniformly on the shelf and upper slope (Fig. VI-15-C).

Fig . VI-16 shows the distribution and CPUEs of *N. gouldi* in the Survey No. 2 which was carried out during 24th October and 24th November 1981. There were only 22 stations where the size data were collected, then it was difficult to describe distribution pattern of each age group very well based on the results of Survey No. 2. High CPUEs for squid of 4-6 months old which corresponded to May-July classes were obtained from northern part of the waters off west coast of the North Island, comparing with those in the southern part (Fig VI-16-A). Contrarily, relatively higher CPUEs for squid of 7-9 months old group, which corresponded to February-April classes, were obtained from the southern part (Fig. VI-16-B). Squid of 10-12 months old which corresponded to January, November and December classes was sparsely distributed over the survey area (Fig. VI-16-C).

B. *N. sloanii* on the Canterbury Bight and Chatham Rise (Survey No. 3 to 5)

The bottom trawl surveys were carried out in the waters off east coast of the South Island three times

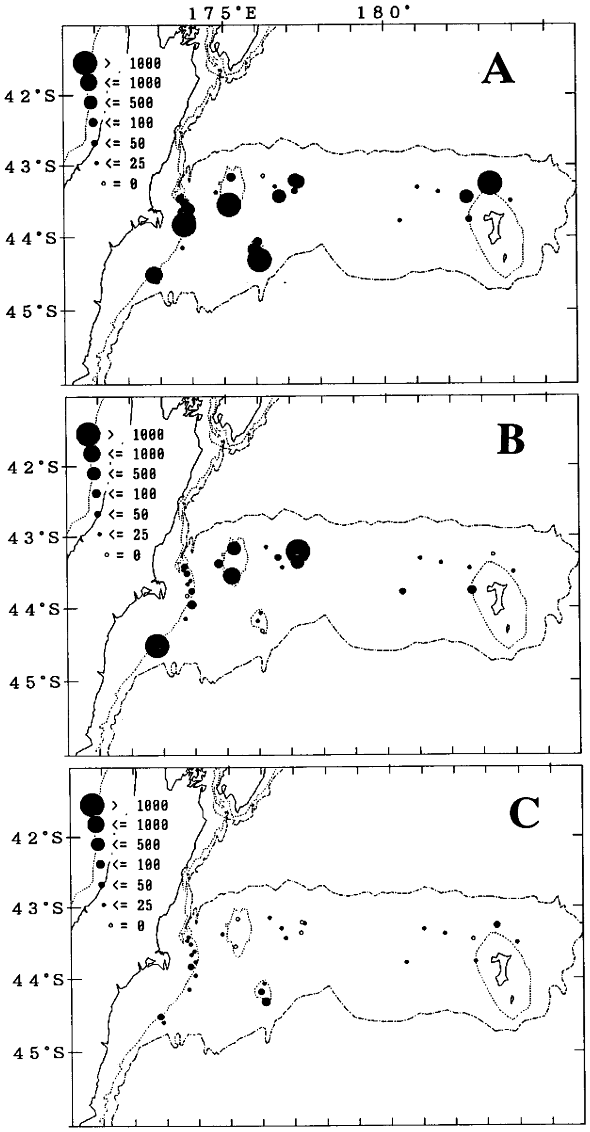


Fig. VI-17. Distribution and CPUEs (number/ standard trawl haul, 0.028 n mile^2) of *N. sloanii* in the Survey No. 3 during 2nd and 30th March 1983. A: 4-6 months old group, B: 7-9 months old group, and C: 10-12 months old group.

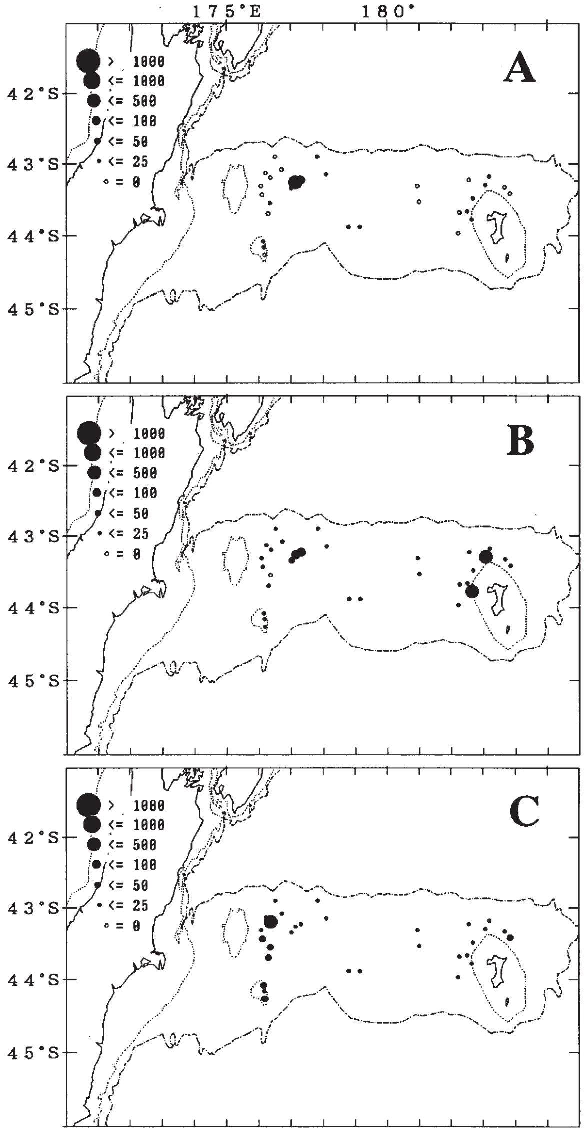


Fig. VI-18. Distribution and CPUEs (number/ standard trawl haul, 0.028 n mile^2) of *N. sloanii* in the Survey No. 4 during 22nd November and 12th December 1983. A: 4-6 months old group, B: 7-9 months old group, and C: 10-12 months old group.

(Survey Nos. 3-5 in Table VI-1). The main purposes of these surveys were to estimate abundance indices of the commercial important species such as hoki (*Macruronus novaezelandiae*), barracouta (*Thyrsites atun*), and arrow squid on the banks and upper slope area.

The Survey No. 3 covered the edge part of the Canterbury Bight where was outside of the prohibited area for offshore trawlers in the Bight by the New Zealand government (Fenaughty and Uozumi, 1989). In the latter two surveys (Survey Nos. 4 and 5), the Canterbury Bight was eliminated form the survey area (Hatanaka *et al.*, 1989 and Livingston *et al.*, 1991). Then it is difficult to describe the distribution pattern of *N. sloanii* on the Canterbury Bight based on the results of these surveys. The three surveys covered the Chatham Rise shallower than 800m very well and covered austral summer, autumn, and winter, though the Mernoo Bank was eliminated from the survey area in the Survey No. 4. During these three surveys, the size samples were collected from almost all of the positive-catch stations of squid, because arrow squid was one of the important species for the surveys.

Figs. VI-17 - 19 show the catch in number per standard trawl haul at each bottom trawl station in Survey Nos. 3 - 6 by age groups. The corresponded month classes to each age class by the surveys are shown in Table VI-2.

Squid of 4-6 months old group which corresponded to September-November classes was widely distributed in the waters shallower than about 200 m depth in the Survey No. 3 (Fig. VI-17-A). Namely, the squid was distributed on the edge of the Canterbury Bight, Mernoo, Veryan, and Reserve Banks, and around the Chatham Island. There was few squid in the stations which located in the waters deeper than about 200 m depth. Squid of 7-9 months old which corresponded to June-August classes was also widely distributed as same as 4-6 months old group (Fig. VI-17-B). The distribution pattern of squid of 10-12 months old which

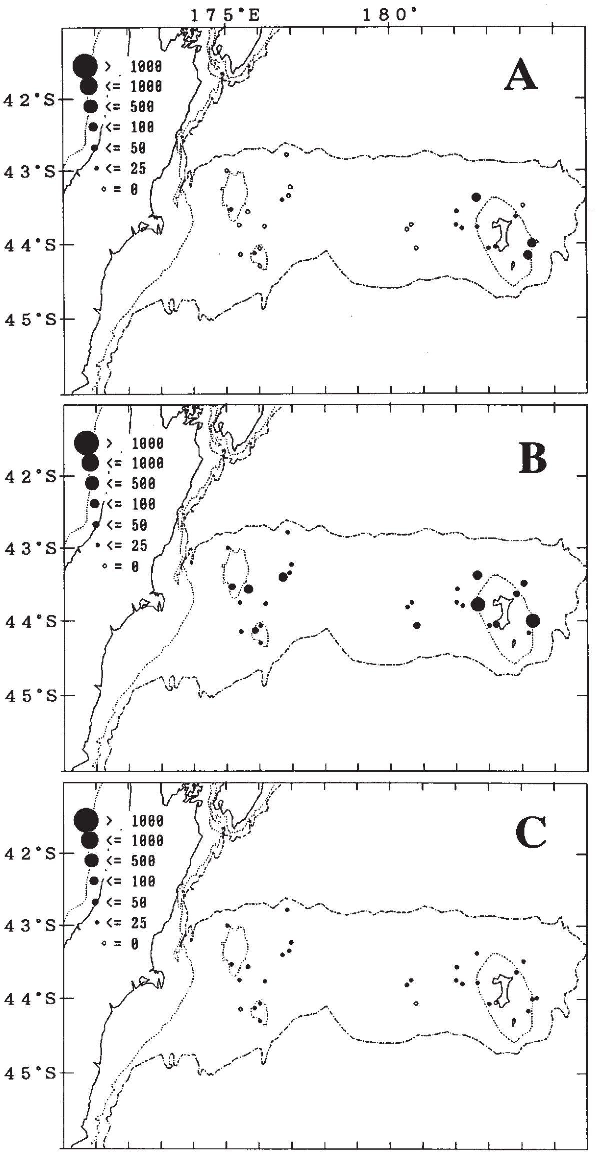


Fig. VI-19. Distribution and CPUEs (number/ standard trawl haul, 0.028 n mile^2) of *N. sloanii* in the Survey No. 5 during 25th June and 25th July 1986. A: 4-6 months old group, B: 7-9 months old group, and C: 10-12 months old group.

corresponded to March-May classes was also same as the former age groups, though the CPUEs of this age group was low (Fig. VI-17-C).

Squid of 4-6 months old which corresponded to June-August classes was obtained mainly from the waters on the Reserve Bank in the Survey No. 4 (Fig. VI-18-A). There was a few squid of this age group in the other area, even though the stations were shallower than 200 m depth. Squid of 7-9 months old which corresponded to March-May classes was widely distributed in the shallower waters of the survey area (Fig. VI-18-B). Squid of 10-12 months old, which corresponded to January, February, and December classes, was distributed widely as same as squid of 7-9 months old group, but the CPUEs of this age group in the western side of the survey area were relatively higher than those in the eastern side (Fig. VI-18-C).

Squid of 4-6 months old which corresponded to January-March classes was widely distributed in the shallower waters in the survey area, but obtained mainly from the waters around the Chatham Islands during the Survey No. 5 (Fig. VI-19-A). Squid of 7-9 months old which corresponded to October-December classes was distributed uniformly over the shallower waters of the survey area (Fig. VI-19-B). Squid of 10-12 months old which corresponded to July-September classes was distributed as same as the 7-9 months old group, though the CPUEs of this age group were lower than those of the 7-9 months old group (Fig. VI-19-C).

C. *N. sloanii* on the Snares Shelf, Auckland Island Shelf, and Campbell Plateau (Survey Nos. 6 to 10)

The bottom trawl surveys were carried out in the southern waters of New Zealand five times as shown in Table VI-1. The survey area of the former three surveys were restricted in the Snares-Auckland Islands area (Kawahara and Tokusa, 1987; Uozumi *et al.*, 1987; Hurst *et al.*, 1990). The area of Survey No. 8 was limited only on the Snares Shelf. The main purpose of these three surveys was to obtain biological information on squid and the other commercially important species distributed in the shallower waters. The survey area of the last two surveys expanded to over the Campbell Plateau and the Bounty Platform including the Snares and Auckland Island Shelves

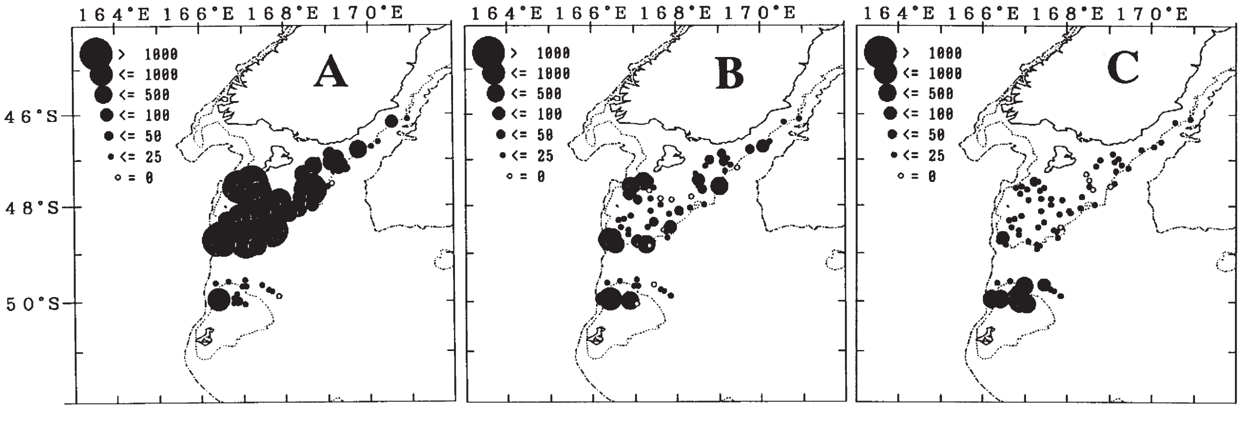


Fig. VI-20. Distribution and CPUEs (number/ standard trawl haul, 0.028 n mile^2) of *N. sloanii* in the Survey No. 6 during 25th January and 2nd March 1981. A: 4-6 months old group, B: 7-9 months old group, and C: 10-12 months old group.

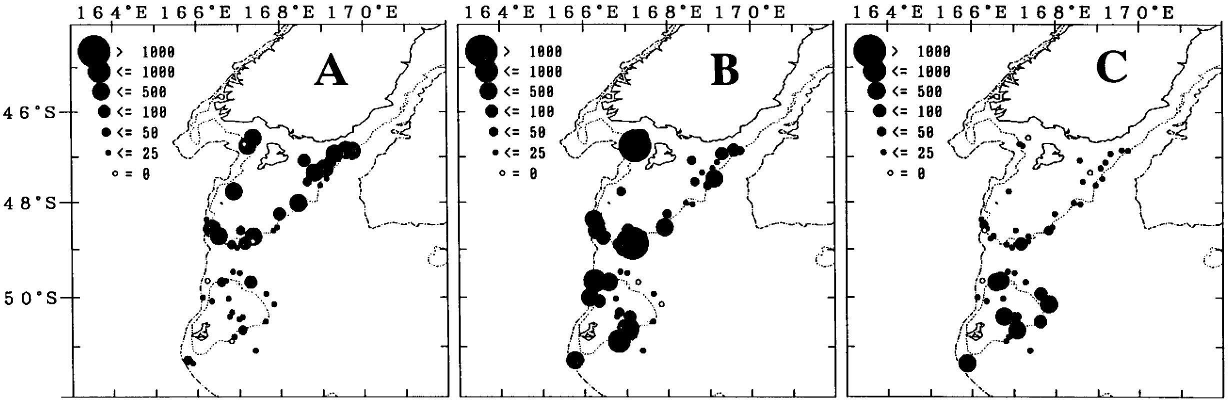


Fig. VI-21. Distribution and CPUEs (number/ standard trawl haul, 0.028 n mile^2) of *N. sloanii* in the Survey No. 7 during 31st March and 29th April 1983. A: 4-6 months old group, B: 7-9 months old group, and C: 10-12 months old group.

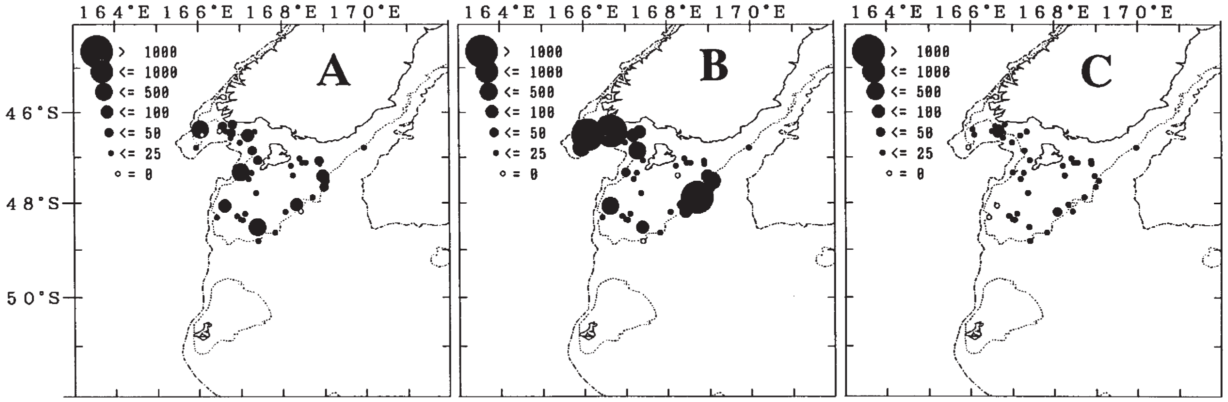


Fig. VI-22. Distribution and CPUEs (number/ standard trawl haul, 0.028 n mile^2) of *N. sloanii* in the Survey No. 8 during 5th and 23rd June 1986. A: 4-6 months old group, B: 7-9 months old group, and C: 10-12 months old group.

(Kono and Tokusa, 1985; Hatanaka *et al.*, 1989). The main purpose of the two surveys was to obtain some biological information on the commercially important species distributed in the shelf and upper slope waters shallower than 800 m depth. At almost all of the positive-catch station of squid the size samples of squid were collected. The low coverage of sample in the Survey No. 9 was due to huge catch of squid at positive-catch stations (Table VI-1).

Squid of 4-6 months old which corresponded to August-October classes was widely distributed on the Snares Shelf and also caught at almost stations on the Auckland Island Shelf during the Survey No. 6 (Fig. VI-20-A). Squid of 7-9 months old which corresponded to May-July classes was distributed uniformly over the survey area (Fig. VI-20-B). CPUEs in the central part of the Snares Shelf were relatively lower than those in the edge of the Shelf. Squid of 10-12 months old which corresponded to February-April classes was uniformly distributed on the Snares Shelf (Fig. VI-20-C).

Squid of 4-6 months old which corresponded to October-December classes was widely distributed on the Snares Shelf and also on the Auckland Island Shelf during the Survey No. 7 (Fig. VI-21-A), except for the central part of the Snares Shelf, where the CPUEs were lower than 10 squid per standard haul and eliminated from the estimation of month class. Squid of 7-9 months old which corresponded to July-September classes was distributed uniformly over the survey area as same as 4-6 months old group (Fig. VI-21-B). The distribution pattern of 10-12 months old group which corresponded to April-June classes was as same as for the younger two groups (Fig. VI-21-C).

Squid of 4-6 months old which corresponded to January, February, and December classes was widely distributed on the Snares Shelf during the Survey No. 8 (Fig. VI-22-A), except for the central part of the Snares Shelf. The distribution pattern of 7-9 months old group, which corresponded to September-November classes, was very similar to it of 4-6 months old group (Fig. VI-22-B). Squid of 10-12 months old group which corresponded to June-August classes was distributed uniformly on the Shelf (Fig. VI-22-C).

Squid of 4-6 months old which corresponded to September-November classes was distributed widely in the shallower waters than about 200 m depth during Survey No. 9 (Fig. VI-23-A), except for the waters on the Campbell Islands Shelf. Squid of this age group was sparsely distributed in the central part of the Snares Shelf. Squid of 7-9 months old which corresponded to June-August classes was distributed on the Snares and Auckland Island Shelves as same as 4-6 months old group, but few on the other shallower waters such as the Campbell Island Shelf, Pukaki Rise, and Bounty Platform (Fig. VI-23-B). Squid of 10-12 months old which corresponded to March-May classes was distributed widely in the survey area (Fig. VI-23-

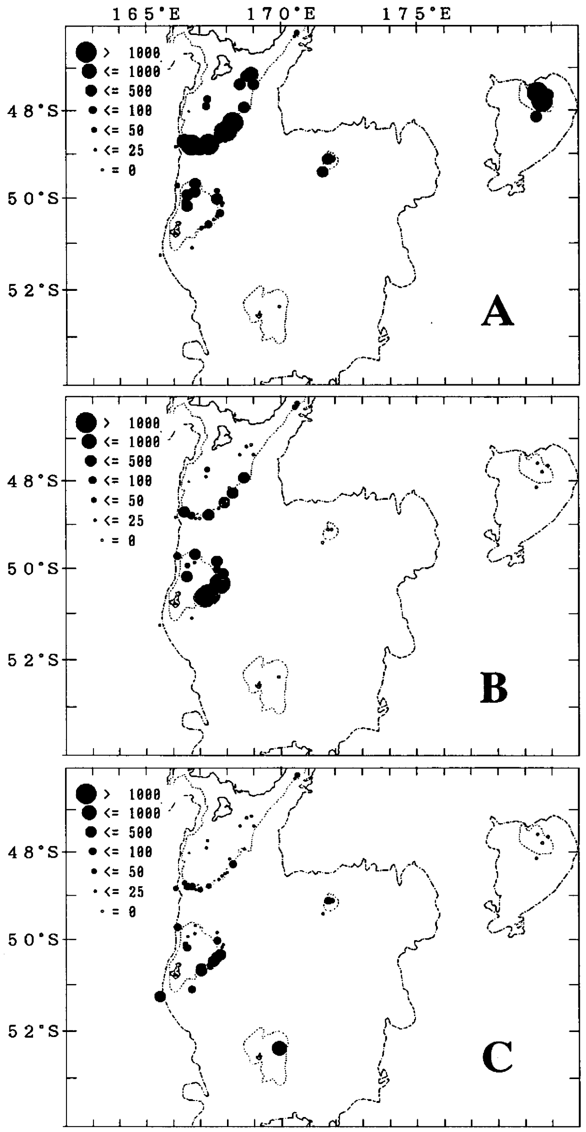


Fig. VI-23. Distribution and CPUEs (number/ standard trawl haul, 0.028 n mile^2) of *N. sloanii* in the Survey No. 9 during 7th March and 30th April 1982. A: 4-6 months old group, B: 7-9 months old group, and C: 10-12 months old group.

C).

In Survey No. 10, the CPUEs of squid in the Campbell Island Shelf and Pukaki Rise were lower than 10 squid per standard haul and there was no size data for the stations in the area. A few stations were allocated in the central part of the Snares and Auckland Island Shelves. Then it was difficult to describe the distribution pattern in these Shelves.

Squid of 4-6 months old which corresponded to April-June classes was distributed widely in the shallower waters on the Snares and Auckland Island Shelves and Bounty Platform during the Survey No. 10 (Fig. VI-24-A). CPUEs of this age group were very low. Squid of 7-9 months old which corresponded to January-March classes was distributed on the Snares and Auckland Island Shelves and Bounty Platform (Fig. VI-24-B). High CPUEs of this age group were observed in the edge of the Snares Shelf. The distribution pattern of 10-12 months old group, which corresponded to October-December classes, was very similar to it of 7-9 months old group (Fig. VI-24-C).

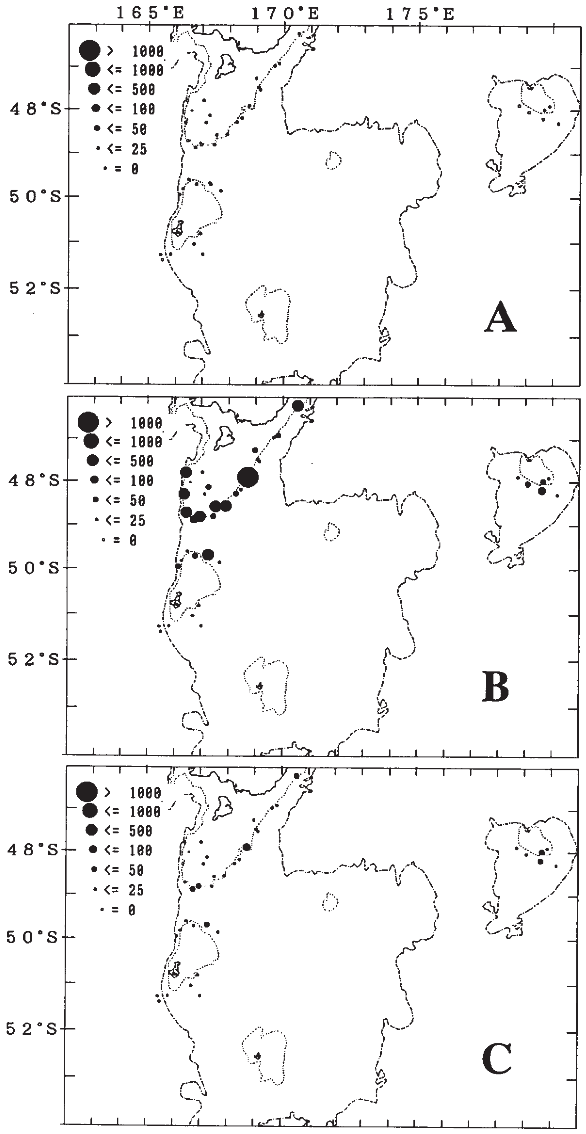


Fig. VI-24. Distribution and CPUEs (number/ standard trawl haul, 0.028 n mile^2) of *N. sloanii* in the Survey No. 10 during 6th October and 19th November 1983. A: 4-6 months old group, B: 7-9 months old group, and C: 10-12 months old group.

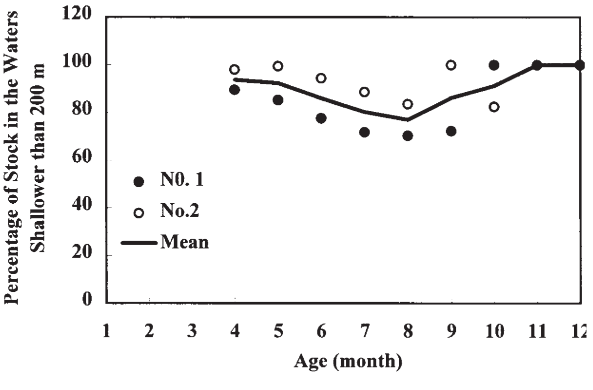


Fig. VI-25 Percentage of *N. gouldi* stock which was distributed in the the waters shallower than 200 m depth. The value of percentage in each age was obtained from abundance indices of each month class by depth range.

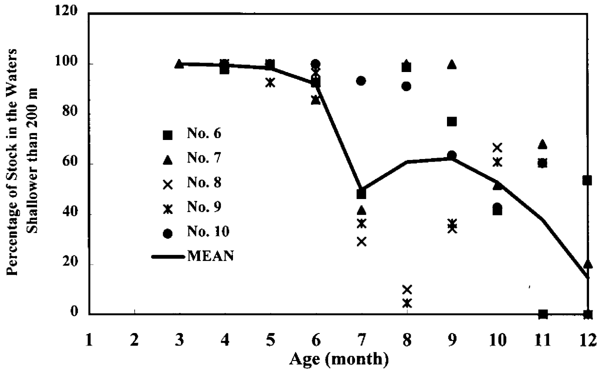


Fig. VI-26. Percentage of *N. sloanii* stock which was distributed in the depth range of 0-200 m on the Snares Shelf. The value of percentage in each age was obtained from abundance indices of each month class by depth range.

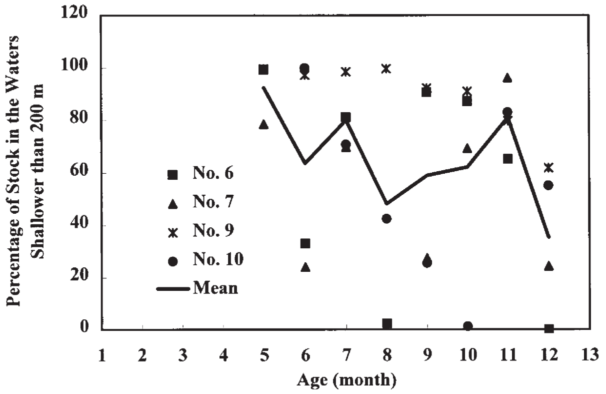


Fig. VI-27. Percentage of *N. sloanii* stock which was distributed in the depth range of 0-200 m on the Auckland Island Shelf. The value of percentage in each age was obtained from abundance indices of each month class by depth range.

The results of five bottom trawl surveys showed that almost all month classes occurred on the Snares and the Auckland Island Shelves.

(8) Change of the precentage of the squid distributed on the shelf by age

A. *N. gouldi* in the waters off west coast of the North Island

To compare the distribution pattern among the ages, the percentage of squid for each month class which was distributed in the 0-200 m depth range was calculated. Fig. VI-25 shows the change of percentage of squid which was distributed in the 0-200 m depth range with age which was converted from month class.

Table VI-3. Percentage of fully matured *N. gouldi* in mature specimens by fine biological sampling area shown in Fig. II-1. A fully Mature male is a mature male with SSI higher than 1.5. A fully matured female is a copulated female with ODSI higher than 4. Percentage shown in thisTable is percentage of fully matured squid in mature males or copulated females.

	Male		Female	
Fine Biological Sampling Area	% of Fully Matured Males	Number of Mature Males	% of Fully Matured Females	Number of Mature Females
B	16.9	178	28.4	74
C	12.7	165	11.4	44
D	9.5	21	9.1	11
E	0.0	5	0.0	2

Table VI-4. Percentage of fully matured *N. sloanii* in mature specimens by fine biological sampling area shown in Fig. II-1. A fully Matured male is a mature male with SSI higher than 1.5. A fully matured female is a copulated female with ODSI higher than 4. Percentage shown in this Table is percentage of fully matured squid in mature males or copulated females.

	Male		Female	
Fine Biological Sampling Area	% of Fully Matured Males	Number of Mature Males	% of Fully Matured Females	Number of Mature Females
A	-	-	-	-
B	50.0	2	-	-
C	0.0	2	-	-
D	0.0	8	50.0	2
E	0.0	7	-	-
F	30.4	332	38.2	238
G	-	-	-	-
H	-	-	-	-
I	24.0	25	36.0	25
J	34.7	49	26.8	41
K	25.7	74	30.9	68
L	50.0	28	73.3	45
M	39.5	129	48.1	77
N	37.6	218	32.4	438
O	0.0	18	1.3	75
P	12.5	8	0.0	22
Q	0.0	3	0.0	12
R	33.3	6	8.3	12

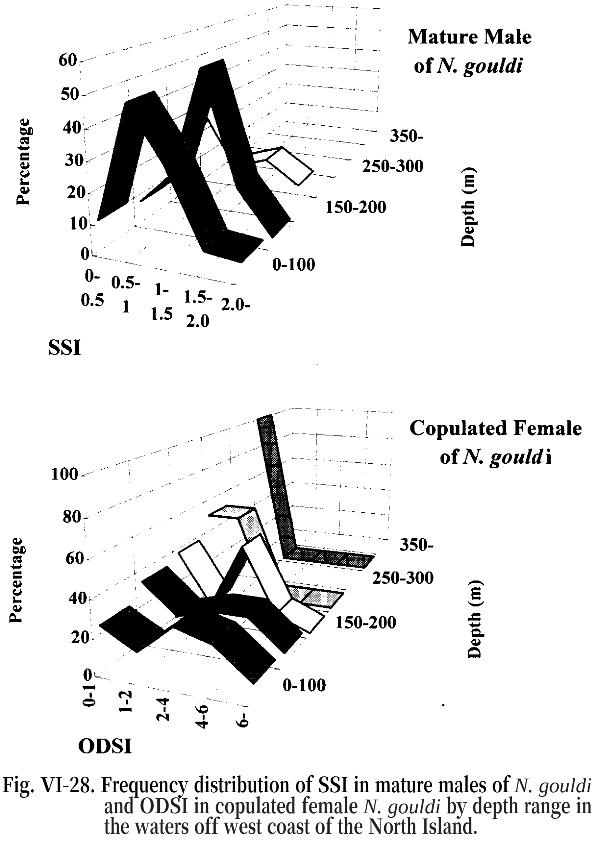


Fig. VI-28. Frequency distribution of SSI in mature males of *N. gouldi* and ODSI in copulated female *N. gouldi* by depth range in the waters off west coast of the North Island.

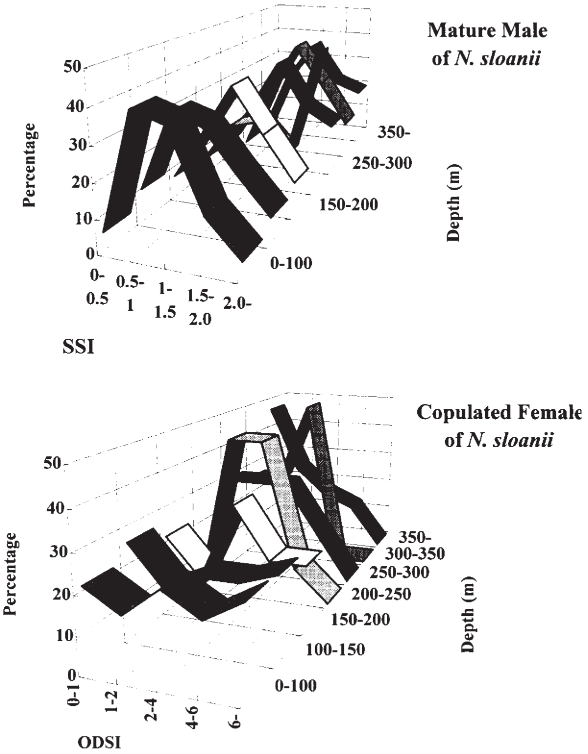


Fig. VI-29. Frequency distribution of SSI in mature males of *N. sloanii* and ODSI in copulated female *N. sloanii* by depth range on the Snares Shelf.

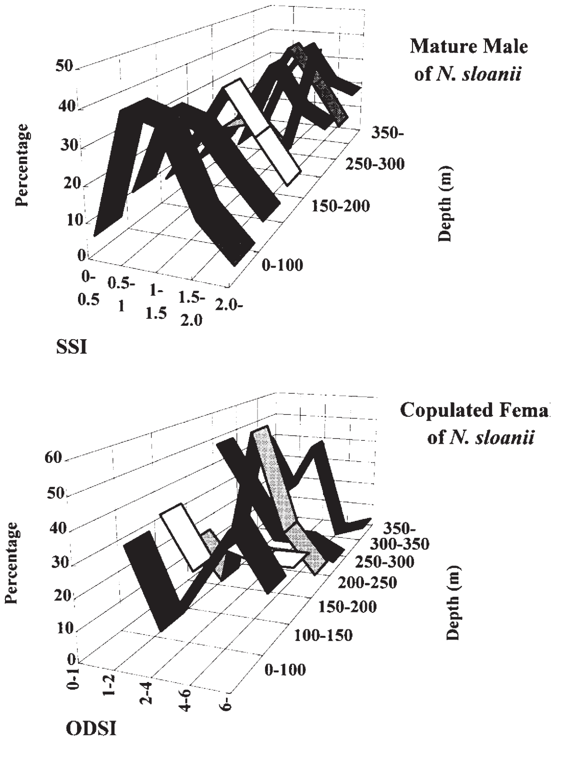


Fig. VI-30. Frequency distribution of SSI in mature males of *N. sloanii* and ODSI in copulated female *N. sloanii* by depth range on the Auckland Island Shelf.

The percentage of stock in the waters shallower than 200 m depth, which indicates the squid distributed on the shelf, decreased gradually from 4 or 5 months old till 8 months old, but it increased to 100% in 12 months old. This trend may mean that some part of stock moved into slope waters with age younger than 8 months old and moved back to shelf waters in age older than 8 months old, if there was no difference in the movement pattern among the month classes.

B. *N. sloanii* on the Snares Shelf

Fig. VI-26 shows that most portion of stock younger than 5 months old was distributed in the depth range of 0-200 m which corresponded to the shelf waters. In 7-8 months old, percentage of stock on the shelf decreased and then mean value became relatively stable in 9-10 months old, though the values were variable among the surveys. In 11-12 months old, the mean value decreased to nearly 10%.

C. *N. sloanii* on the Auckland Island Shelf

Fig. VI-27 shows that most portion of stock younger than 6 months old was distributed in the depth range of 0-200 m which corresponded to the shelf waters. In 6-8 months old, percentage of stock on the shelf decreased and then mean value increased from 8 months old to 11 months old, but decreased again in 12 months old, but the percentage remained about 40% in this age.

(9) Distribution of fully matured squid

Table VI-3 shows the percentage of fully matured squid in matured *N. gouldi* by fine biological sampling area shown in Fig. II-1. It is clear that the higher percentage of fully matured squid for both sexes was observed in more northerly areas. Table VI-4 shows the percentage of fully matured *N. sloanii* by fine biological sampling area. Few fully matured squid were obtained from the water around the North Island and the west coast of the South Island, but most of the other area, fully matured squid was observed. There was no clear difference in the percentage among the area where more than 20 specimens were collected, except for Area L (mid-part of the Chatham Rize).

(10) Distribution of fully matured squid by depth range

Fig. VI-28 shows the frequency distribution of SSI for mature males and ODSI for mature and copulated females of *N. gouldi* in the waters off west coast of the North Island by depth range. No mature male was obtained from the waters deeper than 250 m. Modes of SSI were obtained in 0.5-1.0 or 1-1.5 and there was no clear difference in the frequency distribution among the depth range. In the waters deeper than 200 m, there was no mature and copulated females with ODSI higher than 4.0. In shallower waters than 200 m, mature and copulated females with ODSI higher than 4.0 were commonly observed and frequency of these females attained to about 50%.

Figs. VI-29 and 30 show the frequency distribution of SSI for mature males and ODSI for copulated females of *N. sloanii* on the Snares Shelf and the Auckland Island Shelf by depth range. For mature males, there was no clear difference in the frequency distributions of SSI among the depth ranges. But for mature and copulated females, the frequency of high ODSI became lower in the deeper area. In the shallower waters, the frequency of higher ODSI increased. These trend for both sexes were very similar to each other between the Snares and Auckland Island Shelves.

3. Discussion

In the present surveys the size ranges of rhynchoteuthion and transition stages of paralarval *N. sloanii* were 1.5-8 mm and 4-12 mm in DML, respectively. Forch (1986) showed that sizes of paralarvae of *Nototodarus* ranged from 1.3 to 10.1 mm in DML and transition stage was observed from about 4.5 mm DML. The present results are consistent with those of Forch (1986). Hatanaka (1986) showed that size ranges of *Illex illecebrosus* at rhynchoteuthion and transition stages were 1.6-5.7 mm and 4.0-8.2 mm DML. The size range of Todarodes pacificus at paralarval stage is 0.7-15.5 mm DML (Hamabe,1962), though DML at the end of the stage is variable from about 7-16 mm (Okiyama, 1965; Okutani, 1968). The size ranges of the two *Nototodarus* species at rhynchoteuthion stage are similar to those of *I. illecebrosus* and *T. pacificus*, although the duration of the paralarval stage for each species is unknown.

The ageing results suggest that growth at the juvenile stage approaches to about 24 mm per month. The difference in modal length between the 1st and 2nd period of the *Kaiyo Maru* fine mesh midwater trawl survey ranged from 10 to 15 mm. The difference between modal size was less than that predicted by the ageing result. This mismatch was even clearer in the hatching month calculations for juvenile *N. gouldi* and *N. sloanii* (Fig. VI-14).

This discrepancy between estimated growth and size composition may be caused by the change in the catchability of midwater trawl with size, including both mesh selectivity of the gear and greater avoidance ability of older juveniles. The smaller juveniles and paralarvae than 10 mm DML may not be retained in the cod-end with a 10 mm mesh liner. The larger squid may avoid the gear, because few squid larger than 50 mm DML were caught by the midwater trawl, although many squid of 50-100 mm DML were caught by the bottom trawl surveys (Survey Nos. 5 and 8) in the same season and area (see Figs. VI- 19 and 22).

The DML of specimens caught by the bongo net ranged from 1.5 to 11 mm, and with most less than 5 mm DML. In contrast, juveniles larger than 10 mm DML were frequently caught by the larva-net. There was a large difference in the range of DML of squid captured by the bongo net and the larva-net, though the diameter of the ring of the net and the mesh size were the same. Since the larva-net filtered water emerging from the cod-end of bottom trawl net, it is suggested that the turbulent flow from the cod-end makes easier to catch larger juveniles.

Based on the linear relationship between age and DML in juvenile *N. sloanii*, the hatching month of juveniles caught in 1st and 2nd periods of the fine mesh midwater trawl survey was estimated. These results showed that most juvenile *N. gouldi* and *N. sloanii* caught during the survey might be born in April/May and May/June, respectively. The growth of juvenile *N. gouldi* is not known, but the results in the Chapter III showed that there is little difference in growth between *N. sloanii* and *N. gouldi* smaller than about 150 mm. If the linear equation of juvenile *N. sloanii* is used to estimate age of juvenile *N. gouldi*, there may not be serious bias in the estimation. On this basis it is probable that most juveniles of *N. gouldi* and *N. sloanii* caught in the fine mesh midwater trawl survey hatched in austral autumn (April/June).

It was difficult to estimate the birth date of paralarvae caught by bongo net and larva-net using by the Age-DML equation derived from the juvenile samples. Applying the equation suggests that *N. sloanii* of 20 mm DML are about 97 days old. If squid smaller than 20 mm DML grow linearly after hatching, it may take about 25 days to grow to 5 mm DML and 50 days to grow to 10 mm DML. Based on these rough estimations, the paralarvae caught by the larva-net might have been born in April/June which suggests a similar seasonal group to that sampled by the fine mesh midwater trawl. This also suggests that the duration of paralarval stage may be 50-60 days for both species.

Forch (1986) presents data suggesting that the paralarvae of *Nototodarus* species are distributed on the continental shelf and the adjacent area. The present results also show that paralarvae of *N. sloanii* occur on the shelf around the mainland, on the Mernoo and Veryan Banks, and around the Chatham Is. Furthermore, the results of the larva-net survey support the hypothesis that the paralarvae of *N. sloanii* do not occur in off-shore waters, although no paralarva caught in either survey was confirmed as *N. gouldi*. Forch (1986) showed that paralarvae of *Nototodarus* sp. occur in coastal waters where *N. gouldi* are abundant. Based on these results, it can be surmised that the paralarvae of *N. sloanii* are mainly distributed in coastal waters, including on the banks and around the islands. Furthermore, it is probable that the paralarvae of *N. gouldi* may be similarly distributed in the coastal waters.

The bongo net sampling revealed that paralarvae of *N. sloanii* are distributed off the west coast of South Island, but the fine mesh midwater trawl sampling revealed that there was no juvenile of *N. sloanii* in this area. Some paralarvae of *N. sloanii* were caught at the stations on the slope area, especially for the area in the southern part of the west coast of the South Island, but few juveniles were caught at the stations which located on the slope area. The comparison of the distribution pattern between paralarva and juvenile *N. sloanii* shows that the distribution area of the juveniles may be restricted more closely to the shelf than the paralarvae. This difference in the distribution pattern may be one of the reasons why no juvenile *N. sloanii* was caught in the waters off the west coast of the South Island, especially for the area in the southern part where almost stations located on the slope waters.

As for adult *N. gouldi*, the surveys covered the waters off west coast of the South Island two times, but species identification was not carried out at the species level, though this species is distributed around the North Island and west coast of the South Island where both species coexist. Then the detail of the distribution pattern of adult in this area is still unknown. For *N. sloanii*, the surveys covered very well on the main distribution area such as the Chatham Rise, Snares Shelf, Auckland Island Shelf, Campbell Plateau, and the Bounty Platform, though they did not covered the east coast of the North Island.

In the waters off west coast of the North Island, adult *N. gouldi* is distributed widely throughout all survey area and there was no clear difference in the distribution pattern among the age groups from 4 to 12 months old. The surveys covered mainly summer season in this area and then there was insufficient information to know the change of distribution by age for all month classes of *N. gouldi*. The changes of percentage of stock in the waters shallower than 200 m depth by age indicated that *N. gouldi* migrates into the deeper waters since about 5 months old and peaked at 8-10 months old and then migrates to the shallower waters in the age older than 10 months old. The frequency distributions of SSI for males and ODSI for females suggested that females migrate into shallower waters with maturation, especially with the ovulation, but males may not migrate clearly with maturation. The surveys covered only the waters shallower than 300 m depth and this depth range might be not sufficient to describe the whole figure of the vertical distribution of this species.

There is no clear evidence which shows the spawning ground of *N. gouldi* directly. The results from the surveys on paralarva and adult stages of *N. gouldi* indicates that this species may spawn on the shelf and one main spawning site may occur on the North Taranaki Bight (shelf waters north of 39° S), because the fully matured squid was obtained mainly from the North Taranaki Bight (Fig. VI-28 and Table VI-3). The results of tagging experiments showed that some squid migrated north (Sato, 1985). This result of the tagging experiment also supports the existence of the spawning site in the North Taranaki Bight. Gibson (1995) also pointed out the northern movement with maturation. But juveniles were distributed widely on the shelf off west coast of the mainland and there was no clear trend of size composition of juveniles. These phenomenon may suggest that the spawning does not occur only in a restricted area.

The bottom trawl surveys made it clear that adult *N. sloanii* is distributed widely in the waters off east coast of the South Island, Chatham Rise, Snares Shelf, Campbell Plateau, and Bounty Platform. This species is distributed in the waters shallower than 600 m depth and mainly distributed in the waters shallower than 400 m depth. The surveys covered almost seasons for the Chatham Rise, Snares and Auckland Island Shelves and these results showed that there was no clear differences in the geographical distribution among ages and among month classes. There was no evidence on migration among the areas from the results of the tagging experiments (Sato, 1985; Yamada and Kattoh, 1987). Yamada and Kattoh (1987) showed that the time elapsed was shorter, the distance per day was longer. It is suggested that these squid repeated the small irregular movement. There was no record that the squid released on the Snares Shelf was recaptured in the other area (Yamada and Kattoh, 1987). Sato (1985) also reported that no squid released on the Canterbury Bight was recaptured in the other areas. These results supported that *N. sloanii* does not make long distant migration.

These results show that *N. sloanii* may not migrate among the areas on a large scale, but change of the percentage of squid shallower than 200m depth by age suggested the clear inshore-offshore migration (Figs. VI-26 and 27). On the Snares Shelf almost all squid younger than 5 months old is distributed on the shelf and some part of squid older than 6 months old begin to migrate into slope waters. More than 50% of squid older than 7 months old is distributed in the waters deeper than 200 m. The similar migration pattern was also observed in the Auckland Island Shelf.

There was no clear differences in the frequency distribution of SSI in the mature male among the depth range (Figs. VI-29 and 30), but there was a clear difference in the frequency distribution of ODSI in the mature female among the depth range and there were few mature females with ODSI higher than 4.0 in the slope waters deeper than about 200 m. These trend suggested that mature males do not migrate clearly between shelf and slope waters with further maturation, but copulated mature female may migrate to shallower waters with further maturation, though Figs. VI-26 and 27 did not show the such migration pattern from the slope waters to shelf waters. Mattlin *et al.* (1985) showed the change of the size composition of *N. sloanii* by depth which was very similar to the results shown by Fig. VI-26 and 27 and it also showed that squid larger than 30 cm DML are distributed in the waters shallower than 50 m depth where is out of the present survey area. Gibson (1995) also pointed out that the larger squid is distributed in the water shallower than 50 m depth. These results support the migration from the slope waters to the shallower waters with maturation and suggest that the spawning ground may exist in the coastal waters shallower than 50 m depth.

The present surveys showed that the distribution pattern of juveniles is very similar to it for the adult stage around the mainland of New Zealand, except for the absence of *N. sloanii* on the west coast of the South Island. These results show that both of *N. gouldi* and *N. sloanii* are distributed mainly on the shelf and upper slope through all their life spans and the spawning grounds of these species might be located on the shelf. The younger squid is distributed on the shelf and migrates into slope waters shallower than about 400 m depth with growth. After squid attains to the mature stage, female migrates back to shelf waters to spawn. There was no clear trend of migration with maturation in males. This means that males may mate females in the wide area from shelf to slope waters.

VII. Food

Information on what squid eat is derived from (1) stomach contents, (2) direct observation in the sea, (3) laboratory studies. These methods have some inherent difficulties. The most important single source of information is from the analysis of stomach contents. But in this analysis, it is usually difficult to identify the species found in the diet, because the prey is broken into small fragments. This will lead to an underestimate of the number of species eaten since those with little or no hard parts will go undetected.

In the present study, the rough categories of food such as fish, squid, and crustacean were used for the observation in the most case. Based on the observations of stomach content, the changes of feeding activity and prey animals with size, maturation, season etc. are analyzed in this chapter.

1. Material and method

(1) Samples

Specimens used for this chapter were collected from the catch of the Japanese commercial trawlers, squid jiggers, and research vessels from 1979 to 1992. Until 1982 the species identification of *Nototodarus* species was not sufficient as shown in Chapter II, but the result in Chapter II also indicated that almost all of *Nototodarus* squid in the eastern and southern waters off the South Island belong to *N. sloanii*. Then all of specimens collected from these waters before 1982 are considered as *N. sloanii*. The specimens, which were collected before 1982 from the west coast of the main Islands where both of the two species coexist, were not used in this chapter. Summary of the samples is shown in Tables VII-1 and 2. Stomach contents were observed after measurements and observation shown in Chapter III-1-(2). The prey items were classified into four categories such as squid, fish, crustacean, and others. Further identifications were carried out, if possible. The occurrence of each food category was recorded.

The accurate time when the sample was collected was not recorded, but the times when the trawl or jigging operation was started and terminated were recorded for some of the samples. For the analyses with the factor of time, only the samples were used in the case that the duration of each operation was less than four hours. Using the medial time of each operation, the time of sample collected was classified into the four time-strata such as night, dawn, day, and dusk.

(2) Statistical method

It is probable that the occurrence of empty stomach and each food category may belong to binomial distribution. The occurrence of empty stomach and food categories (squid, fish, and crustacean) were observed for different levels of the factors such as year, season (quarter of the year), area (fine biological sampling area, Fig. II-5), DML (-100, 100-150, 150-200, 200-250, 250-300, 300-350, and 350 mm-), sex, maturation stage, and gear (trawl or jig). In the present study, a logistic regression for these data was applied as a generalized linear model with the occurrence equal to the binomial proportion (number of occurrence/number of specimens). For these data, year, season, area, DML, sex, and maturation stage were used as explanatory variables. The GENMOD procedure in SAS (release 6.09), which is a procedure for a generalized linear model analysis, was used with logit as link function (SAS, 1993). A full model, which includes all of factors mentioned above and two-way interactions, was used as the first trial. Then insignificant factors and interactions were deleted in several trials.

2. Results

(1) Food items

It was very difficult to identify the species of preys in the stomach of squid, because the prey were broken into small particles. Based on the morphology of otolith and scale, most of prey fish might belong to Myctophidae and some of them were sprat (*Sprattus antipodum*) and/or pilchard (*Sardinops neopilchardus*) . As for the squid found in the stomachs, most of prey squid might be *Nototodarus* species, judging from the estimated thickness of mantle tissue and color of the mantle pieces. The species of crustacean found in stomach were hardly identified. Some of them belonged to Mysid, Isopod, and Euphasid. Some megalopa larvae were found.

(2) Occurrence of empty stomach

The occurrence of empty stomach was analyzed by the generalized linear model with the factors of year, season (quarter of the year), DML, maturation, sex, area, and gear. A total of 2,455 and 15,096 specimens of *N. gouldi* and *N. sloanii* were observed on stomach condition, and 1,048 and 5,179 empty stomachs were found for the two species. For *N. gouldi*, the results of the analysis showed that the factors of year, season, maturation, and gear were significant, but the other factors were insignificant. For *N. sloanii*, the results showed that all of the factors are significant, except for sex.

The expected value of occurrence ratio of empty stomach was estimated for each level of the significant factors (Figs. VII-1-3). For *N. gouldi*, the ratio of empty stomach was stable during 1982-1987, but the ratios in 1991 and 92 became lower (Fig. VII-1). It was observed that the ratio changed slightly with seasons, highest in winter (Jul.-Sep.) and lowest in summer (Jan.-Mar.). Fig. VII-1 showed that the ratio of empty stomach gradually increased with the maturation, and it in the sample by trawl gear was higher that it by jigging.

For *N. sloanii*, the ratio of empty stomach decreased from 1979 till 1982, and then became stable till 1987 (Fig. VII-2). The ratios in 1991 and 92 became lower than those in the previous period. The expected value of the ratio showed the clear seasonal change, highest in winter and lowest in summer. This trend is consistent with it for *N. gouldi* The result also showed the clear trend of the ratio with DML, namely the ratio decreased with increase of DML. Contrarily the ratio

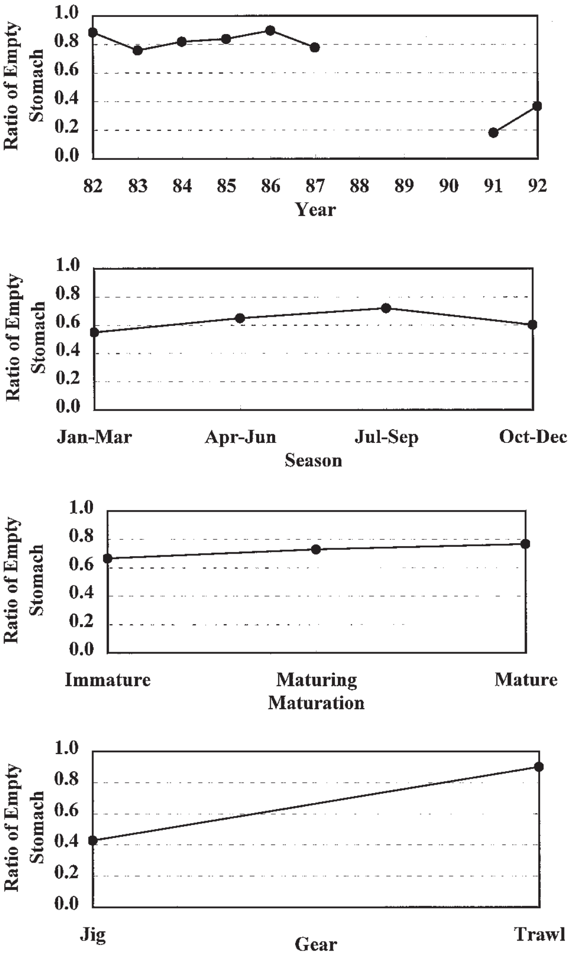


Fig. VII-1. Changes in the ratio of empty stomach in *N. gouldi* with the factors, which are significant in the generalized linear model analysis.

increased with the maturation. There were some differences in the ratio of empty stomach among the areas. The ratio was lowest in Area N (around the Auckland Island), but it was highest in Areas O, P, Q, and R (sub-Antarctic waters). The ratio in the sample by jigging was higher than it by trawl gear.

The ratio of empty stomach by time of day (night, dawn, day, and dusk) was observed for 376 and 7,387 specimens of *N. gouldi* and *N. sloanii*, respectively. For these specimens the analyses by generalized linear model showed that the factors of year, season, and time were significant for *N. gouldi*, though there was insufficient data for samples by trawl gear. As for *N. sloanii*, the factors of year, season, DML, area, gear, and time were significant and interaction between time and gear was also significant. The result showed ratio of empty stomach was highest at dusk and lowest at night for *N. gouldi*, though there was no data at dawn (Fig. VII-3). The results showed that there is an interaction between time and gear in daily change of ratio in *N. sloanii*. Then the expected value of ratio of empty stomach was estimated for each level of time strata by gear as shown in Fig. VII-3. Although the change of the ratio with levels of time was very small for both gears, except for the ratio at dusk for jigging, the ratio was lowest at day and highest at dusk for both gears.

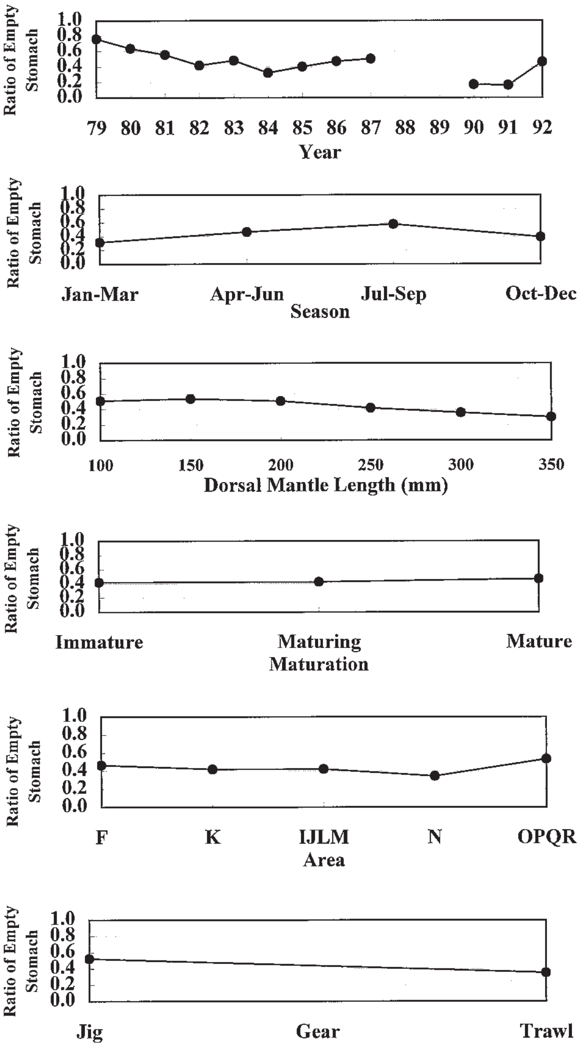


Fig. VII-2. Changes in the ratio of empty stomach in *N. sloanii* with the factors, which are significant in the generalized linear model analysis.

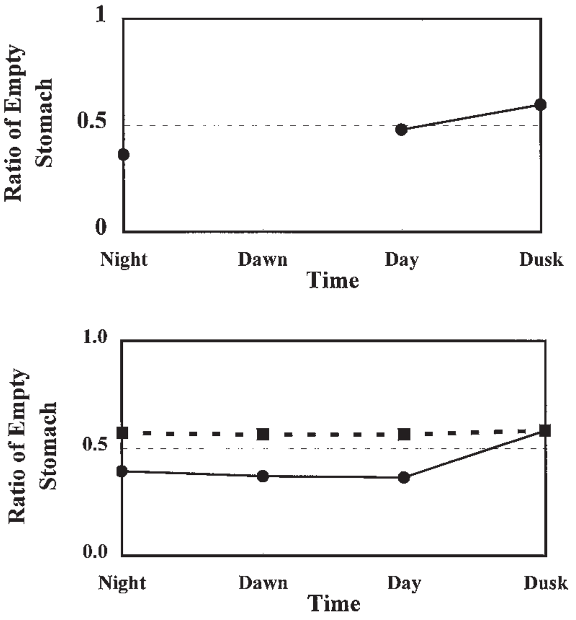


Fig. VII-3. Changes in the ratio of empty stomach with levels of time. Top: *N. gouldi*, Bottom: *N. sloanii*. Solid line: jig, broken line: trawl.

Table VII-1. Summary of the samples of *N. gouldi* for the biological measurements. Fishing year is from November 1st to October 30th. Fine biological sampling area is shown in Fig. II-1. Maximum and minimum dorsal mantle length (mm) are shown in the bottom lines.

	Fine Biological Sampling Area																		
Fishing Year	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	Total
1979/80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1980/81	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1981/82	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1982/83	-	-	13	43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	56
1983/84	-	370	252	73	-	-	-	28	-	-	5	-	-	-	-	-	-	-	728
1984/85	-	122	82	192	-	8	-	-	-	-	-	-	-	-	-	-	-	-	404
1985/86	-	133	82	183	-	14	-	-	-	-	2	-	-	-	-	-	-	-	394
1986/87	-	59	81	16	71	-	-	-	-	-	1	-	-	-	-	-	-	-	228
1987/88	-	-	104	15	49	-	-	-	-	-	-	-	-	-	-	-	-	-	168
1988/89	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1989/90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1990/91	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1991/92	-	60	392	175	-	-	-	-	-	-	-	-	-	-	-	-	-	-	627
1992/93	-	70	83	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	153
Total Number	-	794	1,089	697	120	22	-	28	-	-	8	-	-	-	-	-	-	-	2,758
Maximum(mm)	-	396	380	384	317	378	-	238	-	-	442	-	-	-	-	-	-	-	442
Minimum(mm)	-	112	101	134	174	144	-	202	-	-	154	-	-	-	-	-	-	-	101

Table VII-2. Summary of the samples of *N. sloanii* for the biological measurements. Fishing year is from November 1st to October 30th. Fine biological sampling area is shown in Fig. II-1. Maximum and minimum dorsal mantle length (mm) are shown in the bottom lines.

	Fine Biological Sampling Area																		
Fishing Year	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	Total
1979/80	-	-	-	-	-	316	-	-	-	-	-	-	-	78	-	-	-	19	413
1980/81	-	-	-	-	-	159	-	-	-	-	-	-	-	1,483	504	88	15	38	2,287
1981/82	-	-	-	-	-	1,120	-	-	-	-	-	-	-	928	-	-	3	-	2,051
1982/83	-	-	-	55	-	374	-	-	-	25	85	-	-	499	-	-	-	-	1,038
1983/84	-	3	62	75	-	736	4	1	42	260	368	69	117	730	-	-	20	78	2,583
1984/85	-	-	6	26	9	553	-	-	10	188	237	-	-	1,550	-	46	20	39	2,684
1985/86	-	13	3	102	-	502	-	-	31	128	526	-	32	1,184	-	34	1	23	2,579
1986/87	-	-	13	-	41	780	-	-	51	115	239	96	248	1,350	-	23	-	26	2,982
1987/88	-	-	15	7	37	329	-	-	20	20	20	-	-	390	-	-	-	-	838
1988/89	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1989/90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1990/91	-	-	-	-	-	118	-	-	-	-	51	-	-	-	-	-	-	21	190
1991/92	-	-	1	12	-	1,065	-	-	-	-	120	-	-	-	-	-	-	-	1,198
1992/93	-	1	2	-	-	424	-	-	42	-	-	-	-	22	-	-	-	-	491
Total Number	-	17	102	277	87	6,476	4	1	196	736	1,664	165	397	8,214	504	191	59	244	19,334
Maximum(mm)	-	294	293	338	280	420	311	238	411	383	402	415	423	447	440	420	410	345	447
Minimum(mm)	-	155	135	120	155	170	117	238	150	200	150	107	105	101	140	101	166	156	101

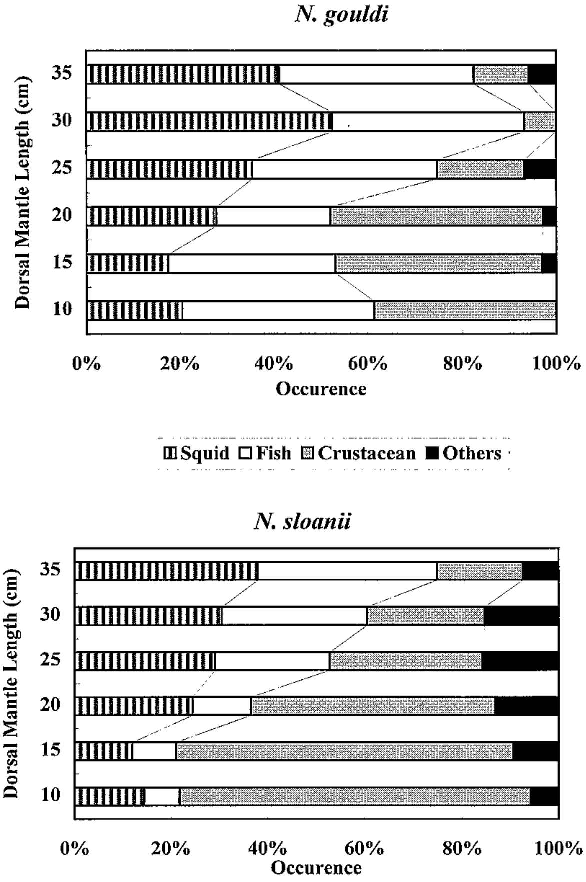


Fig. VII-4. Changes in diet composition by dorsal mantle length. Top: *N. gouldi*, Bottom: *N. sloanii*.

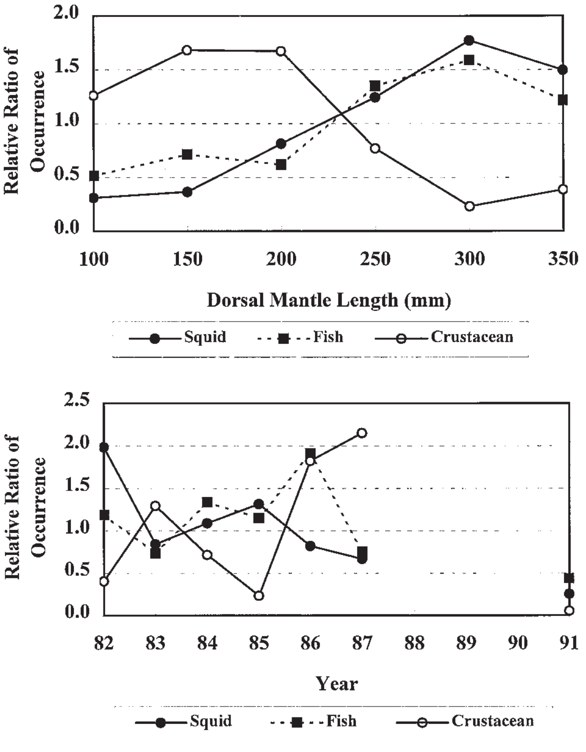


Fig. VII-5. Changes in relative ratio of occurrence for each food category in *N. gouldi* with dorsal mantle length and year, which were significant in the generalized linear model analysis.

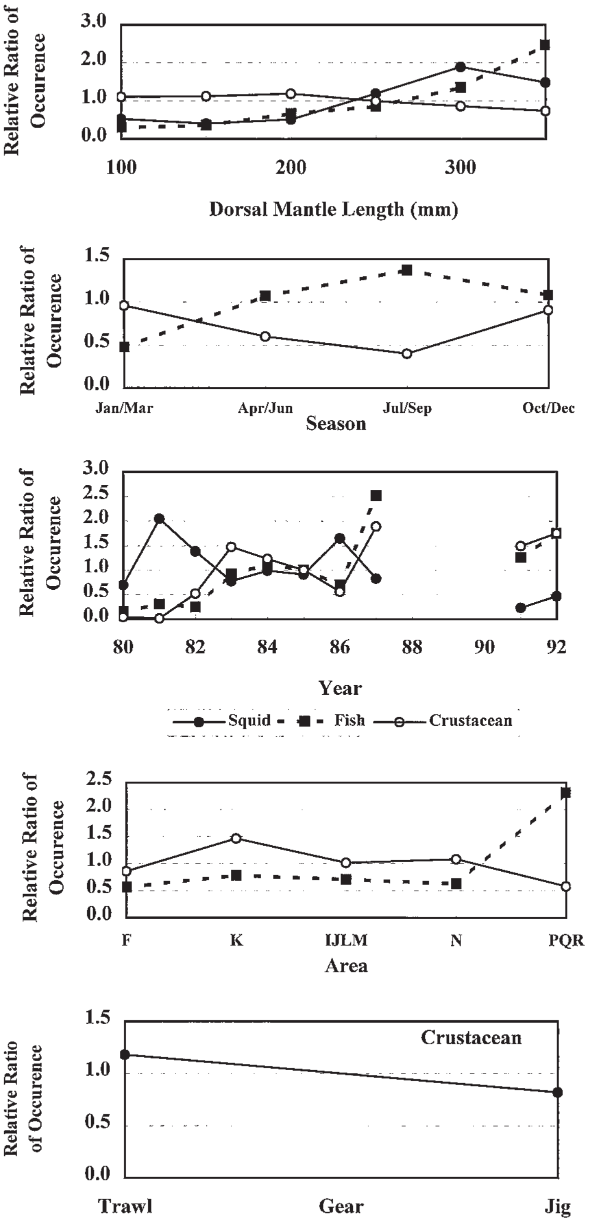


Fig. VII-6. Changes in relative ratio of occurrence for each food category in *N. sloanii* with the factors, which were significant in the generalized linear model analysis.

(3) Occurrence of food category

Occurrence of each food category by DML classes (5 cm intervals) is shown in Fig. VII-4. A total of 1,488 and 10,499 stomach were observed in *N. gouldi* and *N. sloanii*, respectively, except for the empty stomachs. In *N. gouldi*, occurrence of squid ranged from 20 to 50% and this ratio increased with DML. The occurrence of fish ranged from 20% to 40% and there was no clear trend with DML. The occurrence of crustacean ranged from 10% to 40% and the ratio decreased with DML. In *N. sloanii*, the trend in occurrence of squid and crustacean with DML was very similar to it in *N. gouldi*, but the occurrence of fish also increased with DML. The occurrence of crustacean was much larger than it in *N. gouldi*.

The results of the analyses showed that the factors of DML and year were only significant in *N. gouldi*, and in addition to the two factors season and area were also significant in *N. sloanii*. The effect of each factor are shown in Figs. VII-5-6. In these Figures, the ratio of occurrence is shown as the relative value to the overall mean of the ratio to show the trend more clearly, because the ratio of occurrence was very variable among the food categories. In *N. gouldi*, the occurrences of squid and fish increased with DML, but the occurrence of crustacean decreased contrarily (Fig. VII-5). The results of the analyses suggested that the occurrences of food category changed significantly with year. The trends in squid and fish were similar to each other, but the trend of crustacean was negatively correlated to those of squid and fish.

In *N. sloanii*, the trends with DML and year were very similar to those in *N. gouldi* (Fig. VII-6). The seasonal changes of occurrence were significant for fish and crustacean, but it was not significant for squid. The seasonal trend of fish and crustacean was negatively correlated to each other. The occurrence of fish peaked in winter (July-September) and was lowest in summer (January-March). The occurrence of fish and crustacean were different among the areas. The occurrence of fish was highest in the sub-Antarctic area (Areas P-Q-R) and lowest in the Snares shelf (Area F). It of crustacean was highest in the Canterbury Bight (Area K) and lowest in sub-Antarctic area. The occurrence of crustacean was significantly different between the gears, but there was no clear difference in the other two categories between the gears.

The number of specimen observed for stomach contents by time strata was 173 and 5,131 for *N. gouldi* and *N. sloanii*. The analysis with the levels of time was not carried out for *N. gouldi*, because there were

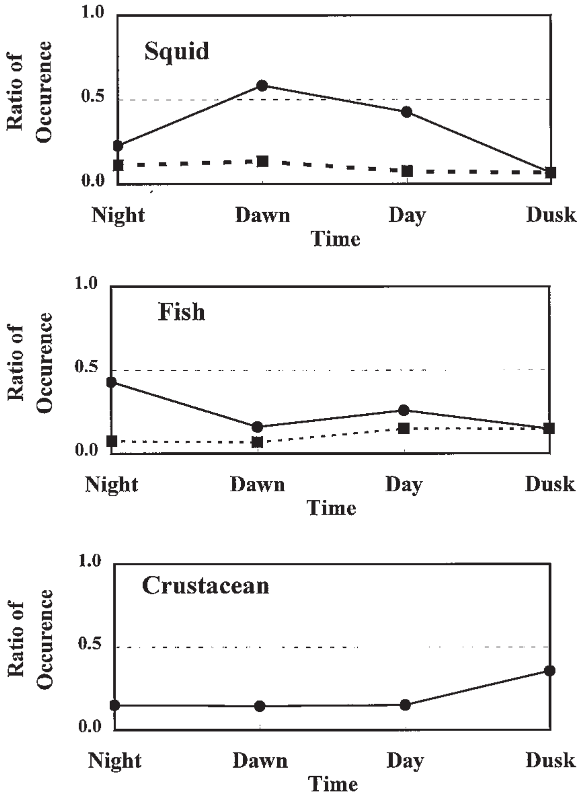


Fig. VII-7. Changes in the ratio of occurrence for each food category in *N. sloanii* with levels of time. Solid line : jig, broken line: trawl.

insufficient number of specimens. For *N. sloanii*, the results of analyses showed that the factors of year, season, DML, area, gear, and time were significant. An interaction between time and gear was also significant, except for the occurrence of crustacean. Fig. VII-7 shows the occurrence ratio of each food category by levels of time. For the category of squid, the occurrence peaked at dawn for both gears, though the range of changes in ratio for trawl was much smaller than it for jig. For fish, the occurrence peaked at night, but was stable for the other levels of time for jig. The occurrence of fish in trawl sample increased gradually from night to dusk, though the range was very small. The time-gear interaction was not significant in the occurrence of crustacean and the change with level of time is shown as the gear combined one. The occurrence of crustacean was very stable, except at dusk when the occurrence peaked.

3. Discussions

Yastu (1986) investigated the stomachs of *N. sloanii* caught by a bottom trawl on the Snares Shelf and around the Auckland Island and found the most frequent fish was Myctophid species and some southern blue whiting (***Micromesistuis australis***). It was also observed that *Nyctiphanes australis* (Euphausidae) was most common crustacean in the stomach. The prey squid was identified to *N. sloanii* based on the feature of the mantle pieces. O'Sullivan and Cullen (1983) also investigated the stomach of *N. gouldi* caught by a squid jigging in the Bass Strait, Australia and identified 47 different prey categories with 16 generic or specific groups. It was suggested that the most common prey fishes were pilchard and barracouta (*Thyrsites atun*). The common prey crustaceans were ***Leptochela sydniensis*** (Caridae) and *Cirolana* sp. (Eurydicidae). It was pointed out that the majority of prey squid belonged to *N. gouldi,* but some *Todarodes filippovae, Rossia, Onychoteuthis, Brachioteuthis*, and *Sepioteuthis* spp. were observed. These results showed that *Nototodarus* species feed common species in fish, crustacean, and squid in the study area.

In the present study, the species identification was not sufficiently carried out and the species composition in food was still unknown. but judging from some observations on stomach contents in the present study, the results of Yatsu (1986) and O'Sullivan and Cullen (1983), the major species occurred in stomach might be some myctophid species, pilchard, and barracouta for fish, some euphasid species for crustacean, and *Nototodarus* species for prey squid. It is probable that the species composition of prey animals may change spatially and temporally.

The ratio of empty stomachs and the occurrence ratio of food categories changed with year, season, and area. This result suggested that there might be some differences in abundance of prey animals and also predator squid. But there is no data for the abundance of prey animals and further discussion is not able at this stage. The ratio of empty stomach increased with maturation was observed in both species. The same relationship was observed in *N. gouldi* in the Austrian waters (O'Sullivan and Cullen, 1983). O'Dor *et al.* (1980) found that females of *Illex illecebrosus* ceased to feed as their ovaries developed in the laboratory. Furthermore, it was observed that starvation induced experimentally in females of *Illex illecebrosus* promote the development of gonads and Nidamental gland (Rowe and Mangold, 1975). The maturation occurs very quickly after 200 days old in male and 270 days for female as shown in Chapter IV. The present results indicated that these rapid development of gonad and accessory organs may be related to the feeding activity.

It was observed that there is a consisted trend in the change of the occurrence ratio of food categories with DML, namely the occurrence of crustacean decreased but those of squid and fish increased with DML. The similar phenomenon was also observed in *N. gouldi* in the Australian waters (O'Sullivan and Cullen, 1983), in *N. sloanii* (Yatsu, 1986), and in *Todarodes pacificus* (Hamabe and Shimuzu, 1966). This phenomenon has been explained by these authors as follows, "The predominance of crustaceans in the diet of smaller squid can easily be understood because the average size of these prey is likely to be smaller than the alternatives (fish and squid), and smaller predators will generally takes smaller prey." O'Sullivan and Cullen (1983) showed the positive co-relationship between size of predator squid and prey squid, which was estimated by the size of beaks, found in stomachs. Although there was no data on sizes of preys and predator in the present study, it was probable that the change of food category with DML may reflect the change in the size of preys.

Most of prey squid found in the stomachs were identified as the same species of predator squid based on the thickness and color of mantle particles. The occurrence ratio of squid attained to more or less 20% for both of the two species. Cannibalism are observed in the various species of squid (Nixon, 1987). O'Sullivan and Cullen (1983) and Yatsu (1986) also observed cannibalism *in N. gouldi* and *N. sloanii.* Several authors have suggested the apparent 'cannibalism' may be exaggerated, since captured squid attack anything with which they come in contact (Amaratunga, *et al.,* 1979; Ennis and Collins, 1979). The same problems may occur for the samples collected by squid jigging, because the squid caught by jig may be alive for a time in the collecting trays or bins. But O'Sullivan and Cullen (1983) concluded that cannibalism after capture is unimportant for *N. gouldi* captured by jig, based on the results of the observation on the stomach contents for the time stratified samples after capture. But the effect for the samples by trawlers has been still unknown. In the present study there was no significant difference in the occurrence of squid between the two gears, except for crustaceans in *N. sloanii*. These results suggested that the effect of cannibalism in the trawl net may not so important. Cannibalism is observed in the various cephalopod species in the various families such as Sepiidae, Loligonidae, Gonatidae, and Ommastrephidae (Nixon, 1987). Hixon (1983) discussed on the cannibalism observed in *Loligo opalescens* that incidence of cannibalism increase on the spawning ground and this is interpreted as a behavioral response to overcrowding. Cannibalism in *I. Illecebrosus* is encouraged by a shortage of alternative food (Ennis and Collins, 1979; O'Dor *et. al.*, 1980). But there is no clear relationship between occurrence of squid in stomach of *N. gouldi* and empty stomach (O'Sullivan and Cullen, 1983). The present results suggested that cannibalism is an important element in *N. gouldi* and *N. sloanii*, but it is very difficult to prove the significance of cannibalism.

It is difficult to investigate the daily periodicity of feeding by the frequency-of-occurrence method used in the present study. The rough classification into the time strata and rough record of sampling time also make it difficult to compare the change in occurrence. The significant differences were observed in some factors between the gears. But it is difficult to conclude that these differences is caused by the difference types of gears, because there were some differences in sampling area, samples by jig mainly from the surface-midwater layers in the water shallower than 150 m, but those by trawler from bottom layers in the waters deeper than 150 m.

VIII. Month class composition and annual variation of abundance

The squid fisheries, trawl and squid jigging fisheries, have exploited the present two species since the beginning of the 1970s up to now. The information on the squids from these fisheries is the best available one to observe the change in abundance of squid and month class composition of the stock, because of high time-area coverage, comparing with the survey data shown in the previous chapter. The results of ageing showed that the spawning occur throughout the year for both species and suggested there may be some seasonal cohorts in the stock of each species. Then the information on size composition is essential for monitoring the abundance of each seasonal cohort.

Data from commercial fishery operations provides one of the most available sources of information, which can be used, for monitoring of the abundance of the stock. For assessment of the stock abundance, the most important statistics is often catch per unit effort (CPUE). The usefulness of CPUE derives the basic assumption that CPUE is proportional to abundance. But it is recognized that fishing power generally differs among vessels and density of fish is different among areas (depth strata) and among seasons. Then CPUE must be standardized, if it is to be proportional to abundance.

Recently a form of the log-linear model for modeling CPUE has been applied for the standardization of CPUE. Under the assumption that CPUE is a log-normally distributed variable, the estimator of CPUE will be a minimum variance unbiased estimator. This method was developed by Gavaris (1980) and Kimura (1981) and applied to the standardization of CPUE of the various fisheries in the Northwest Atlantic Fisheries Organization (NAFO) and in the International Commission for the Conservation of Atlantic Tunas (ICCAT). In the present study, generalized linear model (GLM), which is commonly used for the standardization of CPUE in NAFO and ICCAT, is applied for the standardization of CPUE of squid jigging and trawl fisheries by areas to observe the change of the abundance of squid.

In this chapter, the size composition of the catch is estimated using the size composition of each size-category and number of trays produced for each size-category, because the squid catch is sorted into 16 categories and 12 ones in the squid jigging and trawl fisheries, respectively. It is very convenient to estimate size composition of catch form these information. The estimated size composition of the catch in each operation is decomposed into month class composition by iterative month length key (IMLK) as shown in the Chapter V, and the CPUE of each month class is standardized by GLM. The change of abundance was analyzed based on these standardized CPUEs. Based on the standardized CPUE by month classes, occurrences of seasonal cohort and annual fluctuation on abundance for each seasonal cohort were analyzed. This analysis was carried out for both of squid jigging and trawl fisheries, but this application was limited to the main fishing ground for each fishery. The analysis was done for squid jigging fishery in the waters off west coast of the North Island, on the Snares Shelf, and on the Canterbury Bight. The results in the first area may reflect the abundance of *N. gouldi* and those in the other two areas may reflect it of *N. sloanii*. The analysis was done for trawl fishery on the Snares Shelf and on the Auckland Island Shelf. The results in these areas may reflect the abundance of *N. sloanii*.

1. Materials and methods

(1) Samples and data

A. Data of the size composition for each size-category

a. Squid jigging fishery

There are 16 size categories, which are defined by the number of squid in a tray in the Japanese squid

Table VIII-1. Mean dorsal mantle length and standard deviation in each size category of the Japanese aquid jigging fishery for *N. gouldi*.

Size Category	Mean Number per Tray	Mean DML (cm)	Standard Deviation (cm)	Number of Samples
6-10	9	29.4	1.57	3
11-15	13	26.5	1.63	4
16-20	18	24.7	1.41	6
21-25	23	22.4	1.38	5
26-30	28	21.8	1.25	6
31-35	32	20.8	1.29	5
36-40	38	19.9	1.30	5
41-45	44	19.3	1.29	5
46-50	48	18.6	1.50	6
51-55	54	18.1	1.38	3
56-60	62	17.3	1.31	2
61-70	62	17.7	1.55	4
71-80	75	15.6	1.44	2
81-90	90	15.0	1.20	1
91-100	97	15.0	1.52	3
101-	115	14.8	1.37	2

Table VIII-2. Mean dorsal mantle length and standard deviation in each size category of the Japanese aquid jigging fishery for *N. sloanii.*

Size Category	Mean Number per Tray	Mean DML (cm)	Standard Deviation (cm)	Number of Samples
6-10	9	34.2	2.22	7
11-15	13	30.3	1.54	7
16-20	18	27.5	1.75	10
21-25	23	24.7	1.87	14
26-30	28	23.8	1.38	11
31-35	33	22.6	1.41	10
36-40	38	21.7	1.57	13
41-45	43	21.0	1.40	14
46-50	48	20.2	1.39	12
51-55	55	19.4	1.47	10
56-60	58	19.2	1.44	4
61-70	68	18.0	1.14	6
71-80	78	17.1	1.34	4
81-90	87	16.7	1.09	3
91-100	97	15.5	1.21	2
101-	126	14.5	1.19	8

jigging fishery as shown in Tables VIII-1 and 2. The name of each size category means the range of number of squid in a tray. Mean DML and standard deviation in each size category were calculated using the samples obtained from the some commercial vessels. The catch are usually sorted by species and then sorted into each size category and packed in a tray. Then the mixture of the two species in a tray was very rare. There was no mixture of the species in the samples observed in the present study. The mean DML and standard deviation in each size category are shown in Table VIII-1 and 2 by species.

b. Trawl fishery

There are twelve size categories, which are defined by number of squid in a tray in a Japanese trawl company whose trawlers have operated in New Zealand waters. This company presented the samples of each size category voluntarily to National Research Institute of Far Seas Fisheries (NRIFSF). These samples were collected on the Snares and Auckland Island Shelves. All squid in each samples were identified as *N. sloanii*. The mean DML and standard deviation of each size category are shown in Table VIII-3. No sample for *N. gouldi* was obtained.

Table VIII-3. Mean dorsal mantle length and standard deviation in each size category of the Japanese trawl fishery for *N. sloanii.*

Size Category	Mean Number per Tray	Mean DML (cm)	Standard Deviation (cm)	Number of Samples
8L	11	36.1	2.08	4
7L	19	30.2	1.19	4
6L	22	28.3	1.48	4
5L	28	26.8	1.34	2
4L	34	25.3	1.20	4
3L	46	22.9	1.16	4
2L	67	20.5	1.11	4
L	73	20.1	1.08	4
M	84	19.3	1.44	4
S	125	17.8	1.07	4
2S	152	16.5	1.11	2
3S	179	15.1	1.13	4

Table VIII-4. The number of the Japanese vessels sampled for the catch by size category and total Japanese vessels operated in each fishing year.

	Squid Jigging Fishery			Squid Jigging Fishery		
Fishing Year	No. of sample vessels	No. of vessels operated	Coverage	No. of sample vessels	No. of vessels operated	Coverage
79/80	15	150	10.0	0	23	0.0
80/81	15	88	17.0	6	20	30.0
81/82	14	83	16.9	9	17	52.9
82/83	14	101	13.9	8	19	42.1
83/84	30	110	27.3	8	18	44.4
84/85	10	103	9.7	7	17	41.2
85/86	26	84	31.0	7	22	31.8
86/87	23	112	20.5	7	29	24.1
87/88	8	67	11.9	7	32	21.9
88/89	10	138	7.2	4	33	12.1
89/90	15	45	33.3	8	30	26.7
90/91	15	29	51.7	5	22	22.7

B. Data of the catch by size categories and fishing effort

a. Squid jigging fishery

The catch by size categories in each day operated was reported voluntarily to NRIFSF since 1979/80 fishing year. The coverage of reported catch in the total operation of the Japanese squid jigging vessels ranged about 7% to 31% as shown in Table VIII-4. Each record in the voluntary basis report was composed of squid catch (number of trays by size categories) in a day, locality, maximum depth of gear, bottom depth, surface temperature and hours operated. The size category in this report was composed of 12 classes such as 1-10, 11-20, 21-30, 31-40, 41-50, 51-60, 61-70, 71-80, 81-90, 91-100, 101-150 and 151- squid in a tray. For convenience sake, the catches in some pairs of actual size categories shown in Tables VIII-1 and 2 were combined into one class and reported.

There was no report on fishing effort (number of jigging line used in each day operated) in the voluntary report before 1987/88 fishing year when the mandatory report system was started. The questionnaire on number of lines used in each fishing years were collected from 34 Japanese commercial vessels operated through the period of 1979/80-1987/88 fishing years and mean number of lines in each fishing year before 1987/88 was calculated as shown in Fig.

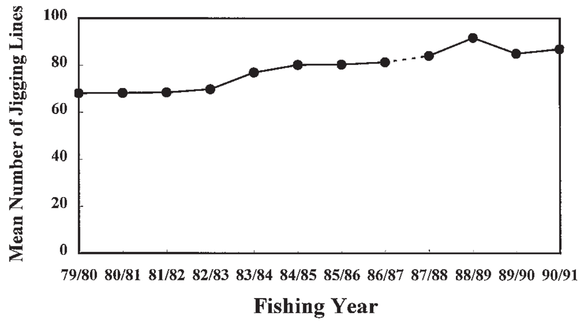


Fig. VIII-1. Mean number of jigging lines in each fishing year for the Japanese squid jigging vessels operated in New Zealand waters. Means in the fishing years before 1987/88 were obtained from the questionnaires collected from the 34 Japanese squid jigging vessels which operated in New Zealand waters. Means after 1987/88 were calculated from the data of all vessels operated.

VIII-1. After 1987/88 fishing year, number of lines used in each day operated was reported from all vessels operated in New Zealand waters. In this analysis, fishing effort in terms of number of jigging line used in each day operated was used. Before 1987/88 fishing year, mean number of jigging line by fishing years was used for each operation. Since 1987/88 fishing year, reported number of jigging lines in each day was used.

Number of observations (number of the operation days in which the catch by size category are available) for squid jigging fishery in each ten-day period by areas are shown in Appendix tables VIII-1 to 3. The analysis was carried out for the period from 1979/80 to 1990/91, except for 1984/85, 1985/86, and 1988/89 fishing years in the waters off west coast of the North Island, except for 1980/81-1982/83 on the Snares shelf, and except for 1990/91 on the Canterbury Bight when the number of observations were insufficient for analysis.

b. Trawl fishery

The catch (number of trays) in each day operated by size categories shown in Table VIII-3 were collected from the Japanese trawlers belonged to a major Japanese fishing company in the period from 1980/81 to 1990/91 fishing years. The number of sample vessels and coverage of samples are shown in Table VIII-4. The coverage ranged from 12% to 53%. Based on this data, mean catch composition by size categories was calculated by area, depth strata (0-100, 101-200, 201-300, 301m -), and by ten-day period in each fishing year. Mean weight of mean catch composition was also calculated using the relationship between DML and body weight obtained by Yamada and Kattoh (1987) for *N. gouldi* and by Uozumi *et al.* (1987) for *N. sloanii*.

The reports of catch and effort have been submitted to the Japanese government mandatorily by the fishing companies and have been compiled at NRIFSF. In this analysis, the statistics from 1980/81 to 1990/91 were used. Each record in the database of the statistics compiled by NRIFSF is composed of fishing effort (number of hauls and hours trawled) and catch in weight by species in 30 minutes in latitude x 30 mintues in longitude square block in a day for each vessel operated. One 30x30 square block where the vessel mainly operated in a day was selected. Furthermore there are the target species, main depth operated and mesh size in a record as the additional information. All operations by the Japanese trawlers were reported.

Using the mean catch composition by size category and mean weight of the composition in each stratum, the squid catch in weight in each record was transformed into catch by size categories. If there was no mean catch composition in a stratum, the operation record in this stratum was deleted in the present analysis.

Number of observations (number of the operation days in which the catch by size category are available) for trawl fishery in each ten-day period by areas are shown in Appendix tables VIII-4 and 5. The analysis was carried out for the period from 1980/81 to 1989/90 on the Snares Shelf, and for the period from 1980/81 to 1988/89 on the Auckland Island Shelf.

(2) Methods

A. Estimation of size composition of catch

The size composition of the catch in each observation (catch in a day for each vessel) was estimated from calculated catch composition by size categories, and mean DML, standard deviation, and mean number in a tray of each size category shown in Tables VIII-1 to 3 under an assumption that size distribution in each size category belongs to normal one.

B. Estimation of catch by month class

The obtained size composition for each observation was decomposed into month class composition by iterative month class length keys obtained in the Chapter V.

C. Standardization of CPUE

Using the database for each fishery constructed in the previous parts in this chapter, the CPUEs of each fishery are standardized by the General Linear Model (GLM). The analysis was carried out using the GLM procedure in SAS ver 6.09.

There are some limitations for usage of the estimated catch by month class, because the size composition, from which the month class composition was estimated, was derived from catch by size categories and size composition in each size category. The smallest size category includes various range of size smaller than the size of the next larger size category. The largest size category also has same situation. Then it is impossible to observe correctly the size composition smaller and larger than the mean length of smallest and largest size categories. Then the reliability for the catch by month class is very low beyond this size limitation. Furthermore, it is known that there is size selectivity of the trawl gear for arrow squid (Anon., 1978). The size composition smaller than DML at 50% retention point (L50) is not reliable. The mesh size of cod-end is mostly 100 mm in New Zealand waters under the regulation by the New Zealand Government, except for the waters around the Auckland Islands where the 60 mm mesh net is usually used. The DML at 50% retention point is about 180 mm and 120 mm DML for 100 mm and 60 mm mesh cod-end, respectively (Anon., 1978). Considering the reliability of size composition and mean size of each month class at every ten-day period, the period for analysis by month class is limited as shown in Tables VIII-5 to 7 in the present analysis.

a. Squid jigging fishery

The squid jigging CPUEs in three areas, the waters off west coast of the North Island, Canterbury Bight, and the Snares Shelf, were standardized. The factors for the standardization of CPUE used in the present study are year, ten-day, area, and tonnage class of vessel. Gross tonnage of vessel was classified into 5 levels such as less than 300 ton, 300-350, 350-400, 400-450, and 450- ton. CPUE is expressed in the catch

Table VIII-5. Reliable period for each month class in the analysis of the squid jigging data for *N. gouldi*. The period was estimated based on the mean DML at each ten-day and mean DML of largest and smallest size categories.

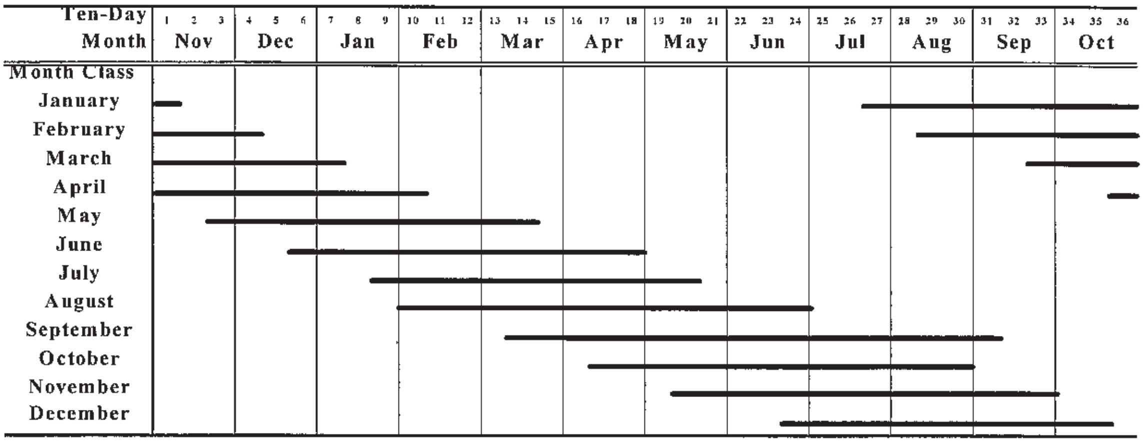
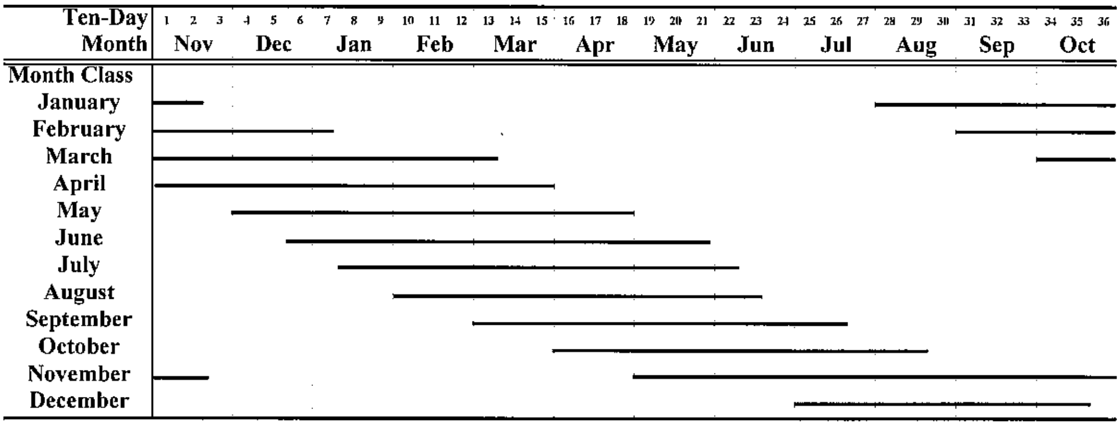


Table VIII-6. Reliable period for each month class in the analysis of the squid jigging data for *N. sloanii*. The period was estimated based on the mean DML at each ten-day and mean DML of largest and smallest size categories.



in number per 10-line per day. The factor of area was used in the waters off west coast of the North Island and on the Snares Shelf. The two levels of area were used for both areas. In the west coast of the North Island, the area was divided into two area by the latitudinal line of 39° 30 'N. On the Snares Shelf, the area was divided into two areas by the latitudinal line of 47° 30 'N.

A model used in the test runs is as follows,

$$LOG(CPUE_{ijkl}+1)= \mu +Year_i+Ten\text{-}day_j+ Area_k +Tonnage\ Class_l + Interactions +e_{ijkl}$$

where LOG : natural logarithm,

$CPUE_{ijkl}$: nominal CPUE (catch in number per 10 lines per a day per one vessel, in year i, ten-day j, tonnage class k), μ : overall mean, interactions : any combinations of two way interaction, e_{ijkl} : normal error term.

First of all this model is applied to the CPUE for overall component which is expressed by total catch of squid per unit effort, irrespective of month class. The selected final model for this component is applied for each month class. The standardized CPUE was calculated for each month class for the reliable period shown in Tables VIII-5 and 6. The number of observations in each fishing season for the squid jigging fishery is shown in Appendix tables VIII-1 to 3. The fishing years which had insufficient number of observations were excluded in the present analysis as shown in the previous section.

The expected value of CPUE for the tonnage class of 400-450 tons in each ten-day was calculated using the estimated parameters by GLM. In the waters off west coast of the North Island and on Snares Shelf, the expected value of CPUE in the northern area was calculated.

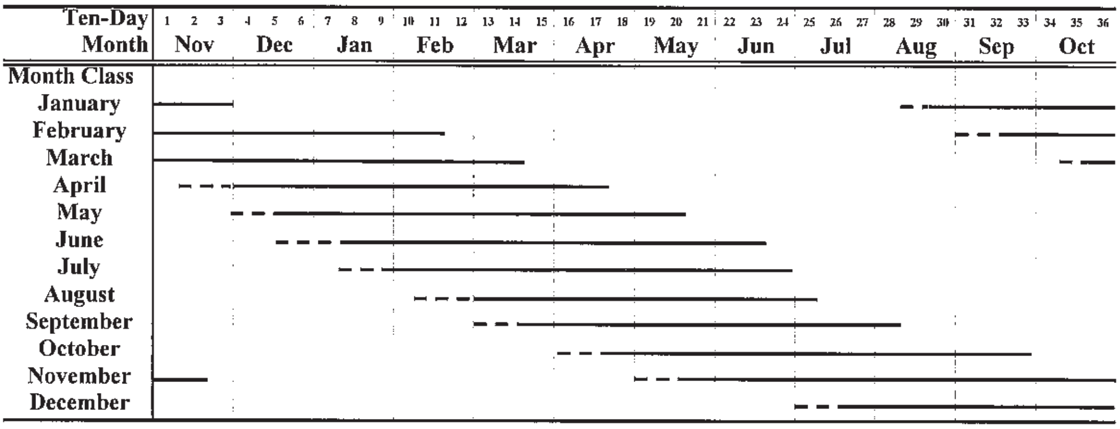
b. Trawl fishery

The trawl CPUEs in two areas, the Snares Shelf and the Auckland Island Shelf, were standardized. The factors for the standardization of CPUE are year, ten-day, tonnage class of vessel, target species, and depth of operation. CPUE is expressed in the catch in number per one hour trawled. Tonnage class of vessel is classified into three levels (550-1,499, 1,500-2499, and 2,500-4,999 tons). The target species is classified into 4 classes (squid, jack mackerel, barracouta, hoki, and others). The factor of depth is classified into three levels (0-199, 200-299, and 300- m).

A model used in the test runs is as follows,

$$LOG(CPUE_{ijklm}+1)= \mu +Year_i+Ten\text{-}day_j+Tonnage\ Class_k+Target_l+Depth_m+ Interactions+e_{ijklm}$$

Table VIII-7. Reliable period for each month class in the analysis of the squid jigging data for *N. gouldi*. The period was estimated based on the mean DML at each ten-day, DML at 50% retention point of cod-end, and mean DML of largest and smallest size categories. The solid lines show the reliable period in the case of the 100 mm mesh cod-end and the broken lines show the reliable period for 60 mm mesh cod-end on the Auckland Island Shelf.



where LOG: natural logarithm,

$CPUE_{ijklm}$: nominal CPUE (catch in number per one hour trawled per one vessel, in year i, ten-day j, tonnage class k, target species l, and depth stratum m), μ : overall mean, interactions : any combinations of two way interaction, e_{ijklm} : normal error term.

First of all this model is applied to the CPUE for overall component which is expressed by total catch per unit effort, irrespective of month class. The selected final model for this component is applied for each month class. The standardized CPUE was calculated for each month class for the reliable period shown in Table VIII-7.

The expected value of CPUE of 2500-4999 tonnage class targeted squid was calculated using the estimated parameters by GLM with weighting factor by area of depth strata. The area of each stratum in Uozumi *et. al.* (1987) was used for the calculation. The fishing years which have insufficient number of observations were excluded in the present analysis as shown in the previous section.

D. Annual abundance index

For each month class, the expected value of CPUE at 210 days old which was commonly observed youngest age for most month classes, was calculated using the estimated parameters obtained from GLM analysis. This expected value of CPUE for each month class was used as the annual abundance index of recruitment for each month class. As the same manner, the expected value of CPUE at 300 days old for each month class was calculated as the annual abundance index of spawner. This age was the oldest one commonly observed for major month classes.

2. Results

A) Final model for the standardization of the CPUEs

1) Squid jigging fishery

After several test runs, the model with the main factors of year, ten-day, tonnage class, and area and interaction between area and ten-day was selected as the final model for the squid jigging CPUEs in the waters off west coast of the North Island and on the Snares Shelf. The final model for the Canterbury Bight was one with the main factor of year, ten-day, and tonnage class. For the standardization of overall component, all of the factors in the present analysis (year, ten-day, and tonnage class of vessel) were highly significant, except for the main factor of area in the west coast of the North Island. The interactions between area and ten-day were also highly significant in the former two areas. The results of analysis of variance for the areas are shown in Tables VIII-8 to 10. The final model selected for the squid jigging fishery is as follows,

for the waters off west coast of the North Island and on the Snares shelf

$$LOG(CPUE_{ijk}+1)= \mu + Year_i + Ten\text{-}day_j + Area k + Tonnage\ Class_k + Area_k * Ten\text{-}day j + e_{ijk}$$

for the Canterbury Bight

$$LOG(CPUE_{ijk}+1)= \mu + Year_i + Ten\text{-}day_j + Tonnage\ Class\ A_k + e_{ijk}$$

This model is applied for all month classes in all of three areas. Based on the estimated parameters in this model, the expected CPUE in each area stratum was estimated.

2) Trawl fishery

After several test runs, The final model for the two areas, Snares and Auckland Island Shelves, have the factors of year, ten-day, tonnage class, target species and depth. For the standardization of overall component, all of the factors in the present analysis were highly significant. The results of analysis of variance for the areas are shown in Tables VIII-11 and 12. The final model selected for the trawl fishery is as follows,

$$LOG(CPUE_{ijklm}+1)= \mu + Year_i + Ten\text{-}day_j + Tonnage\ Class_k + Target_l + Depth_m + e_{ijklm}$$

Table VIII-8. The results of analysis of variance in the final model for the standardization of the squid jigging CPUE for *N. gouldi* on the waters off the west coast of the North Island.

Source	Degree of Freedom	Sum of Squares	Mean Square	F Value	Pr>F
Model	103	1077.900	10.465	17.730	0.0001
Error	2486	1467.711	0.590		
Corrected Total	2589	2545.611			

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Year	8	399.626	49.953	84.61	0.0001
Ten-day	17	86.425	5.084	8.61	0.0001
Tonnage Class	4	14.847	3.712	6.29	0.0001
Area	1	0.133	0.133	0.23	0.6344
Ten-day*Area	11	35.918	3.265	5.53	0.0001

Table VIII-9. The results of analysis of variance in the final model for the standardization of the squid jigging CPUE for *N. sloanii* on the Snares Shelf.

Source	Degree of Freedom	Sum of Squares	Mean Square	F Value	Pr>F
Model	95	2881.662	30.333	23.42	0.0001
Error	4535	5873.134	1.295		
Corrected Total	4630	8754.796			

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Year	8	592.434	74.054	57.18	0.0001
Ten-day	14	453.365	33.383	25.01	0.0001
Tonnage Class	4	25.489	6.372	4.69	0.0006
Area	1	19.143	19.143	14.78	0.0001
Ten-day*Area	12	67.301	5.608	4.33	0.0001

Table VIII-10. The results of analysis of variance in the final model for the standardization of the squid jigging CPUE for *N. sloanii* on the Conterbury Bight.

Source	Degree of Freedom	Sum of Squares	Mean Square	F Value	Pr>F
Model	130	4268.571	32.835	27.470	0.0001
Error	5188	6200.597	1.195		
Corrected Total	5318	10469.168			

Source	Degree of Freedom	Sum of Squares	Mean Square	F Value	Pr>F
Year	10	681.247	68.125	57.000	0.0001
Ten-day	17	1615.291	95.017	79.500	0.0001
Tonnage Class	4	31.945	7.986	6.680	0.0001

Table VIII-11. The results of analysis of variance in the final model for the standardization of the trawl CPUE for *N. sloanii* on the Snares Shelf.

Source	Degree of Freedom	Sum of Squares	Mean Square	F Value	Pr>F
Model	213	41668.311	195.626	73.430	0.0001
Error	8684	23135.073	2.664		
Corrected Total	8897	64803.385			

Source	Degree of Freedom	Sum of Squares	Mean Square	F Value	Pr>F
Year	8	548.612	68.576	25.740	0.0001
Ten-day	35	2961.371	84.611	31.760	0.0001
Tonnage Class	2	255.331	127.665	47.920	0.0001
Target	3	2761.029	920.3429	345.46	0.0001
Depth	2	1005.196	502.5978	188.66	0.0001

Table VIII-12. The results of analysis of variance in the final model for the standardization of the trawl CPUE for *N. sloanii* on the Auckland Island Shelf.

Source	Degree of Freedom	Sum of Squares	Mean Square	F Value	Pr>F
Model	133	4857.591	36.523	31.880	0.0001
Error	2926	3352.516	1.146		
Corrected Total	3059	8210.108			

Source	Degree of Freedom	Sum of Squares	Mean Square	F Value	Pr>F
Year	8	303.175	37.897	37.080	0.0001
Ten-day	27	906.494	33.574	29.300	0.0001
Tonnage Class	2	54.528	27.141	23.690	0.0001
Target	1	502.0409	502.0409	438.17	0.0001
Depth	2	69.26215	34.63108	30.23	0.0001

B) Annual abundance for *N. gouldi* in the waters off west coast of the North Island

1) Comparison of abundance among month classes at 210 days old

The standardized CPUE for each month class at 210 days old was estimated by the GLM. Based on these CPUEs, the comparison of mean standardized CPUEs for the nine fishing years among the month classes at same age was carried out (Fig. VIII-2). This comparison shows which month class was dominated through the fishing years.

In the most fishing years, the CPUEs of September-December and January-April classes were not available, mainly due to few operations in the season from June to November when these month classes are vulnerable to the fishery. Then the comparison was valid for May-August classes. In the most fishing years, the CPUE of June class was relatively higher than the other month classes and the CPUE of July was followed. It was observed that the CPUE pattern at the same age among the month classes was dome shape with the peak at the June class, though the confidence intervals were very wide.

2) Correlation of annual abundance at 210 days old among the month classes

Table VIII-13 shows the correlation coefficients on the standardized CPUE of *N. gouldi* obtained from squid jigging fishery among month classes in the waters off west coast of the North Island. There was high positive correlation between May and June classes, though all of the coefficients were statistically insignificant at 95% level. The positive coefficients were obtained between June and July, and between July and August, but the other three coefficients were negative.

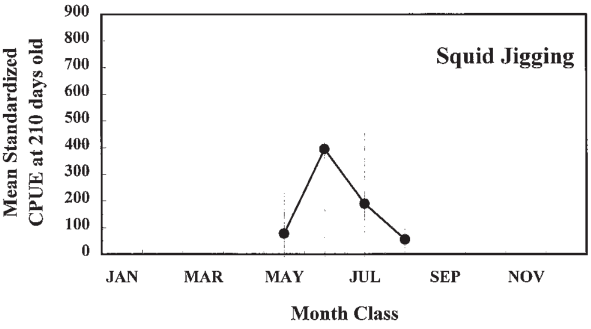


Fig. VIII-2 Mean of the standardized CPUE (number/10 jigging lines) of *N. gouldi* for each month class at 210 days old obtained by squid jigging fishery for the nine years in the waters off west coast of the North Island. Vertical bar shows the 95% confidence interval of mean.

Table VIII-13. Correlation coefficicients on standardized CPUE for *N. gouldi* obtained by squid jigging fishery between month classes in the waters off west coast of the Noth Island.

	MAY	JUN	JUL	AUG
MAY	1			
JUN	0.63	1		
JUL	-0.23	0.21	1	
AUG	-0.50	-0.47	0.16	1

These correlation coefficients suggested that May and June classes had relatively similar trend of annual variation of abundance to each other, and July and August classes had also similar trend. Then the four month classes observed in the present analysis may combined into two seasonal cohorts such as May-June and July-August classes.

3) Annual trend of abundance for each seasonal cohort

Annual CPUE of each seasonal cohort was constructed by summation of standardized CPUEs of member month classes. Annual trends of standardized CPUE at 210 days old for May-June and July-August classes are shown in Fig. VIII-3. Before 1984/85 fishing year, the CPUE of May-June class was much higher than it of July-August class and the trend of variation was negatively correlated with each other. The CPUE of May-June class increased from lower level of 1979/80 to relatively higher level in 1980/81 and fluctuated in the higher level for the next two years. Then it decreased to the same level of 1979/80 in 1983/84. In the same period, the CPUE of July-August class was relatively stable. In 1986/87, the CPUE of May-June class became the mean level in the previous period, but it of July-August class became much higher than it in the previous period and was almost same level as it of May-June class.

C) Annual abundance for *N. sloanii* on the Snares Shelf

1) Comparison of abundance among month classes at 210 days old

Based on the standardized CPUEs, the comparison of mean standardized CPUEs for the nine fishing years among the month classes at 210 days old was carried out (Fig. VIII-4).

In the most fishing years, the CPUEs of October-December and January-April classes for squid jigging fishery and those of January, February, and December classes for trawl fishery were not available, mainly due to the few operations in the season when these month classes are vulnerable to each fishery. Then the comparison was valid for May-September classes for the squid jigging and for March to November classes for the trawl fishery.

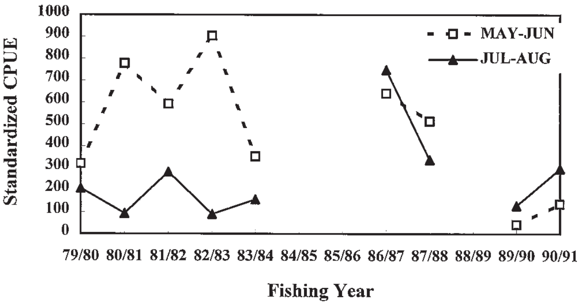


Fig. VIII-3 Annual change of standardized CPUE (number/10 jigging lines) of *N. gouldi* at 210 days old for each seasonal cohort in the waters off west coast of the North Island.

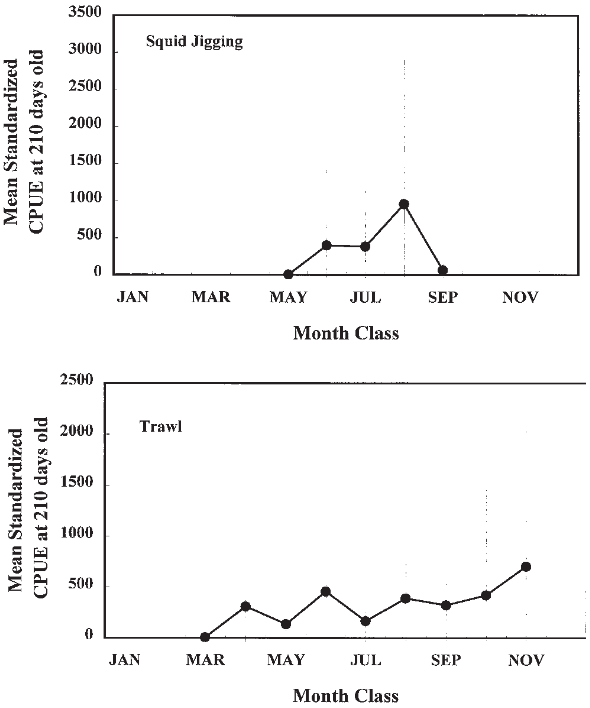


Fig. VIII-4 Mean of the standardized CPUE (number/10 jigging lines for squid jigging and number/hour for trawl) of *N. sloanii* for each month class at 210 days old obtained by fisheries for the years observed on the Snares Shelf. Vertical bar shows the 95% confidence interval of mean.

The mean CPUE of August class was highest in the squid jigging fishery and the mean CPUEs of June and July were followed, but the means of May and September were very low. There was no clear difference in the mean CPUE among the month classes except for March class, which has the lowest CPUE in the trawl fishery.

2) Correlation of annual abundance at 210 days old among the month classes

Tables VIII-14 and 15 show the correlation coefficients on the standardized CPUE of *N. sloanii* by the fisheries. Relatively high positive coefficients were obtained between May and June classes, and between June and July classes in the jigging fishery (Table VIII-14). In contrast, relatively high negative coefficients were obtained between May and August classes, between June and August classes, and between July and September classes. Based on these coefficients, the month classes were classified into the two groups such as May-July classes and August-September classes.

Table VIII-15 shows the coefficients for the trawl fishery. There was a high positive coefficient between March and April classes, but there was a negative one between April and May classes. There were relatively high coefficients between May and June, and between June and July classes. It was observed that the coefficient between July and August was low and it

Table VIII-14. Correlation coefficicients on standardized CPUE for *N. sloanii* obtained by squid jigging fishery between month classes in the snares Shelf. The coefficient in the shaded cell is significant at 95% level.

	MAY	JUN	JUL	AUG	SEP
MAY	1				
JUN	0.47	1			
JUL	0.08	0.65	1		
AUG	-0.68	-0.40	-0.20	1	
SEP	-0.08	-0.07	-0.57	0.14	1

Table VIII-15. Correlation coefficicients on standardized CPUE for *N. sloanii* obtained by trawl fishery between month classes on the Snares Shelf. The coefficients in the shaded cells are significant at 95% level.

	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
MAR	1								
APR	0.99	1							
MAY	-0.11	-0.09	1						
JUN	0.72	0.76	0.37	1					
JUL	0.83	0.85	0.24	0.75	1				
AUG	0.21	0.17	0.17	-0.02	0.07	1			
SEP	-0.13	-0.12	0.22	0.03	0.04	0.21	1		
OCT	-0.22	-0.18	0.05	0.25	-0.10	-0.49	-0.24	1	
NOV	-0.23	-0.16	0.79	0.44	0.08	-0.23	-0.03	0.44	1

between September and October was negative. Based on these relationships, the month classes were classified into four groups such as March-April, May-July, August-September, and October-November classes. This classification is similar to it based on the standardized CPUE of the squid jigging fishery.

3) Annual trend of abundance for each seasonal cohort

Annual trend of standardized CPUE at 210 days old for each seasonal cohort is shown in Fig. VIII-5. It was observed from the standardized CPUE of squid jigging fishery that abundance of May-July class increased from 1983/84 to 1985/86 and then decreased in 1987/88. In 1988/89 fishing year, the abundance increased abruptly to the highest level, but decreased to the lowest level in the next fishing year. The abundance of August-September class decreased from 1983/84 to 1989/90, except for the 1986/87 fishing year. The abundance in 1989/90 was the lowest level, but it increased abruptly to the highest level in the next year. The level of abundance and fluctuation of a seasonal cohort was very similar to each other.

Based on the abundance index of each seasonal cohort obtained from the standardized CPUE of the trawl fishery, the abundance of March-April class was very stable at the lowest level among the seasonal cohorts observed, but it increased to the highest level of this seasonal cohort in 1988/89. The abundance of May-July class was also relatively stable through the fishing years observed, except for the 1988/89 fishing year when the abundance increased to the highest level. The abundance of August-September class was lower level during 1980/81 to 1982/83 fishing years, but it increased in 1983/84 and became stable. The abundance of October-November class was highest in the first two years, but it decreased drastically in the next year. It increased again in 1984/85, but decreased to the lowest level in the next year and then it became stable at lower level. The level of fluctuation for this seasonal cohort was the largest. There were not big differences in abundance among the seasonal cohorts, but those of May-July and August-September classes were more or less higher than the other seasonal cohorts.

4) Comparison of Standardized CPUEs between the fisheries

There were two kinds of the abundance indices for *N. sloanii* on the Snares Shelf such as the standardized CPUE for the squid jigging and trawl fisheries. Fig. VIII-6 shows the relationship between these two abundance indices by seasonal cohorts. It was clear that there were two different relationships between the CPUEs of the two fisheries. Namely the one relationship was observed in the plots of the CPUE of squid jigging lower than about 500 (number/ 10 jigging lines) and the other was in the plots higher than about 500. These relationships between the CPUEs of the two fisheries seemed to be linear ones.

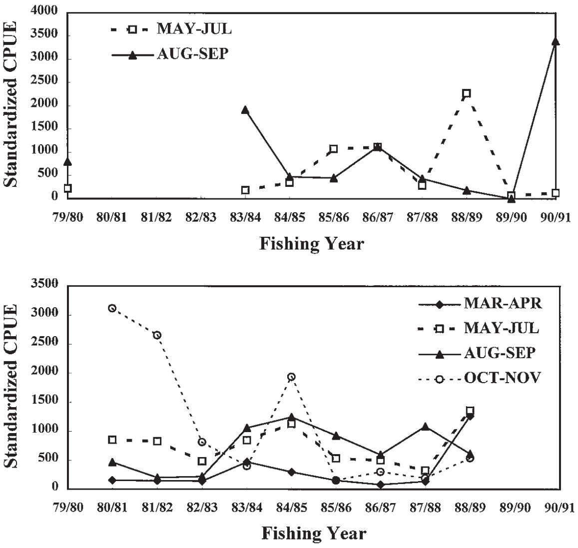


Fig. VIII-5 Annual change of standardized CPUE (number/10 jigging lines for squid jigging and number/hour for trawl) of *N. sloanii* at 210 days old for each seasonal cohort on the Snares Shelf.

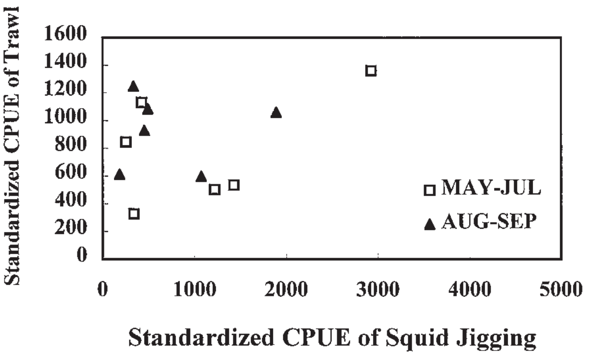


Fig. VIII-6 Relationship between CPUEs of *N. sloanii* by squid jigging and trawl by seasonal cohorts on the Snares Shelf.

D) Annual abundance for *N. sloanii* on the Canterbury Bight

1) Comparison of abundance among month classes at 210 days old

The means of standardized CPUE at 210 days old are shown in Fig. VIII-7 with 95% confidence interval of mean. In the most fishing years, the CPUEs of January-April and October-December classes were not available, mainly due to the few operations in the season when these month classes were vulnerable to the squid jigging fishery. Then the comparison was valid for May-September classes.

The mean level of abundance was not different among the month classes except for September class, which had higher mean than the other classes, though the confidence interval of each class was very wide. The means of May and July classes were more or less lower than the other classes.

2) Correlation in variation of annual abundance among the month classes

Table VIII-16 shows the correlation coefficients on the standardized CPUE of squid jigging fishery for *N. sloanii* on the Canterbury Bight. Positively significant coefficients were obtained between June and July, between July and August, and between June and August classes. Except for these three coefficients, there were relatively low negative coefficients. Based on these results, the month classes were classified into three seasonal cohorts such as May, June-August and September classes.

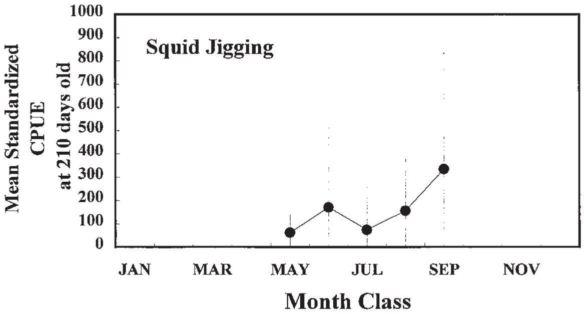


Fig. VIII-7 Mean of the standardized CPUE (number/10 jigging lines) of *N. sloanii* for each month class at 210 days old obtained by squid jigging fishery for the years observed on the Canterbury Bight. Vertical bar shows the 95% confidence interval of mean.

Table VIII-16. Correlation coefficicients on standardized CPUE for *N. sloanii* obtained by squid jigging fishery between month classes on the Canterbury Bight. The coefficients in the shaded cells are significant at 95% level.

	MAY	JUN	JUL	AUG	SEP
MAY	1				
JUN	-0.04	1			
JUL	-0.34	0.88	1		
AUG	-0.25	0.67	0.75	1	
SEP	-0.09	-0.34	-0.35	-0.44	1

3) Annual trend of abundance for each seasonal cohort

Annual trend of standardized CPUE of squid jigging fishery at 210 days old for each seasonal cohort is shown in Fig. VIII-8. The abundance of May class was stable at low level compared with the other seasonal cohorts through the fishing years observed. The abundance of June-August class was also stable through the years, except for 1988/89 when it abruptly increased to the highest level, The abundance of September class was also stable, except for 1980/81 fishing year when the abundance abruptly increased highest level of this seasonal cohort. There was a clear negative correlation in the annual trend of abundance between June-August and September classes.

E) Annual abundance for *N. sloanii* on the Auckland Island Shelf

1) Comparison of abundance among the month classes at 210 days old

The means of standardized CPUE at 210 days old are shown in Fig. VIII-9 with 95% confidence interval of mean. In the most fishing years, the CPUEs of January-March and November-December classes were not available, mainly due to few operations in the season when these month classes were vulnerable to the squid jigging fishery. Then the comparison was valid for April-October classes.

The means of CPUE for April, May, and June classes were very low. The later month class had higher mean of CPUE, though the confidence intervals were very wide. The mean of August and September classes were similar to each other and it of October class was the highest among the month classes observed.

2) Correlation in variation of annual abundance among the month classes.

Table VIII-17 shows the correlation coefficients on the standardized CPUE of the trawl fishery for *N.*

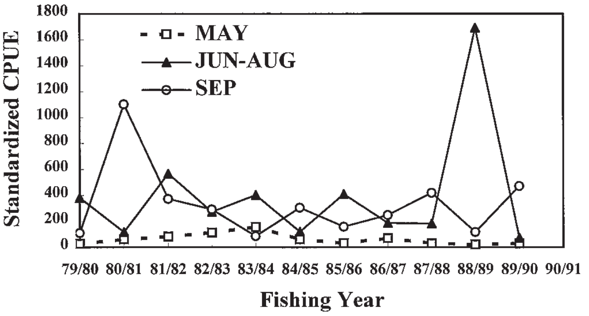


Fig. VIII-8 Annual change of standardized CPUE (number/10 jigging lines) of *N. sloanii* at 210 days old for each seasonal cohort on the Canterbury Bight.

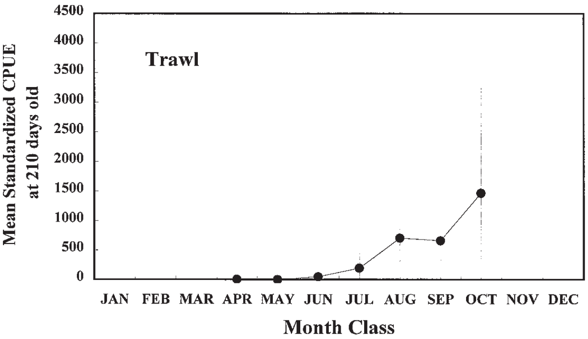


Fig. VIII-9 Mean of the standardized CPUE (number/hour for trawl) of *N. sloanii* for each month class at 210 days old obtained by trawl fishery for the years observed on the Auckland Island Shelf. Vertical bar shows the 95% confidence interval of mean.

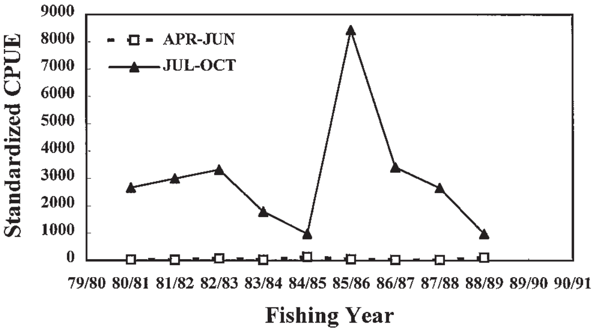


Fig. VIII-10 Annual change of standardized CPUE (number/hour for trawl) of *N. sloanii* at 210 days old for each seasonal cohort on the Auckland Island Shelf.

sloanii. Positively significant coefficients were obtained between April and May, between May and June, between July and August, and between July and October classes. Furthermore, the relatively high positive coefficients were obtained among July, August, September, and October classes, though these were statistically insignificant. Based on these relationship, these month classes were classified into two seasonal cohorts such as April-June and July-October classes.

3) Annual trend of abundance for each seasonal cohort

Annual trends of standardized CPUE at 210 days old for the two seasonal cohorts are shown in Fig. VIII-10. The abundance of April-June class was very low and stable throughout the fishing years observed. The abundance of July-October class was much higher than it of April-June class. It increased gradually from 1980/81 to 1982/83, but decreased in the next two years. The abundance increased drastically to the highest level in 1985/86, but continued to decrease during the next three years.

F) Correlation in variation of abundance among the seasonal cohorts

Table VIII-18 shows the correlation coefficients among the seasonal cohorts observed in the four areas. As for the abundance indices of seasonal cohort on the Snares Shelf, the standardized CPUE of the trawl fishery was used as abundance indices in this area, because there were more seasonal cohorts observed than the CPUE of squid jigging.

There was no significant correlation coefficient among the seasonal cohorts within the area, except for it between March-April and May-July classes on the Snares Shelf. The low and/or negative coefficients were obtained from any pair of seasonal cohorts within each area. There were several significant coefficients among the areas, but it was hard to find out any rational meanings from these coefficients. Most of coefficients among the seasonal cohorts were very low.

G) Component of seasonal cohort of *N. sloanii* by area

Table VIII-19 shows the month class composition of each seasonal cohort of *N. sloanii* by areas. The order of the areas is north-south direction in the Table. There are two to four seasonal cohorts in each area, though there was no information on the summer month classes (January, February, March, November, and December). In the Canterbury Bight where is the northernmost area observed for *N. sloanii*, there were three seasonal cohorts such as May, June-August, and September cohorts. In the Snares Shelf, there were four seasonal cohorts such as March-April, May-July, August-September, and October-November cohorts. In the Auckland Island Shelf where is the southernmost area observed, there were two seasonal cohorts such as April-June and July-October ones. The month class composition of each seasonal cohort changed with the area as shown in Table VIII-19. The corresponded seasonal cohort in the southern area is composed of the earlier born month classes than in the northern area.

The mean abundance of the earliest seasonal cohort, which is expressed as mean standardized CPUE per a month class, was the lowest among the seasonal cohorts observed in each area as shown in Table VIII-19. The seasonal cohort which was composed of the

Table VIII-17. Correlation coefficients on standardized CPUE of *N. sloanii* obtained by trawl fishery between month classes on the Auckland Island Shelf. The coefficients in the shaded cells are significant at 95% level.

	APR	MAY	JUN	JUL	AUG	SEP	OCT
APR	1						
MAY	0.89	1					
JUN	0.34	0.72	1				
JUL	−0.19	0.01	0.27	1			
AUG	−0.28	−0.35	−0.33	0.66	1		
SEP	−0.46	−0.55	−0.32	0.06	0.21	1	
OCT	−0.32	−0.34	−0.26	0.74	0.58	0.37	1

Table VIII-18. Correlation coefficients on standardized CPUEs between seasonal cohorts. Abbreviations in the parenthesis are as follows, WJ:squid jigging in the waters off west coast of the North Island, ST: trawl on the Snares Shelf, CJ: squid jigging on the Canterbury Bight, AT: trawl on the Auckland Island Shelf. The coefficients in the shaded cells are significant at 95% level.

	MAY-JUN (WJ)	JUL-AUG (WJ)	MAR-APR (ST)	MAY-JUL (ST)	AUG-SEP (ST)	OCT-NOV (ST)	MAY (CJ)	JUN-AUG (CJ)	SEP (CJ)	APR-JUN (AT)	JUL-OCT (AT)
MAY-JUN (WJ)	1										
JUL-AUG (WJ)	0.06	1									
MAR-APR (ST)	░ -0.66	-0.41	1								
MAY-JUL (ST)	-0.18	-0.41	░ 0.77	1							
AUG-SEP (ST)	░ -0.77	0.14	0.08	0.06	1						
OCT-NOV (ST)	0.36	-0.41	-0.20	0.36	-0.38	1					
MAY (CJ)	0.33	-0.14	-0.21	-0.09	-0.14	0.06	1				
JUN-AUG (CJ)	0.08	-0.04	░ 0.92	0.63	-0.19	-0.20	-0.20	1			
SEP (CJ)	0.32	-0.27	-0.36	-0.07	-0.28	░ 0.73	-0.09	-0.40	1		
APR-JUN (AT)	░ 0.70	-0.49	0.53	░ 0.66	0.24	0.04	-0.24	0.37	-0.26	1	
JUL-OCT (AT)	░ 0.73	0.45	-0.45	-0.56	-0.06	-0.28	-0.21	-0.22	-0.09	-0.36	1

later month classes had higher abundance in average, though the abundance of October-November cohort was lower than it of August-September cohort on the Snares Shelf. The winter or early spring cohort was more abundant than the other seasonal cohorts.

H) Spawner-progeny relationship

It is assumed that the standardized CPUE at 210 days old for each seasonal cohort represents the abundance of progeny and the CPUE at 300 days old represents the abundance of spawner in the present analysis, because 210 days old was the youngest age and 300 days old was the oldest age which was observed frequently. Figs. VIII-11 to 14 show the spawner-progeny relationships by seasonal cohort and area. Fig. VIII-11 shows the spawner-progeny relationship for *N. gouldi* in the waters off west coast of the North Island. There were so few points (six) in this Figure that it was difficult to find out any relationship between spawner and progeny. Figs. VIII-12 to 14 show the spawner-progeny relationship for *N. sloanii*. These figure suggested that there was no clear relationship between spawner and progeny.

3. Discussions

(1) Methodology

The results of the standardization show the factors used in the present analysis are highly significant and this means the standardization procedure is important to eliminate the biases from various factors such as size of vessels and area, when the CPUE is applied as an abundance index of squid. The standardization using general linear model is one of the ways to eliminate various possible biases and the estimated CPUE obtained in this chapter is one of the best estimates under the present circumstance, though there are still several problems mentioned below.

In this chapter, there are various assumptions to estimate size composition of catch, month class composition, and abundance indices by seasonal cohorts. First, the size composition of catch was estimated by the size composition of each size category and catch by size category under the assumption that the size composition in each size category is normally distributed and constant through seasons and years. This assumption has a big limitation for the application as shown in Tables VIII-6 to 7. Namely smallest and largest size categories must have larger variations and then the assumption for the size composition in each size category could not be applicable for those size categories. It is probable that the size composition of each size category may be variable by some factors such as season, year and so on.

The estimation of month class composition was carried out under the assumptions that there is no change in growth of each month class among the years and that the size composition of each month class is normally distributed. The interannual variation in growth was pointed out for *Illex argentinus* and *Todarodes angolensis* (Arkhipkin and Laptikhovsky,

Table VIII-19. Month class composition of each seasonal cohort of *N. sloanii* by area. A month class which has a same kind of shade belongs to a same seasonal cohort within an area. Numeric shows the historical mean of standardized CPUE per a month class for each seasonal cohort.

Month Class	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Canterbury Bight	**?**	**?**	**?**	**?**	■ **62.0**	░	░ **133.7**	░	▓ **323.5**	**?**	**?**	**?**
Snares Shelf	**?**	**?**	■	■ **182.1**	░	░ **246.8**	░	▓	▓ **111.1**	■	■ **311.0**	**?**
Auckland Is. Shelf	**?**	**?**	**?**	░	░ **17.4**	░	▓	▓	▓ **156.6**	▓	**?**	**?**

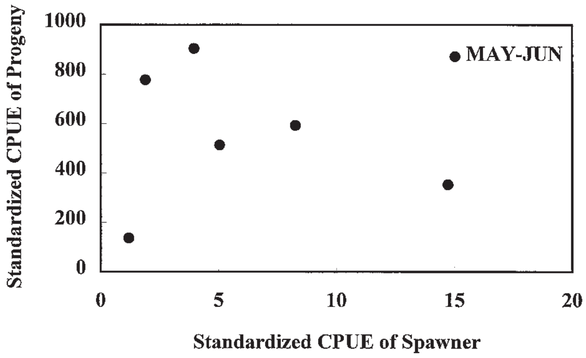


Fig. VIII-11 Spawner-progeny relationship for May-June class of *N. gouldi* in the waters off west coast of the North Island. Standardized CPUE of spawner is expressed as CPUE by squid jigging fishery at 300 days old in a fishing year and the CPUE of progeny is expressed as CPUE at 210 days old in the next fishing year.

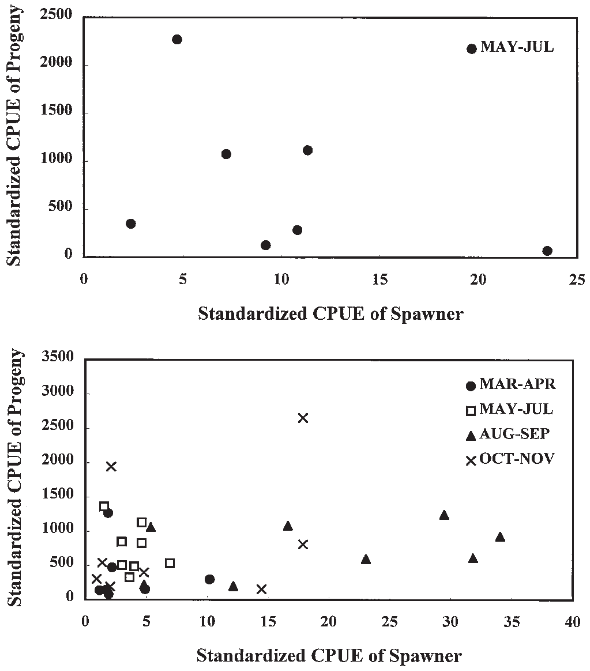


Fig. VIII-12 Spawner-progeny relationship for *N. sloanii* on the Snares Shelf by seasonal cohorts. Top figure shows the CPUEs by the squid jigging fishery and bottom one shows the CPUEs by trawl. Standardized CPUE of spawner is expressed as CPUE at 300 days old in a fishing year and the CPUE of progeny is expressed as CPUE at 210 days old in the next fishing year.

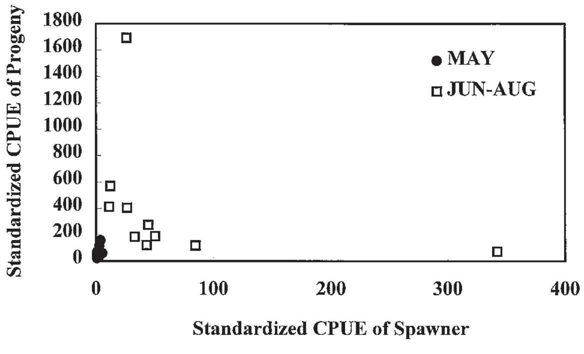


Fig. VIII-13 Spawner-progeny relationship for *N. sloanii* on the Canterbury Bight by seasonal cohorts. Standardized CPUE of spawner is expressed as CPUE by squid jigging fishery at 300 days old in a fishing year and the CPUE of progeny is expressed as CPUE at 210 days old in the next fishing year.

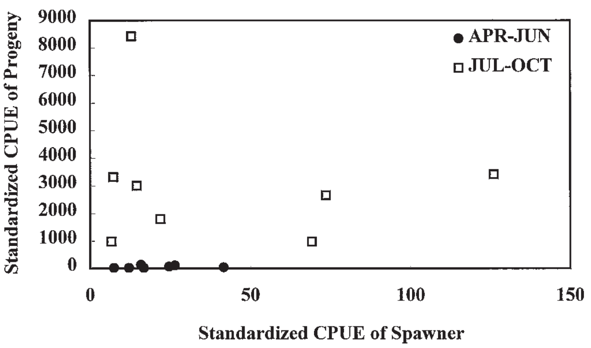


Fig. VIII-14 Spawner-progeny relationship for *N. sloanii* on the Auckland Island Shelf by seasonal cohorts. Standardized CPUE of spawner is expressed as CPUE by trawl fishery at 300 days old in a fishing year and the CPUE of progeny is expressed as CPUE at 210 days old in the next fishing year.

1994; Villanueva, 1992). Arkhipkin and Laptikhovsky (1994) showed that the interannual difference in growth of *Illex argentinus* was considerably smaller than those observed between various hatching-months within one year. If the situations of the present two species are same as those of *Illex argentinus*, the interannual difference may not introduce significant bias on the results. Furthermore, the assumption of normal distribution for size composition in each month class is an arbitrary one for the present analysis and there is no information on the shape of size distribution of each month class.

These problems may be solved by the additional observations as follows. The size composition of each size category should be sampled by at least time-area strata (10-day and major fishing ground) in each year. This information will eliminate the limitation mentioned above and a part of the bias. The trawl survey as shown in the Chapter VI will supply some direct information on the size composition of each month class obtained by the month class length key which is constructed directly using the statolith samples during the survey. These information will give some new ideas for the analysis.

The results of Chapters III and VI show that the two species of arrow squid spawn throughout the year and they are distributed widely in New Zealand waters. Therefore, it is very difficult and wasteful to monitor the abundance of each seasonal cohort by the survey cruises. Generally, information from the survey cruise is accurate but not so precise due to a small amount of samples, information from the fishery is vice versa not accurate but precise. The most practical way to monitor the abundance of each seasonal cohort is the analysis based on the information from the fisheries with some additional data from the survey activities.

When the information on the stock abundance from the fishery such as CPUE based on catch and effort data is used for monitoring of abundance, the standardization of effort is inevitable process to get an unbiased abundance index. In the present study, a generalized linear model (GLM) was applied for the standardization with an assumption that the factors are multiplicative and CPUE is log-normally distributed. This method and assumption are very common in the analysis of CPUE so far. But Cooke and Lankester (1995) and Dong and Restrepo (1995) discussed on the structure of random components and suggested that it is necessary to analyze the error structure in every fishery when the most suitable model is selected.

Gear selectivity is one of the most serious problems in the analysis of CPUE by month class. Trawl has been well studied on the selectivity compared with the other gears (Pope *et al*., 1975), but there is little study on the selectivity of squid jigging. In the present study, the selectivity of trawl was considered, but it for squid jigging was unknown.

The comparison of standardized CPUE between trawl and squid jigging could be done only for *N. sloanii* on the Snares Shelf (Fig. VIII-6). This figure suggested that there may be two linear relationships between CPUEs of trawl and squid jigging in the cases of the lower and higher CPUEs of squid jigging. The trawl vessels operate individually in a fishing ground, but the squid jigging vessels operate as a group at the best fishing spot in a fishing ground after some trial operations in various areas. Furthermore, each trawl vessel has catch quotas of various species and then she has some limitations on her activity on the fishing ground. As the result, each trawl vessel can not move among the fishing grounds freely. But squid jigging vessels have no limitation and can move freely among the fishing ground. Squid jigging vessels can select the best fishing ground based on the some trial operations in each fishing ground. Then whether the high density area was found out in the area or not might affect on CPUE of squid jigging greatly. These differences in operation strategy between the fisheries may be one of the factors which affected on the relationship of CPUEs between the fisheries.

These results raise the basic problems on factors affecting CPUE. Based on this comparison, it is probable that the magnitude of annual variation in CPUE of squid jigging may bigger than it in CPUE of trawl. Furthermore, the CPUE of trawl fishery may be relatively more accurate abundance index than one of squid jigging fishery, considering the operational strategies of these two fisheries and relatively independent operations of trawl vessels compared with one of squid jigging fishery.

These assumptions and problems mentioned above may introduce various biases in the estimate of abundance index for each month class. Then the estimated value of abundance indices should be treated as rough estimates of them under the present circumstance.

(2) Seasonal cohort

In the earlier Chapters, month class was arbitrarily defined as one kind of micro-cohorts to observe the stock structure in detail. In this Chapter, it was tried to observe existent cohorts in each area, comparing the trend of annual variation of abundance among the month classes.

The fisheries target squid mainly in austral summer, especially squid jigging fishery operates very seasonally from December to March. As the result, the sufficient data had been obtained for May to September classes (autumn and winter month classes) which are vulnerable for the fisheries in the season. The results of trawl surveys in Chapter VI suggested that the abundance of summer and spring month classes of *N. sloanii* may be lower than those of autumn and winter ones.

In *N. gouldi*, it was usually observed that June and July classes were dominant. But there was no clear correlation between these two dominant month classes. Fig. VIII-3 shows that there was negative correlation between them before 1984/85 fishing year, but it became positive correlation after that. In the present study these month classes were treated to belong to the different seasonal cohorts, but generally it is difficult to explain the independent fluctuation of adjacent month classes which are dominant than the other month classes. The further detailed observations are desirable before the final conclusion on the structure of seasonal cohorts of *N. gouldi*.

In *N. sloanii*, it was observed that there were some seasonal cohorts in each area and there was a trend in month class composition in north-south direction as shown in Table VIII-19. The abundance of a later seasonal cohort was more abundant in average than it of an earlier one in each area. The most abundant seasonal cohort in each area is winter (late-winter) one which include September class. The winter month classes live at about 180-200 days old, in which the growth speed is the highest in their life span as shown in the Chapter III, in summer season. The ratio of empty stomach is the lowest in summer season and highest in winter (Fig. VII-2). This result suggests that summer season may supply the most suitable situation on environment for squid. This suitable situation may result in good growth and survival of these month classes. It is known that the winter cohort is dominant in the species of *Illex illecebrosus*, *Illex argentinus*, *Todarodes pacificus*, and *Todarodes angolensis* (Squire, 1967; Dawe et al., 1984; Uozumi and Shiba, 1993; Araya, 1976; Villanueva, 1992). These species are major ones in the short-finned squid fisheries over the world and this means the abundance of these species are dominant. The life histories (life span, growth rate, size at mature, and so on) of these species including the present two species are roughly same to each other, except for the type of migration (Hatanaka *et al*., 1985). The domination of a winter cohort in these species may be closely related with the common environmental factors among their habitats. Murayama and Kasahara (1988) suggested that the availability of food is one of the important factors on the domination of a specific seasonal cohort.

Gerig *et al*. (1988), Ranhmstof (1992), and Chiswell (1994) showed the interannual variation of sea surface temperature (SST) around the mainland of New Zealand from 1967 to 1991, though they did not describe these variations sufficiently by areas. Then the interannual variation in each area of the present study was not describe very well. But Greig *et al*. (1988) showed that there was little difference in the interannual variability in SST among the areas. Furthermore, they pointed out the correlation between SST anomaly and El Ninõ phenomenon. Namely negative anomaly of SST was observed around New Zealand when El Ninõ phenomenon occurred. Minima which appeared in Southern Oscillation Index (SOI) were observed in 1982/83, 1987, and 1991/92, and a maximum was observed in 1988/89 during the period of the present study (NOAA, 1996). These El Ninõ and La Ninã phenomena suggested that interannual variation of SST might be large in these years. Especially OSI changed from a minimum to a maximum during 1987 to 1988.

Figs. VIII-3, 5, 8, and 10 showed that there was no correlation between interannual variation of abundance and El Ninõ phenomenon, except for March-April and May-July cohorts of *N. sloanii* on the Snares Shelf and June-August cohort of *N. sloanii* on the Canterbury Bight whose abundance increased clearly in 1988/89 fishing year. These cohorts were born in 1988 when an apparent La Ninã phenomenon occurred. There was no data for *N. gouldi* in this fishing year, because most fishing efforts were concentrated on the Canterbury Bight where the high CPUE was observed (Tables VIII-5 to 7). This means indirectly that no good fishing ground was found in the water off west coast of the North Island in 1988/89 fishing year.

Dow (1976) indicated the positive correlation between SST and catch of *Loligo pealei* around the Maine coast. Chelho and Rosenberg (1984), and Caddy (1983) also showed the positive relation between SST and CPUE (catch per day) of *Illex illecebrosus* on the Scotian Shelf. But they had no explanation on the mechanism which makes the positive correlation. It was difficult to make any conclusions about the relationship between SST and abundance of two species of *Nototodarus* based on the present results, because there was only one La Ninã phenomenon during the period of the present study.

Table VIII-18 showed that there was no clear positive correlation in abundance among the areas and this result suggested that the seasonal cohorts in each area fluctuate more or less independently. This phenomenon suggests that the large scale environmental events such as El Ninõ and La Ninã phenomena may not have common effects on the cohorts in all areas, but some environmental factors in local area may be more important on the fluctuation of abundance. Furthermore, the environmental factors including SST may be related with abundance of stock complexly in various development stages of squid and SST may also be related with other environmental factors complexly. The detailed observations on environmental factors are necessary to clarify this relationship.

There was a few reports on the stock-progeny relationship of squid and this relationship is weak (Mohn, 1981; Caddy, 1983; Beddington *et al*., 1990). Cirke (1987) showed the weak stock-progeny relationship in *Illex argentinus* on the Patagonian Shelf. Araya (1974) showed the positive relationship of *Todarodes pacificus*, though the correlation coefficient was low. He suggested that the relationship was very unstable and it means that the density independent factors affect strongly on the recruitment. Mohn (1981) also showed that there was no clear relationship in *Illex illecebrosus* on the Scotian Shelf and suggested the importance of the environmental factors. In the present study, the spawner-progeny relationships by area and seasonal cohorts were presented. All results suggested that there is no clear relationship between spawner and progeny in *N. gouldi* and *N. sloanii*. This result means that density dependent factors do not dominate population dynamics very well and most of variation in abundance may be caused by environmental factors as shown in the other ommastrephid squids mentioned above, if the abundance index used in the present study express the actual dynamics correctly.

There was no clear historical trend in abundance in each seasonal class for both of the two species as shown in Figs. VIII-3, 5, 8, and 10. In the present analysis there is no available statistics on catch of squid and effort by sufficient time-area strata for all countries, except for Japan. Then it was impossible to sufficiently assess the effects of fishing on squid stocks. But these trends of abundance may suggested that there was no serious affect of fishing on stock status.

IX. General discussions and a consideration on assessment and management

1. Stock structure

The results of ageing shows that spawning activity of these two species continues through the year (Chapter III). The results of the trawl surveys also indicated the existence of squid hatched through the year (Chapter VI). In the present study, “ month class ” was arbitrarily adopted to investigate about variability of biological characteristics, such as stock structure, fluctuation of abundance by seasonal groups, and so on, among the individuals which hatched in different season. Month class was selected as a suitable microcohort for the present study considering the precision of ageing.

The results of the trawl surveys showed that all of 12 month classes were observed in the main distribution area and there was no unique distribution pattern for each month class. All month classes observed were distributed in all of the area surveyed. Furthermore, the results of the trawl surveys and tagging experiments (Sato, 1985; Yamada and Kattoh, 1987) showed there is no clear large scale migration, though there is a inshore-offshore migration with age, and some northward migration of *N. gouldi* with maturation was observed off west coast of the mainland. These results suggested that the present two species spawn through the year in all main distribution area and do not migrate on large scale.

The stock structure of *N. gouldi* in the whole distribution area were not reviewed in the present study, because there were no sufficient data which showed the distribution pattern and fluctuation of abundance by species off the west coast of the mainland, especially off the west coast of the South Island. But some biological data showed the northward migration with sexual maturation as shown in Chapter VI. Therefore, there is high possibility that there may be one regional stock of *N. gouldi* off the west coast of the mainland, though there are some weak seasonal segregation as shown in Chapter VIII.

There were very low correlation coefficients in abundance among the areas where *N. sloanii* is mainly distributed (Chapter VIII). This result suggested that the stock of *N. sloanii* in each area such as the Canterbury Bight, Snares Shelf, and the Auckland Island Shelf may be relatively independent to each other and the migrations among the areas may not be so significant that there is no clear positive relationship in fluctuation of abundance among the areas. But these results do not mean that there is no mixing among the areas, because there is not so strong geographic barrier that prevents any migrations.

The some seasonal cohorts were recognized for both species based on the similarity in abundance fluctuation among the month classes in each area. The seasonal cohorts are recognized based on the relationships in abundance on the average for the ten years among the individuals hatched in different days. Therefore, it is probable that some different seasonal cohorts may be recognized in each particular year. This means that the seasonal cohort is not so rigid cohort, but very variable one. Individuals which hatch in the similar season in an area may grow under similar environmental conditions such as temperature, food, and so on. As the results, these individuals may have similar growth, distribution pattern and similar mortality. Then these individuals may be recognized to belong to one group such as a seasonal cohort applied in the present study and there is no clear boundary among these seasonal cohorts, because there is no drastic changes on the environmental factors between seasons. There is a possibility that some progenies of these individuals may belong to another seasonal group in the next year, because there is some variability in maturation and spawning among these individuals which belong even to a same month class. The results as shown in Chapter IV suggested that the maturation process is not only related with age, but also related with size. This phenomenon also supports that the timing of spawning may be variable among the individuals that belong to a same month class, due to some variations in growth and maturation. Therefore, there is a low probability that these seasonal cohorts may be genetically independent to each other. Therefore, the stock structure of the present two species is not so clear and very variable, and may depend on many environmental and biological factors.

2. Assessment and management

In the present study, no assessment on the stock status was carried out, except for the observation on the historical trend of CPUE for each seasonal cohorts in each area. Then there was no analysis on the effect of fishery to the squid stock such as an estimation of fishing mortality. The main reasons are as follows, 1) there are no available fisheries data for the other countries except for the Japanese ones by the fine time and area scale. The vessels of the difference countries have different operational pattern and then it is very difficult to estimate the details of catch of the foreign countries based on the Japanese catch. 2) it was found that there is a discrepancy in the CPUE between trawl and jig fisheries (see Figs. VIII-5 and 6). The reason of this discrepancy is still unknown, but this result suggests the necessity of the investigation on the characteristics of CPUE by gears in detail. Especially for the squid jigging, there is no sufficient studies on the size selectivity. The squid jigging vessels operate as a group at the best fishing spot in a fishing ground and these characteristics may introduce some biases when the CPUE is treated as an abundance index. 3) effects of immigration and emigration of squid may be significant on the CPUE trend when the Leslie-De Lury type assessment is carried out. This type of assessment is very useful and only one for the estimation of absolute value of the abundance of squid stocks as mentioned below. But the both trawl and jigging fisheries starts to exploit squid older than about 180days old when the squid start to migrate into deeper waters than 200 m. Then there may be the effect of emigration on CPUE since the start of fishing. 4) due to the assumption on the construction of size composition of catch from size composition of each size category and catch by size categories, available duration for the observation of the CPUE trend is not long enough. This may hamper a reliable estimation of abundance by the Leslie-De Lury type method. 5) the assumption used in Chapter VIII, growth of each month class is constant among the years, may introduce some biases when the detailed assessment is carried out.

In this section, the methodologies for assessment and management for squid stock are briefly reviewed and consider the applicability of these methods on the arrow squid based on the results on the biological characteristics of the arrow squid stocks in the present study for the rational assessment and management in the future.

a. Brief review of assessment methodologies

Generally the biology of squid poses particular problems for the fishery assessment and management, both in respect of the poor state of knowledge of each species and as a consequence of the short life cycle (Pierce and Guerra, 1994). Most squid species live for only one year. Then generations may not overlap and no spawning stock is carried over from a year to another. Annual recruitment contributes almost the entire overall stock (Caddy, 1983; Beddington *et al.*, 1990; Resenberg *et al.*, 1990). The stock exploited by fishery is entirely composed of recruits. This means that the residual animals through the year will affect the next year fishing only by the spawning success. In other words, the fishery in one year relates to the fishery in subsequent years solely through any spawner-progeny relationships, however, this relationship is weak as mentioned in Chapter VIII.

If the stock was composed of single cohort, length-based method might be applicable very well. But squid species have protracted spawning seasons and consequently multiple microcohorts are present at any one time. This situation makes it difficult to apply the length-based method simply. Furthermore, if the cohort migrates with growth, the results of length-based method must have some biases (Uozumi and Shiba, 1993; Uozumi, 1994). Then the assessment should be carried out correctly only by the age-based method with the results of ageing using some hard parts such as statolith.

A consequence of the short life span is that management of squid stocks requires assessment to carry out on a shorter time scale than is necessary for many finfishes which live longer. Basson *et al.* (1994) summarized that there are two general categories of assessment: in-season assessment and post-season assessment. The former method uses the data which are collecting during the fishing season and is to be used to adjust the fishing level during a fishing season. On the other hand, the latter one uses the completed dataset for a season and is to be used to establish management goals for the following seasons. To minimize the risk of over-exploitation, real time (in-season) assessment is desirable.

There are several assessment methods, stock-recruitment models, production models, sequential population models (virtual population analysis; VPA), Leslie-De Lury models, and so on. But most of them were developed for assessment of finfishes which live longer years and then most of them are not suitable for the assessment of squid stocks. Stock-recruitment models need the functional relationship between spawner and progeny, but this process is a stochastic one, and the stock-progeny relationship is weak and highly variable in squid stocks as shown in Chapter VIII. Production models have been one of most popular models for assessment of fishes, for which only catch and effort statistics are available, but this type of model assumes that strong density dependent effects dominate population dynamics, implying a strong depensatory stock-recruitment relationship whereas, in practice, recruitment of squid may depend on environmental conditions (Pierce and Guerra, 1994). Sequential population models, so-called " VPA ", provide the estimates of absolute value of population size and fishing mortality based on the catch at age data. This model is applicable to the squid stocks, if the catch at size is converted to catch at age by some suitable methods such as age-length key based on the ageing results with statolith microstructure, even though there are some microcohorts in a stock. This model has a good estimation of population size in younger ages than in older ages (Pope, 1972) and this method needs completed sequential data for all countries 'catch. Therefore, this method is not suitable for the in-season assessment.

Leslie-De Lury models have many variations, but assumes a closed population declining as a consequence of fishing mortality. A modified Leslie-De Lury model has been applied to estimate the biomass during the fishing season in the fishery for *Illex argentinus* around the Falkland Islands (Rosenberg *et al.*, 1990). The estimates of recruitment and catchabilities of the fleets are used for the control of the fishery in the residual fishing season to keep minimum biomass of spawner and evaluate the quantity of fishing efforts licensed in the next fishing season. The application of this model in the Falkland Island fishery is closely related to the situation of fisheries and characteristics of the stock.

The last method is the use of independent information from the fishery such as a larval net survey and a trawl survey. The abundance index, which can be transformed to an absolute value of population size with some assumptions, can be obtained by a fishery independent survey. In *Todarodes pacificus* fishery in the Japan Sea, the abundance index of larval squid has been calculated from the result of the larval survey, and is applied to estimate the abundance of the recruits in advance of the fishing season on the basis of the significantly positive correlation between the abundance indices of larvae and total catch in the next year (Okutani and Watanabe, 1983; Murata, 1989). The stratified random trawl survey has been applied for various stocks such as the *Illex illecebrosus* and *Loligo pealei* in the northwest Atlantic (Lange and Sissenwine, 1983; Rowell *et al.*, 1985), the *Loligo vurugaris reynaudii* stock in the South Africa (Uozumi *et al.*, 1985), the *Illex argentinus* stock in the Patagonian Shelf (Sato and Hatanaka, 1983), and the *Nototodarus* stocks in New Zealand waters as shown in Chapter VI. Kawahara *et al.*, (1993) reviewed the suitable kind of the surveys in each development stage of squid for the estimation of abundance index in advance of the fishing season and proposed the most suitable survey for the *I. argentinus, I. illecebrosus*, and *Nototodarus* stocks. Yamada and Hiramatsu (1991) tried to forecast the catch of *T. pacificus* in the Japan Sea using the results of larval surveys and squid jigging surveys which are carried out in the different timing in a fishing season with Bayesian probability theory. It is impossible to estimate absolute value of population size by the results of surveys without any assumptions, because there is no precise estimation of gear efficiency and gear selectivity. Then it is necessary to observe the correlation between the abundance indices and the catch or absolute abundance which is estimated from the other method such as VPA and Leslie-De Lury methods, when the abundance index is applied for the forecast of the recruitment.

b. Brief review of management strategy

The main target of management for a fishery on annual squids should be to allow enough spawners to escape the fishery at the end of fishing season so as not to reduce appreciably the probability of good recruitment in the following year (Beddington *et al.*, 1990). There are two major options in the management: catch regulation and effort regulation. Catch regulation is not suitable for squid stocks, because of the high variability in stock abundance (Caddy,1983; Beddington *et al.*, 1990). High variability of stock abundance makes it necessarily to change the total allowable catch (TAC) year by year. The decision on TAC must be done before the start of the fishing season. But it is very difficult to estimate recruitment in advance of the fishing season as shown in the previous section. This is why the catch regulation is not practically suitable for the management of squid fishery. Rosenberg *et al.* (1990) considered the characteristics of squid stocks and concluded that the most effective means of managing squid fishery is by regulating fishing effort.

A simple application of effort regulation is to allow a constant proportional escapement in each season. Proportional escapement is defined as the number of spawners alive at the end of fishing season as a proportion of those that would have been alive had there been no fishing (Rosenberg *et al.*, 1990). Effectively constant escapement ratio means constant fishing mortality. A target of 40% proportional escapement has been applied by Northwest Atlantic Fisheries Organization (NAFO) which has managed *I. illecebrosus* stocks and by the Falkland Islands Government, which has managed *I. argentinus*. This value of proportional escapement was derived by the simulation model which was designed to assess the effect of fishing on *I. illecebrosus* (Sissenwine and Tibbetts, 1977). The value of 40% was derived with a assumption that recruitment is moderately dependent on spawning stock size. This value is further increased with a weaker stock-recruitment relationship. Therefore, a 40% escapement target is used as a conservative level for the conservation of the spawning stock in the Falkland Islands fishery and NAFO waters.

Theoretically the effort regulation is a rational way to manage the squid fisheries. But the practicality of effort regulation is mostly depend on the characteristics of fisheries and squid stocks. As for the stock of *I. argentinus*, the stock is usually composed of a dominant winter cohort and only two kind of fisheries, squid jigging and trawl fisheries which are operated by the foreign countries, and every vessel needs a license from the Falkland Island Government. Under the relatively simple structure of fisheries and stock, the Falkland Islands Government has successfully managed this stock by the effort regulation. In the NAFO waters, stock structure in the major fishing ground is simple and composed of a dominant winter cohort, but there are various kinds of fisheries such as squid target fishery (the Japanese trawl and jigging fisheries), trawl fisheries of various countries which catch squid as by-catch, coastal small squid jigging fisheries, and various types of set net at shore. Scientific Council of NAFO recognized that the fishing effort regulation is theoretically rational way to keep exploitation rate a target constant level under the variation of the abundance which is not able to predict in advance (Uozumi and Kawahara, 1991). However, there are many difficulties which obstacle the enforcement of fishing effort regulation. The major difficulty is to estimate effective fishing effort which is influenced by various factors which may change with time. Under the circumstance, the compromised management regime between catch and fishing regulations, namely the TAC regulation with fishing effort constraint, is accepted.

3. Toward the rational exploitation and management of arrow squid in New Zealand waters

A consequence of the jurisdiction of 200 mile exclusive economic zone in New Zealand waters is that the New Zealand Government started to manage arrow squid stocks since 1978. The New Zealand Government obtained the preliminary guess for biomass estimate of 600,000 metric tons by the areal expansion method and 1978-79 commercial catch data from jig and trawl fisheries (Mattlin, 1986). The Government set total allowable catch (TAC) at 15% of the original biomass estimate. Escapement ratio of about 40% is accepted by NAFO and the Falkland Island Government as mentioned above. However, because there was no satisfactory estimate of the actual stock size, a conservative approach was taken. Based on the TAC, the quarter for the trawl fishery has been set, while the limitation of vessel numbers has been set for the jigging fishery. The limitation of the jigging vessel numbers was determined by the average catch in a fishing season by a standard vessel and total catch quarter for jigging fishery. The trawl fishery catches various species including arrow squid. It is practically very difficult to set a limitation on fishing effort which targets squid. Contrarily jigging fishery targets only squid, and effort regulation can be carried out easily for the management.

Except for the Southern Islands fishery, for which a separate TAC is set, the two species are managed as a single fishery within an overall TAC. This is possible because most of the fishing effort on the main islands fisheries is applied by jigging vessels which tend to concentrate effort where squid population densities are highest (Annala, 1992). The Southern Islands fishery (primarily the Auckland Island Shelf fishery) is almost entirely a trawl fishery. Because the trawl fishery can catch squid with little by-catch of other finfishes which are managed by quota limitation, the stock in this area is an attractive resource for trawlers. A quota has been set separately for the Southern Islands in order to reduce the risk of overfishing this stock (Annala, 1992). In 1986 the Individual Transferable Quota system (ITQ system) was introduced and both of the squid fisheries became regulated by a catch quota set in tons (Gibson, 1995). TAC has been set at about 122,000 metric tons after 1986 without no significant change, because there was no biomass estimates so far (Annala, 1994).

The situation of squid fishery in New Zealand waters is similar to it in the Falkland Island fishery, though the trawlers in the N.Z. waters target not only squid, but also other finfishes even in the squid fishing season. In spite of the relative simplicity of the squid fishery, the stock structure of arrow squids is more complex than it of *I. argentinus* There are many seasonal cohorts in each area and the abundance of each cohort fluctuate independently. Basically the winter cohort dominates, but the level of dominance is not so large compared with the other species such as *Illex argentinus* and *I. illecebrosus*. And it usually occurs that the seasonal cohort which dominates in a year is different year by year. This complex situation of stock hampers the application of systematic assessment and management.

It is very difficult to carry out the research cruise to estimate abundance of recruitment in advance of the fishing season, because the major seasonal cohort is usually different year by year and then the timing of the survey should be changed to monitor the recruitment appropriately by the survey gear which has specific size selectivity. The variability of the timing of survey hampers the effective practice of the survey. Therefore, the survey can not be the major source for the assessment of the stock. But this does not mean the survey is needless. The survey is still very important to get various information on the biological phenomena which are difficult to get from the fishery and very useful to assist in the major assessment activity as mentioned below.

The assessment method applied by the Falkland Island Government is one of the best way based on the fishery information so far. But there are some difficulties which should be overcome before the application in New Zealand waters. It may be easy to overcome some of them, but for the others the specific surveys and research activities are essential. In this section these difficulties and the researches are discussed based on the results of the present study.

a. Future Assessment

It is necessary to divide the overall CPUE into one for each seasonal cohort, when the Leslie-De Lury type assessment is carried out in New Zealand waters where the stock structure is so complex. It is not so difficult to carry out this separation when the method used in the present study is applied, though the some improvements of the method are desirable. The method for separation of CPUE used in the present study is composed of the two main processes, estimation of size composition of catch and decomposition into month class composition (or seasonal cohort).

The first step, estimation of size composition of catch is carried out based on the size composition of each size category used in each fishery and catch by size categories. There are 16 and 12 size categories in the Japanese squid jigging and trawl fisheries. The squid caught are selected by size into these size categories very well. This information is very useful to estimate size composition of catch and it is not so difficult to collect the catch by size categories for the Japanese fisheries, because there are significant differences in market price among the size categories and each vessel makes catch record by size categories. There is one problem in the estimation of size composition by this method. Namely the size composition in each size category is variable, especially in the largest and smallest size categories. But this problem may be overcome easily to collect the samples for each size category by appropriate area and time strata in each fishing year. This samples are also useful to get species composition by time-area strata, especially for the waters off west coast of the South Island.

Furthermore, this samples of each size category are also useful to collect the samples of statoliths for ageing which are essential for the decomposition of size compositions into month class one. The direct ageing is time-consuming and this process has been replaced by the length-based method such as MULTIFAN in the many studies so far. But there is high possibility that the results by the length-based methods may have some biases, if the squid migrates with age (Hatfield and Rodhouse, 1994; Uozumi, 1994). Therefore, the direct ageing is basic, even though this process is time-consuming. Recent development of the graphic analyzer will overcome this difficulty and some other techniques such as the estimation procedure used by Rodhouse *et al.* (1994) will be helpful. Based on the ageing results which will be carried out for some years, the more rational way of sampling will be get, which will minimumize the number of sample for ageing. Furthermore, there is a possibility that the length-based method which will be validated by ageing will be available.

There are some problems on CPUE which may reflect the abundance of squid. One big problem in the present study is the relationship in CPUE between the trawl and squid jigging fisheries as pointed out in the Chapter VIII. The reason for the relationship is still unknown, but it may be clear when the more fine scale comparison will be done between the CPUEs of trawl and jigging fisheries. The fishing ground for the trawler is limited in the edge of shelf and the upper slope area as shown in Fig. I-10, while the fishing ground of jigging vessels expand on the shelf. Basically there is a clear difference in the locality of the fishing ground between the fisheries. This difference makes some differences in target size between the fisheries and make it difficult to compare the CPUE between the fisheries.

Furthermore, there is another troublesome problem for the CPUE, standardization, which was already discussed in detail in Chapter VIII. The problems related to CPUE are ones of the most important points for the assessment procedure and the most difficult ones.

The emigration to deeper water with growth is also important factor which should be considered when the CPUE is analyzed. The bottom trawl surveys revealed this phenomenon, but this phenomenon is still unclear for *N. gouldi*, because there has been no suitable trawl survey which had no sufficient coverage of the depth of *N. gouldi* distribution in the waters off the west coast. The time sequential bottom trawl surveys with sufficient depth strata will obtain the quantitative information of emigration speed with growth. This quantitative information will be helpful to evaluate the effect of emigration on the CPUE of the commercial vessels.

The Leslie-De Lury type analysis require the sequential CPUE data, but the squid jigging fishery changes the fishing ground very frequently and length of the fishing season for each seasonal cohort in a area is usually so short that it becomes to be difficult to estimate abundance by Leslie-De Lury method. But there is no necessity to estimate the parameters for all seasonal cohorts in all area, and the estimate of catchability for a specific seasonal cohort in a particular area may be applicable to the other seasonal cohorts. Therefore, this method is applicable, if the parameters of one cohort can be obtained at least.

The Leslie-De Lury type analysis is one of the most preferable methods for the assessment of squid with the consideration of management applicability. But at the preliminary stage for the assessment, VPA type method is also valuable to understand the variability of stock biomass, the estimate of the level of fishing mortality, and so on, though these estimates are available after the fishing season is finished. Therefore, these estimates are just applicable for the next fishing season when the recruitment can not be estimated. The value of fishing mortality and biomass estimate by VPA may be one of the valuable information for the validation of the Leslie-De Lury type assessment. Furthermore, a stratified random trawl survey will provide some indications of the biomass. In addition to this, the survey will provide some quantitative information on some biological parameters mentioned above. Before the valid assessment system will be established, some different type analyses are desired to collect the essential biological information and to polish the methodology.

B. Future management

Management strategy should be settled with deep considerations on the characteristics of the particular fisheries concerned and also on the characteristics of the stock. Furthermore, the management strategy should be restated with the available information on stock and fishery. The management should be revised with the development of the research and understanding of the stock. Therefore, the management strategy will develop with the progress of assessment. In addition, the management of fishery is not set solely for a single species, but for many species which have different biology and stock status. The management should be set after the compromise process through the consideration on stock status of each species, priority of the species concerned and so on. The present study could not show the effect of the fishery on the arrow squid stocks, but presented several important characteristics of these stocks for the management, though we have not yet enough quantitative information on some of them. It is suggested that the seasonal cohorts are independent weakly to each other, because month classes fluctuate relatively independently and there is no clear boundary between seasonal cohorts as shown in the stock structure section. Squid in each regional area also fluctuates independently. Furthermore, there is no stock-progeny relationship and this means that the abundance of progeny is not depend on the abundance of parental stock.

These two characteristics are the key factors for the management strategy. These tow factors suggests that the strict management on each cohort may not promise the stable catch in future, but the rough management with regardless of cohorts may not lead to the heavy overfishing on a particular stock. Furthermore, the migration with age may reduce the fishing mortality, because the fishing effort of jigging vessel are concentrated on the shelf, but the squid migrates into slope water with age. It is suggested that the spawning ground of *N. sloanii* may locate in the coastal waters shallower than 50m depth where the squid fisheries are prohibited. These characteristics of the stock suggested that arrow squid stocks may be strong for the overfishing.

The fishery has self-regulation characteristics in itself (Uozumi and Kawahara, 1991); the trawl fishery targets squid when the stock is abundant, but fishery changes the target species when the squid becomes less abundant. As for the squid jigging fishery in New Zealand waters, the vessel always search for the area where squid is most abundant around New Zealand and this creates the tendency that the fishing efforts are concentrated in the relatively abundant cohorts and not concentrated in the poor cohorts. This self regulation characteristics is in valid when the fishery does not have severe regulations such as area limitation and quota by area.

The management may be set in rough scale such as the limitation of total fishing effort for each fishery regardless area at the present situation of understanding on the stock. At this moment, the present study suggests that there was no clear effect of fishing on the stock and this suggests that any fishing level occurred in the past are acceptable for the management. But the close monitor on fisheries are essential to prevent potential overfishing and to observe the actual situation of the fisheries in detail. The assessment will present the preliminary guess for fishing mortality and gear coefficient in the future and will give us the figure of total fishing effort for each fishery at the target reference point. These value will tell us the actual exploitation rates which were exposure on the stock.

The research and assessment activities will give us more quantitative information and more variable information on stock. These information make it possible to develop further rational management measure on squid stocks.

X. Summary

The arrow squid stock in New Zealand waters, consisting of *Nototodarus gouldi* and *N. sloanii*, is one of important squid resources for the Japanese squid fishery. The catch of this stock occupied about 10% of the world catch of flying squids (Ommastrephidae) in the 1980s. The present study revealed the biological characteristics of the two species based on the accumulated biological data and statistics of the Japanese fisheries in New Zealand waters. The main purposes of the present study are to reveal some background information on biology of both species and to estimate the biological parameters for the stock assessment and management.

I. Arrow squid fisheries around New Zealand

(1) The arrow squid resources have been exploited by the trawl and squid jigging fisheries since the early 1970s. The total catch fluctuated at about 70,000 metric tons (mt) in the 1980s with a peak of 109,000 mt in the 1984/85 fishing year. Then it decreased rapidly to about 32,000 mt in 1991/92. The Japanese catch occupied about 60-80% of the total squid catch in New Zealand waters.

(2) The Japanese squid fishery in New Zealand

waters is closely related with the Japanese squid fishery in the other waters including the fishery around Japan. The fishery in New Zealand waters had developed rapidly just after the reduction of squid catch around Japan and became smaller with the rapid increase of squid catch in the Argentine waters.

(3) The main fishing grounds of squid jigging fishery have been formed in the coastal waters around the South Island and the West Coast of the North Island. While the main fishing grounds of squid trawl fishery were formed on the Snares Shelf and Auckland Island Shelf. The fishing grounds of squid jigging fishery form widely on a shelf, but those of trawl fishery form on the edge of a shelf.

(4) The fishing season of squid jigging fishery is during austral summer and early autumn from December to May, especially from January to March, while the fishing season of squid trawl fishery is ranged from January to May, especially from February to April.

II. Identification of Todarodinae squids, their geographical distributions, and mixing of *Nototodarus gouldi* and *N. sloanii* in New Zealand waters

(1) It is known that there are at least five Todarodinae squids, *N. gouldi*, *N. sloanii*, *Todarodes filippovae, T. angolensis*, and *Martialia hyadesi* in New Zealand waters. The former two *Nototodarus* species are distributed in the coastal waters, but the other species are distributed in the offshore waters. *Nototodarus gouldi* is distributed in the Australian and New Zealand waters, but *N. sloanii* is an endemic species in New Zealand waters.

(2) Young and adult *N. gouldi* and *N. sloanii* are easily identified by the number of sucker on Arm I among the five Todarodinae squids. It is also possible to identify smaller squid ranged between about 40-150 mm DML by the relationship between DML and number of suckers on Arm I shown in Chapter II-4-C, but it is impossible to identify squid smaller than 40 mm DML by the morphological characters. However, it is easy to identify the larvae and juvenile by the combination of gel-phenotypes of 6-Phosphogluconate dehydrogenase (6-PGD) and α-Glycerophosphotase dehydrogenase (α-GDH) as shown in Table II-6 and Fig. II-2.

(3) Kawakami and Okutani (1981) pointed out the possibility of two types in *N. sloanii*, based on the number of suckers in hectocotylus and club length index, but based on the relationships between number of suckers on hectocotylus and maturation stages and between dorsal mantle length (DML) and club length, it is clear that the morphological differences between the two types of *N. sloanii* were due to the morphological changes with maturation.

(4) Mixing of the two species occurs in the waters off the West Coast of the South Island and the waters off the East Coast of the North Island. In the waters off the west coast of the North Island *N. gouldi* dominates exclusively, while *N. sloanii* dominates exclusively in the waters off the south and east coasts of the South Island. However, the mixing ratio is highly variable in the waters off the West Coast of the South Island.

III. Age and growth based on the daily increments counts in statoliths

(1) By comparing the increase in number of increments in statolith of *N. sloanii* with the number of days elapsed between sampling dates, the daily formation of increments was validated. The similarities in the characteristics of increments in the statolith between *N. sloanii* and *N. gouldi* can permit to assume that the increment of statolith of *N. gouldi* is also formed daily.

(2) Ageing results show that the hatching month ranged from January to December for both species and this means that spawning occurs throughout the year. The age of largest individuals observed suggests that the life span of both species is about one year.

(3) The relationship between statolith radius and dorsal mantle length suggests daily increments width must reflect squid growth well. Back-calculation can be applied to compensate for the short sampling period. There is good similarity in growth trajectory between observed and back-calculated growth.

(4) There are some clear differences in the growth rates of DML for every 60-day period among month classes, which are express, a group comprising the individuals hatched in same month. This differences in growth among month classes are consistent with seasonal changes in water temperature.

(5) The parameters of logistic growth function, which express growth trajectory well, were estimated by non-linear least square method for each month class by sexes. The 24 pairs of the parameters for each species are shown in Table III-9.

(6) There is a clear difference in growth trajectory between sexes for both species. The difference in growth becomes clear in the individuals older than 200 days old. The mean difference in 300 days old was 41 mm for *N. gouldi* and 32 mm for *N. sloanii*.

(7) There was no clear difference in growth pattern of *N. gouldi* between north and south area of the West Coast of the mainland. There was no clear difference in growth trajectory of *N. sloanii* between the Canterbury Bight and the Snares Shelf, but the growth rate in the Auckland Is. Shelf is a little greater than it in the Snares Shelf where the water temperature is warmer than Auckland Is. This result suggests that the factors other than temperature may affects growth.

(8) There was no large difference in DML at age between the two species, though the differences in growth pattern between the two species were variable among the month classes.

IV. Sexual maturation

(1) Based on the ageing results, relationship between age and some gonad somatic indices were analyzed. The maturation patterns of both species are similar to each other, though the sample numbers of *N. sloanii* is not sufficient.

(2) Change of gonad somatic indices suggests that males start to mature from around 200 days old. Testis somatic index (TSI) reaches a maximum at about 270 days. Females start to mature at the time when TSI reaches the maximum in males.

(3) The developments of ovary, oviduct and Nidamental gland occur simultaneously. The copulation also occurs at the same period. It is suggested that spawning may occur within two months after copulation, considering the period of copulation and a single year life span of both species.

(4) *N. gouldi* may mature about one month earlier than *N. sloanii*.

(5) The comparison of the relationship between age and maturation, and between size and maturation suggested that the maturation is not only related with age, but also related with size. This phenomenon may be different in some degree between the two species.

V. Month class-length key and iterative month class-length key

(1) Based on the ageing results, standard age-length key and the iterative age-length key (IMLK) method (Kimura and Chikuni method) were compared to consider the potential usefulness of the iterative age-length key method in the present study. Using this key the month class composition were derived from size composition in the present study. Then this key is called as month class-length key.

(2) Month class-length key for *N. gouldi* was constructed for the data of January to March 1991, and it for *N. sloanii* was constructed for the data of January and February 1991. The relationship between mean DML and correspond standard deviation which was estimated from the size composition of each month class was derived by the month class-length keys. This relationship is applied for the construction of IMLK.

(3) Under the assumption that the size composition of each month class at every ten-day is normally distributed, the relative size composition at every 10-day is estimated by sex for each species using the estimated logistic growth functions and the relationship between mean and standard deviation.

(4) The comparison of the month class composition obtained by both methods revealed the usefulness of IMLK method.

VI. Distribution and migration of *N. gouldi* and *N. sloanii* by development stage

(1) Using the results of the surveys with the four kinds of sampling gears such as bong net, larva-net attached to bottom trawl net, fine mesh midwater trawl, and bottom trawl, the distributions by development stage were described.

(2) The rhynchoteuthion larvae are distributed on the shelf and the shallow waters such as shelf and bank. The larvae are distributed in 50-100 m depth layer of the water column on the shelf. The rough estimation of age showed that the duration of this stage is 50-60 days.

(3) The juvenile of *N. gouldi* ranged from 20 to 40 mm DML (about 90-120 days old) are distributed on the shelf around the North Island and the West Coast of the South Island. On the other hand, the juvenile of *N. sloanii* is distributed on the shelf along the east and south coast of the South Island, on the Auckland Island Shelf, and around the Chatham Islands.

(4) There was no clear difference in size composition of juvenile among the areas surveyed. It was estimated that the paralarvae and juveniles observed in the surveys were hatched in April/June (austral autumn).

(5) There was no clear difference in the geographical distribution of young and adult *N. gouldi* and *N. sloanii* among the three age groups (4-6, 7-9, and 10-12 months old) based on the results of the ten bottom trawl surveys which were carried out in the various seasons. These results suggested that both species may not migrate on large scale in New Zealand waters. This result is consistent with the results of tagging experiments.

(6) The change of the percentage of squid distributed on the shelf by age showed that the squid migrates into slope area with growth. This trend was observed for both species. This result also showed that *N. gouldi* migrates back on the shelf after eight months old, though this trend was unclear for *N. sloanii*.

(7) The difference of distribution pattern of fully matured squid among fine biological sampling areas suggested that *N. gouldi* may migrates northerly with maturation. On the other hand, there was no clear difference among the areas for *N. sloanii* and fully matured squid are distributed widely in the area where *N. sloanii* is commonly distributed.

(8) The distribution of fully matured squid by depth showed that the squid may migrate to shallower than 100m depth with maturation for both species. This

result suggests that both species may spawn in the waters shallower than 100 m depth.

(9) These results suggest that both species are distributed in shallow waters, mainly on the shelf throughout their life span with some inshore-offshore migration with age, but they do not migrate on large scale.

VII. Food

(1) Based on the data on the observation of stomach content, the changes of feeding activities and occurrence of food items with several factors such as DML, maturation, season, and so on were analyzed by the generalized linear model.

(2) It was estimated that the major species occurred in stomach might be some myctophid species, pilchard, and barracouta for fish, some euphasid species for crustacean, and *Nototodarus* species for prey squid. It is probable that the species composition for prey animals may change spatially and temporally.

(3) The ratio of empty stomachs and occurrence ratio of food categories changed with year, season, and area. It was observed for both species that the ratio of empty stomach increased with maturation. The present result indicated the rapid development of gonad and accessory organs may be related to the feeding activity.

(4) There is a consistent trend in change of occurrence ratio of food items with DML, decrease of crustacean and increase of fish and squid with size. This results may reflect the change of the size of preys.

(5) It was observed that cannibalism is an important role in feeding activities for both species, but it is very difficult to prove the significance of cannibalism in the present study.

VIII. Month class composition and annual variation of abundance

(1) Using the catch by size categories and size composition in each size category for the Japanese squid jigging and trawl fisheries, the size composition of squid catch was estimated for time-area strata by the fisheries. Using IMLK method shown in Chapter V, the size composition of catch was converted into month class composition. Based on these data, CPUE for each month class was standardized by generalized linear model and expected values of CPUE at 210 days old and 300 days old were calculated as the abundance indices for recruitment and spawner for each month class by fishing years.

(2) The historical means of the standardized CPUE of each month class at 210 days old shows the abundance of winter month classes is relatively dominant. This phenomenon is commonly observed in the other squid such as *Todarodes pacificus, T. angolensis, Illex argentinus*, and *I. illecebrosus*. The winter classes spend their growing period in summer, which is most suitable season for feeding. This may be one reason why the winter classes are dominant.

(3) Comparison of correlation coefficients of the standardized CPUE at 210 days old between month classes revealed that there are some seasonal cohorts in which some month classes have a similar trend of annual abundance, though almost all of the coefficients were statistically insignificant. For *N. gouldi*, it was observed that there are two seasonal cohorts, May-June and July-August cohorts in the waters off west coast of the North Island. For *N. sloanii*, it was observed that there are four seasonal cohorts on the Snares Shelf, three cohorts on the Canterbury Bight, and two cohorts on the Auckland Is. Shelf.

(4) There was no clear historical trend in abundance for almost all of the seasonal cohorts of both species in all areas. This suggested that the fishing during the 1980s might not have serious effect on the stocks.

(5) The correlation coefficients among seasonal cohorts in the areas were very low and statistically insignificant. This means each seasonal cohort may fluctuate independently within a area and also among the areas. This phenomenon also points out that the small scale environmental factors may be relatively important for the fluctuation of each cohort in a area rather than global factors such as El Ninõ phenomenon.

(6) There is no clear relationship between stock and progeny for both species. This also means that the density dependent factors are not dominant substantially in population dynamics very well and most of variation in abundance may be caused by environmental factors.

(7) There are various assumptions in the complex process of the estimation of standardized CPUE for each month class. These assumptions introduced several limitations on data and some bias might be introduced in the results. Therefore, the results obtained in this Chapter should be considered as one of the rough estimation of the trend of abundance for each month class. Further investigation using more detailed data is recommended.

IX. General discussions and a consideration on assessment and management

(1) Based on the biological characteristics revealed in the present study, general structure of stock for each species was discussed.

(2) The composition of regional stocks for *N. gouldi* is still unclear due to the insufficient information for the waters off West Coast of the South Island. As for *N. sloanii*, there are relatively independent

groups in the Canterbury Bight, Snares Shelf, and Auckland Is. Shelf. However, there is little probability that these regional groups are independent to each other strictly, because there is no strong geographic barrier.

(3) There are also some seasonal cohorts in each area for both species and these cohorts fluctuate independently. However, the correlation coefficient between month classes within a seasonal cohort was relatively low and this means the seasonal cohorts are not stable components and variable year by year.

(4) The complex stock structure hampers the application of systematic assessment and management in the New Zealand arrow squid fisheries. Strict assessment and management for each seasonal cohort in every area is troublesome, and the strict management in each year does not promise the stable catch in a coming year due to poor spawner-progeny relationship.

(5) Leslie-De Lury type method is one of the most applicable stock assessment method for arrow squid to estimate absolute value of stock size and fishing mortality for each cohort, though some technical problems still exist.

(6) The method using catch by size categories and size composition of each size category is one of the best way to estimate size composition of catch for squid fisheries. Size sampling for each size category by suitable time-area strata for each fishing year is essential to overcome some problems mentioned in the present study. This sample is also useful of ageing to make month class -length key.

(7) Further investigation of CPUE for each fishery in detail including size selectivity of squid jigging gear is desired to construct reliable abundance index for Leslie-De Lury type method.

(8) The main target of management for a fishery on annual squid should be to allow enough spawners to escape the fishery at the end of fishing season so as not to reduce appreciably the probability of good recruitment in the next fishing season. Considering the characteristics of arrow squid, effort regulation is the best way to manage the fishery.

(9) At the present circumstance the management may be set in rough scale such as the limitation of the total fishing effort for each fishery regardless area under the existence of self regulation characteristics of the fisheries which tend to target most abundant cohort, because there is no significant difference in the biological characteristics between the two species from the management point of view and CPUE trend suggested that there was no serious effect on stock by the historical fishing level.

(10) The close monitor on the fisheries is essential under the rough management regime to prevent potential overfishing on a particular stock in each fishing year.

XI. Acknowledgments

I wish to express my deep felt gratitude to Dr. Masaru Tanaka, Professor of Kyoto University, who encouraged me during writing this paper and who kindly reviewed my manuscript. I'm also deeply indebted to Drs. Isao Hayashi and Wataru Sakamoto, Proffessors of Kyoto University, for their valuable advice and kind review of the manuscript. During the course of my studies, Dr. Hiroshi Hatanaka, the former Director of National Research Institute of Far Seas Fisheries (NRIFSF), also gave me encouragement and kindly gave me some valuable comments. The late Dr. Ikuo Ikeda, the former Director of NRIFSF, also gave me encouragement and many valuable ideas on research. Dr. Ziro Suzuki, Chief of Pelagic Fish Resources Division of NRIFSF, kindly permitted me to continue my study on squid in this Division and constantly gave me encouragement. Mr. Shigekuki Kawahara, the former Chief of Distant-water Groundfish Section of NRIFSF gave me many chances to involve the research activities on squid in New Zealand waters. Dr. Takashi Okutani, Professor of Nihon University, gave me various and valuable comments on my manuscript. I sincerely thank Dr. Toshio Okazaki, National Research Institute of Aquaculture, kindly assisted me to carry out the observations by gel electrophoresis. I wish to express my thanks to Dr. K. Hiramatsu (NRIFSF) for his many valuable advises on the statistical treatment of the data. I also want my sincere thanks to Dr. Pole Rodhouse, British Antarctic Survey, United Kingdom, who was kind enough to edit the English version of the manuscript. I express my sincere appreciation for their assistance.

Furthermore, I really appreciate the kindness of Japan Marine Resource Research Center (JAMARC) and many staffs of JAMARC who were involved in the research cruises in New Zealand waters. JAMARC kindly permitted me to use the various and huge data obtained by its research activities around New Zealand. The staffs had made huge efforts on the collection of the data. I also wish to thank Japan National Squid Jigging Association, Japan Deep Sea Trawlers Association, and the members of the fishing companies involved in the New Zeland squid fisheries who provided their catch and effort statistics and other useful information they had obtained through their fishing experiences. My thanks also go to many assistant staffs in Distant-water Groundfish Section of NRIFSF who kindly helped me in compiling the data used in this study.

XII. References

Akamine, T. 1986: Expansion of growth curves using a periodic function and BASIC program by Marquardt's method. Bul. Jap. Sea Reg. Fish. Res.

Lab., 36, 77-107.

Alm, G. 1959: Connection between maturity, size, and age in fishes. Inst. Freshwater Res. Drottningholm Rep., 40, 145p.

Amaratunga, T and R.D. Durward. 1979: Standardization of data collected for the short-finned squid *Illex illecebrosus*. Int. Comm. Northw. Atl. Fish. Sel. Pap., 5, 37-41.

Amaratunga, T., J.D. Neilson, D.J. Gills, and D.G. Valdron. 1979: food and feeding of the short-finned squid, *Illex illecebrosus* on the Scotian Shelf in 1978. Int. Comm. Northw. Atl. Fish. Res. Doc. 79/11/11, Serial No. 5335. 24p.

Annala, J.H. (comp.) 1992 : Report from the Fishery Assessment Plenary, May 1992: stock assessments and yield estimates. 222p. (unpublished report held in MAF Fisheries Greta Point library, Wellington, New Zealand)

Annala, J.H. 1994: Report from the fishery assessment plenary, May 1994: stock assessments and yield estimates (unpublished report held in MAF Fisheries Greta Point library, Wellington), 222p.

Anon. 1978: Report of *Kaiyo Maru* survey cruise in 1977 fiscal year. Fisheries Agency, Government of Japan, 259p.

Anon. 1986: Report of *Kaiyo Maru* survey cruise in 1985 fiscal year. Fisheries Agency, Government of Japan, 244p.

Anon. 1966-1993: Annual statistics of fishery products marketing. Statistics and Information Department, Ministry of Agriculture, forestry, and fishery, Japan. (In Japanese).

Anon. 1984 : Enyo-sokobikiami-gyogyo Gyojozu (S. 58). (Summary statistics on the distant water trawl fishery), Southern trawl in 1982. National Research Institute of Far Seas Fisheries. 43p., (In Japanese).

Anon. 1988 : Enyo-sokobikiami-gyogyo Gyojozu (S. 62). (Summary statistics on the distant water trawl fishery), Southern trawl in 1987. National Research Institute of Far Seas Fisheries. 59p., (In Japanese).

Anon. 1993: Annual statistics on the fisheries and aquaculture products. Statistics and Information Department, Ministry of Agriculture, forestry, and fishery, Japan., 296p. (In Japanese).

Araya, H. 1974: Some problems of the conservation for the jigging fishery resources of a common squid, *Todarodes pacificus* Steenstrup in Japan. Fish. Resour. Invest. Sci. Fish. Agency Jap. Gav., 16, 25-66.

Araya, H. 1976: Migration and fishing ground of winter sub-population of the squid, *Todarodes pacificus* Steenstrup, in the northern waters of Japan. Bull. Hokkaido Reg. Fish. Res. Lab. 41, 119-129.

Arkhipkin, A.I. and V.A. Bizikov. 1991: Comparative analysis of age and growth rates estimation using statoliths and gladius in squids. In: Squid age Determination using statoliths, edied by Jereb, P., P.S. Ragonese, and S. von. Boletezky. Proceedings of international workshop held in the Instituto di Technologia della Persca e del Pescato (ITPP-CNR), Mazara del Vallo, Italy, 9-14 October 1989. N.T.R.-I.T.P.P. Special Publications, No. 1, 19-34.

Arkhipkin, A.I. and A. Mikheev. 1992: Age and growth of the squid *Sthenoteuthis pteropus* (Oegopsida: Ommastrephidae) from the Central-East Atlantic. J. Exp. Mar. Biol. Ecol., 163, 261-276.

Arkhipkin, A. and V. Laptikhovsky. 1994: Seasonal and interannual variability in growth and maturation of winter-spawning *Illex argentinus* (Cephalopoda, Ommastrephidae) in the Southwest Atlantic. Aquat. Living Resour., 7, 221-232.

Balch, N., A. Sirois, and G. Hurley. 1988: Growth increments in statoliths from paralarvae of the ommastrephid squid *Illex* (Cephalopoda: Teuthoidea). Malacologia, 29, 103-112.

Basson, M., J.R. Beddington, J.A. Crombie, S.J. Holden, L.V. Purchase, and G.A. Tingley. 1994: Assessment and management techniques for migratory annual squid stocks: the *Illex argentinus* fishery in the Southwest Atlantic as an example. FAO, Rome in press

Beddington, J.R., A.A. Rosenberg, J.A. Crombie, and G.P. Kirkwood. 1990: Stock assessment and the provision of management advice for the short fin squid fishery in Falkland Islands waters. Fish. Res., 8, 351-365.

Bigelow, K.A. 1992: Age and growth in paralarvae of the mesopelagic squid *Abralia trigonura* based on daily growth increments in statoliths. Mar. Ecol. Prog. Ser., 82, 31-40.

Brothers, E.B., C.P. Matthews, and R. Lasker. 1976: Daily growth increments in otoliths from larval and adult fishes. Fish. Bull. US., 74, 1-8.

Caddy, J.F. 1983: The Cephalopods: Factors relevant to their population dynamics and to the assessment and management of stocks. In: Advances in assessment of world cephalopod resources, edited by Caddy, J.F. FAO Fish. Tech. Pap. 231, 416-452.

Caddy, J.F. 1992: Daily rings on squid statolith: an opportunity to test standard population model? In: Squid age determination using statoliths, edited by Jereb, P., P.S. Ragonese, and S. von Boletezky. Proceedings of international workshop held in the Instituto di Technologia della Persca e del Pescato (ITPP-CNR), Mazara del Vallo, Italy, 9-14 October 1989. N.T.R.-I.T.P.P. Special Publications, No. 1, 53-66.

Campana, S.E. and J.D. Neilson. 1985: Microstructure of fish otoliths. Can. J. Fish. Aquat. Sci., 42, 1014-1032.

Carlander, K.D. 1987: A history of scale age and growth studies of North American freshwater fish, In: Age and Growth of Fish, edited by R.C. Summerfelt and G.E. Hall. Iowa State University Press, 3-13.

Chiswell, S.M. 1994: Variability in seas surface temperature around New Zealand from AVHRR images. N.Z. Jour. Mar. Fresw. Res., 28, 179-192.

Cirke, J. 1987: The Patagonian fishery resources and the offshore fisheries in the Southwest Atlantic. FAO Fish. Tech. Rep., 286, 75pp.

Clayton, J.W. and D.N. Tretiak. 1972: Aminecitrate buffer for pH control in starch gel electrophoresis. J. Fish. Res. Bd. Can., 29(8), 1169-1172.

Coehlo, M.L. and A.A. Rosenberg. 1984: Casual analysis of some biological data for *Illex illecebrosus* from the Scotian Shelf. NAFO Sci. Coun. Studies, 7, 61-66.

Cooke, J.G. and K. Lankester. 1995: Consideration of statistical models for catch-effort indices for use in tuning VPA's. ICCAT SCRS/95/77, 16p.

Dawe, E.G., R. O'Dor, P.H. Odense, and G.V. Hurley. 1984: Development of an ageing technique for short-finned squid (*Illex illecebrosus*). NAFO SCR Doc. 84/IX/110, 24p.

Dawe,E.G., R.K. O'Dor P.H. Odense, and G.V. Hurley. 1985: Validation and application of an ageing technique for short-finned squid (*Illex illecebrosus*). J. Northw. Atl. Fish. Sci., 6, 107-116.

Dell, R.K. 1970: A specimen of the giant squid *Architeuthis* from New Zealand. Rec. Dominion Mus., 7 (4), 1-15.

Dong, Q. and V.R. Restrepo. 1995: Notes on the Poisson error assumption made to estimate relative abundance of west Atlantic bluefin tuna. ICCAT SCRS/95/88, 8p.

Doubleday, W.G. 1973: Manual of methods for fisheries resource survey and appraisal. Part 3 - standard methods and techniques for demersal fisheries resource surveys. FAO Fish. Tech. Pap., No. 124, 37p.

Dow, R.L. 1976: Effects of climatic cycles on the relative abundance and variability of commercial marine and estuarial species. J. Cons. int. Explor. Mer., 37(3), 274-280.

Dunning, M.C. 1988: Distribution and comparative life history studies of deep water squid of the family Ommastrephidae in Australian waters. Doctoral thesis, Department of Zoology, University of Queensland. 288p.

Dunning, M.C. 1993: Summer Populations of *Ommastrephes bartramii* (Lesueur, 1821) and *Todarodes filippovae* Adam, 1975 (Cephalopoda: Ommastrephidae) from the Tasman Sea, In: Recent Advances in Cephalopod Fisheries Biology, edited by Okutani, T., R.K. O'Dor, and T. Kubodera. Tokai University Press, Tokyo, 97-118.

Dunning, M.C. and S.B. Brandt. 1985: Distribution and life history of deep-water squid of commercial interest from Australia. Aust. J. Mar. Fresh. Res., 36, 343-359.

Ennis, G.P. and P.W. Collins. 1979: Food and feeding of the short-finned squid, *Illex illecebrosus*, during its seasonal occurrence in the Newfoundland area. Int. Comm. Northw. Atl. Fish. Sel. Pap., 5, 25-29.

Fenaughty J.M. and Y. Uozumi. 1989: A survey of demersal fish stocks on the Chatham Rise, New Zealand, March 1983. N.Z. Fish. Tech. Rep., 12, 1-41.

Forch, E.C. 1986: Rhynchoteuthion larvae from New Zealand coastal waters (Cephalopod: Ommastrephidae). VIE MILIEU, 36(3), 177-183.

Forsythe, J.W. 1993: A working hypothesis of how seasonal temperature change may impact the field growth of young cephalopod. In: Recent Advances in Cephalopod Fisheries Biology, edited by Okutani, T., R.K., O'Dor, and T. Kubodera. Tokai University Press, Tokyo, 133-143.

Forsythe, J.W. and R.T., Hanlon. 1989: Growth of the eastern Atlantic squid, *Loligo forbesi* Steenstrup (Mollusca: Cephalopoda). Aquac. Fish. Manag., 20, 1-14.

Forsythe, J.W. and W.F. Van Heukelem. 1987: Growth. In: Cephalopod Life Cycle, Vol II, edited by Boyle, P.R. Academic Press, London, 135-156.

Garner, D.M. 1961: Hydrology of New Zealand coastal waters, 1955. N.Z. Ocean. Ins. Mem., 8, 1-85.

Gavaris S. 1980: Use of a multiplicative model to estimate catch rate and effort from commercial data. Can. J. Fish. aquat. Sci., 37, 2272-2275.

Gibson, J.M. 1995: The New Zealand squid fishery 1979-93. N.Z. Fish. Tech. Rep., 42, 43p.

Greig, M., N.M. Ridgway and B.S. Shakespeare. 1988: Sea surface temperature variation at coastal sites around New Zealand. N.Z. Jour. Mar. Freshw. Res., 22, 391-400.

Hamabe, M. 1962: Embryological studies on the common squid, *Ommastrephes sloani pacificus* Steenstrup, in the southwest waters of the Sea of Japan. Bull. Jap. Sea Reg. Fish. Res. Lab., 11, 53-64 (In Japanese with English summary).

Hamabe, M and T. Shimizu. 1966: Ecological studies on the common squid, *Todarodes pacificus* Sttenstrup, mainly in the southwestern waters of the Japan Sea. Bull. Jap. Sea Reg. Fish. Res. Lab., 16, 13-55.

Hatanaka, H. 1986: Growth and life span of short-finned squid *Illex argentinus* in the waters off Argentina. Nippon Suisan Gakkaishi, 52, 11-17.

Hatanaka, H., S. Kawahara, Y. Uozumi, and S. Kasahara. 1985: 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, 56-98.

Hatanaka, H., Y. Uozumi, J. Fukui, M. Aizawa and R.J. Hurst. 1989a: Japan-New Zealand trawl survey off southern New Zealand, October-November 1983. N. Z. Fish. Tech. Rep., 9, 52p.

Hatanaka, H., Y. Uozumi, J. Fukui, M. Aizawa, and M.E. Livingston. 1989b: Trawl survey of hoki and other slope fish on the Chatham Rise, New Zealand, November-December 1983. N.Z. Fish. Tech. Rep., 17, 1-32.

Hatfield, E.M.C. and P.G. Rodhuse. 1994: Migration as a source of bias in the measurement of cephalopod growth. Antarct. Sci., 6(2), 179-184.

Heath, R.A. 1975: Oceanic circulation and hydrology off the southern half of South Island New Zealand. N.Z. Ocean. Ins. Mem., 72, 1-36.

Hixon, R.F. 1983: Loligo opalesecens. In: Cephalopod Life Cycles, Volume I Species Accounts, edited by Boyle, P.R. Academic Press, London, 95-114.

Hixon, R.F. and M.R. Villoch. 1983: Growth rings in the statoliths of young laboratory cultured squids (*Loligo opalescens*). Am. Malacol. Bull., 2, 93.

Horn P.L. 1991: Trawl survey of jack mackerels (*Trachurus* spp.) off the central west coast, New Zealand, February-March 1990. NZ Fish. Tech. Rep., 28, 40p.

Hurst, R.J., N.W. Bagley, and Y. Uozumi. 1990: New Zealand-Japan trawl survey of shelf and upper slope species off southern new Zealand, June 1986. N.Z. Fish. Tech. Rep., 18, 50p.

Jackson, G.D. 1989a: The use of statolith microstructure to analyze life-history events in the small tropical cephalopod *Idiosepius pygmacus*. Fish. Bull. US., 87, 265-272.

Jackson, G.D. 1989b: Age and growth of the tropical nearshore loliginid squid *Sepioteuthis lessoniana* determined from statolith growth-ring analysis. Fish. Bull. US., 88, 113-118.

Jackson, G.D. and J.H. Choat. 1992: Growth in tropical cephalopods: an analysis based on statolith microstructure. Can. J. Fish. aquat. Sci., 49, 218-228.

Japan National Squid Jigging Association. 1976 : Report on the results of squid jigging operations in 1975/76 fishing year around New Zealand. 52p., Japan National Squid Jigging Association. (In Japanese).

Japan National Squid Jigging Association. 1977 : Report on the results of squid jigging operations in 1976/77 fishing year around New Zealand. 54p., Japan National Squid Jigging Association. (In Japanese).

Japan National Squid Jigging Association. 1978 : Report on the results of squid jigging operations in 1977/78 fishing year around New Zealand. 51p., Japan National Squid Jigging Association. (In Japanese).

Japan National Squid Jigging Association. 1979 : Report on the results of squid jigging operations in 1978/79 fishing year around New Zealand. 100p., Japan National Squid Jigging Association. (In Japanese).

Jones, J.B. 1990: Jack mackerel (*Trachurus* spp.) in New Zealand waters. N.Z. Fish. Tech. Rep., 23, 28p.

Kailola, P.J., M.J. Williams, P.C. Stewart, R.E. Reichelt, A. McNee, and C. Grieve. 1993: Arrow squid, In Australian fisheries resources. Bureau of Resource Sciences and the Fisheries Research and Development Corporation Australia, 106-107.

Kawahara, S. and K. Tokusa. 1987: Report on 1981 Japan/New Zealand Joint Squid Survey in Area E and F by Shinkai Maru. JAMARC Rep., 22, 75p.

Kawahara, S., Y. Uozumi, and H. Hatanaka. 1993: Is it possible to predict ommastrephid squid abundance in advance of the fishing season? In: Recent advances in cephalopod fisheries biology, edited by Okutani, T., R.K. O'Dor, and T. Kubodera. Tokai University, Tokyo, 728-734.

Kawakami, T 1976: The fishery biological study on a squid *Nototodarus sloani* (Gray) in the New Zealand waters. Bull. Tokai Reg. Fish. Res. Lab., 85, 31-104. (in Japanese with English abstract).

Kawakami, T. and T. Okutani. 1981: A note on identity of Ommastrephid squids of the genus *Nototodarus* exploited in the New Zealand waters. Bull. Tokai Fish. Res. Lab., 105, 17-30.

Kimura, D.K. 1981: Standardized measures of relative abundance based on modeling log(c.p.u.e.), and their application to Pacific ocean perch (Sebastes alutus). J. Cons. int. Explor. Mer., 39, 211-218.

Kimura, D.K. and S. Chikuni. 1987: Mixtures of emprical distribution: an iterative application of the age-length key. Biometrics, 43, 23-35.

Kono, H. and K. Tokusa. 1985: Report of the Japan/New Zealand joint survey on groundfish resources in the waters south of New Zealand by Shinkai Maru, 1982. JAMARC Rep., 21, 112p.

Kubodera, T. 1991: Physiology and ecology of squids. In: Squid - from biology to human consumption, edited by Nasu, K., T. Okutani, and M. Ogura. Seizando Press Tokyo, 33-67. (in Japanese).

Lange, A.M.T. and M.P. Sissenwine. 1983: Squid resources of the Northwest Atlantic. In: Advances in assessment of world cephalopod resources, edited by Caddy, J.F. FAO Fish. Tech. Pap. 231, 21-54.

Lipinski, M. 1986: Methods for the validation of squid age from statoliths. J. Mar. Biol. Ass. U.K., 66, 505-526.

Livingston, M.E., Y. Uozumi, and P.H. Berben. 1991: Abundance, distribution, and spawning condition of hoki and other mid-slope fish on the Chatham Rise, July 1986. N.Z. Fish. Tech. Rep., 25, 47p

Mangold, K. 1987: Reproduction. In: Cephalopod Life Cycles, Volume II, edited by Boyle, P.R. London: Academic Press, 157-200.

Mattlin, R.H. 1986: Arrow squid. In: Background papers for the total allowable catch recommendations for the 1986-87 New Zealand fishing year. Fisheries Research Division & Fisheries Management Division, N.Z. Ministry of Agriculture and Fisheries, 17-10.

Mattlin, R.H., R.E. Scheibling, and E.C. Forch. 1985: Distribution, abundance, and size structure of arrow squid (*Nototodarus* sp.) off New Zealand. NAFO Sci. Coun. Studies, 9, 39-45.

May, B., J.E. Wright, and M. Stoneking. 1979: Joint segregation of biochemical loci in Salmonidae: results from experiments with Salvelinus and review of the literature on the other species. J. Fish. Res. Bd. Can., 36(9), 114-1128.

Mayo, R.K., J. Burnett, T.D. Smith, and C. Muchant. 1990: Growth-maturation interactions of acadian redfish (*Sebastes fasciatus* Storer) in the Gulf of Main-Georges Bank region of the Northwest Atlantic. J. Cons. int. Explor. Mer., 46, 287-305.

Mohn, R.K. 1981: Abiotic factors relation to squid abundance as determined from groundfish cruises 1970-1980. NAFO SCR Doc., 81/34, 11p.

Murata, M. 1989: Population assessment, management and fishery forecasting for the Japanese common squid, *Todarodes pacificus*. In: Marine invertebrate fisheries: Their assessment and management, edited by Caddy, J.F. John Wiley, New York, 613-636.

Murata, M. and S. Hayase. 1993: Life history and biological information on flying squid (*Ommastrephes bartrami*) in the North Pacific

Ocean. In: Symposium on biology, distribution and stock assessment of species caught in the high seas driftnet fisheries in the North Pacific Ocean (held by the standing committee on biology and research at Tokyo, Japan November 4 to 6, 1991), edited by J. Ito, W. Shaw, and R.L. Burger. INPFC Bull., 53(II), 111-146.

Murayama, T. and S. Kasahara. 1988: Stock structure of Japanese common squid in the Japan Sea. Report of the 1987 annual meeting of squid resources and fishing and oceanographical conditions. Hokkaido Reg. Res. Lab. , 22-30. (in Japanese).

Nakamura, Y. and Y. Sakurai. 1991: Validation of daily growth increments in statoliths of Japanese common squid, *Todarodes pacificus*. Nippon Suisan Gakkaishi, 57, 2007-2011.

Natsukari, Y., T. Nakanose, and K. Oda. 1988: Age and growth of the loliginid squid *Photololigo edulis* (Hoyle, 1985). J. Exp. Mar. Biol. Ecol., 116, 177-190.

Nesis, K.N. 1979: Squid larvae of the family Ommastrephidae (Cephalopoda). Zool. Zhur., 58, 17-30.

Nesis, K.N. 1983: Dosidicus gigas. In: Cephalopod life cycle, Volume I, edited by Boyle, P.R. Academic Press London, 215-231.

Nixon, M. 1987: Cephalopod diets. In: Cephalopod life cycles, Volume II, Comparative Reviews, edited by Boyle, P.R. Academic Press, London, 201-220.

NOAA 1996: NOAA Climate Diagnostic Bulletin November 1996. 78p.

O'Dor, R.K. 1983: *Illex illecebrosus*. In: Cephalopod Life Cycle, Volume I, edited by Boyle, P.R. Academic Press, London, 175-199.

O'Dor, R.K., R.D. Durward, E. Vessey, and T. Amaratunga. 1980: Feeding and growth in captive squid, *Illex illecebrosus*, and the influence of food availability on growth in the natural population. Int. Comm. Northw. Atl. Fish., Sel. Pap. 6, 15-21.

O'Sullivan, D. and J.M. Cullen. 1983: Food of the squid *Nototodarus gouldi* in Bass Strait. Aust. J. Mar. Freshw. Res., 34, 261-285.

Okiyama, M. 1965: Some consideration on the eggs and larvae of the common squid *Todarodes pacificus* Steenstrup. Bull. Jap. Sea Reg. Fish. Res. lab., 15: 39-53. (In Japanese with English summary).

Okutani, T. 1968: Studies on early life history of decapodan Mollusca - III. Systematics and distribution of larvae of decapod cephalopods collected from the sea surface on the Pacific coast of Japan. Bull. Tokai Reg. Fish. Res. Lab., 55: 9-57.

Okutani, T. 1980: Useful and latent cuttlefish and squids of the world. Publish from National Cooperative Association of Squid Processors for the 15th Anniversary of its Foundation, Tokyo, 66p.

Okutani, T. 1983: *Todarodes pacificus*. In: Cephalopod Life Cycle, Volime I, edited by Boyle, P.R. Academic Press, London, 201-214.

Okutani, T. 1987: Juvenile morphology. In: Cephalopod life cycles Volume II, edited by Boyle P.R. Academic Press, London, 33-44.

Okutani, T. and T. Watanabe. 1983: Stock assessment by larval surveys of the winter population of *Todarodes pacificus* Steenstrup (Cephalopoda: Ommastrephidae), with a review of early works. Biol. Oceanogr., 2, 433-456.

Okutani, T., M. Tagawa, and H. Horikawa. 1987: Cephalopods from continental shelf and slope around Japan. Japan Fisheries Resources Conservation Association, 194p.

Pierce, G.J. and A. Guerra. 1994: Stock assessment methods used for cephalopod fisheries. Fish. Res., 21, 255-285.

Pope, J.A., A.R. Margretts, E.F. Akyuz, and J.M. Hamley. 1975: Manual of methods for fish stock assessment Part III. Selectivity of fishing gear. FAO Fish. Tech. Pap., 41 (FIRS/T41 Rev. 1), 65p.

Pope, J.G. 1972: An investigation of the accuracy of virtual population analysis using cohort analysis. Int. Comm. Northw. Atl. Fish. Res. Bull., 9, 65-74.

Rahmstorf, S 1992: Modeling ocean temperature and mixed-layer depths in the Tasman Sea off the South Island, New Zealand. N.Z. Jour. Mar. Fresw. Res., 26, 37-51.

Richards L.J., J.T. Schnute, and C.M. Hand. 1990: A multivariate maturity model with a comparative analysis of three lingcod (*Ohpiodon elongatus*) stocks. Can. J. Fish. Aquat. Sci., 47, 948-959.

Ricker, W.E. 1973: Linear regressions in fishery research. J. Fish. Res. Bd. Can., 30, 409-434.

Roberts, P.E. 1978: New Zealand squid resources. In: Proceedings of the Pelagic Fisheries conference July 1977, edited by Habib, G. and P.E. Roberts. N.Z. MAF Fish. Res. Div. Occasi. Publ., 15, 90-93.

Roberts, P.E. 1979: Squid. In: Proceedings of the demersal fisheries conference, October 1978, edited by Elder, R.D. and Taylor, J.L., NZ MAF Fish. Res. Div. Occasi. Publ., 19, 35-41.

Roberts, P.E. 1983: The biology of jig-caught arrow squid (*Nototodarus* spp.) in New Zealand waters. Mem. Nat. Mus. Victoria, 44, 297-303.

Robertson, D.A., P.J. Grimes, and R.I. C.C. Fransis. 1981: Central west coast fish biomass survey. October-November 1981. N.Z. MAF Fish. Internal Rep., 120, 35p.

Rodhouse, P.G. and E.M.C. Hatfield. 1990: Age determination in squid using statolith growth increments. Fish. Res. (Amst.) 8, 323-334.

Rodhouse, P.G. and J. Yeatman. 1990: Redescription of *Martialia hyadesi* Rochebrune and Mabille, 1889 (Mollusca: Cephalopoda) from the southern Ocean. Bull. British Mus. Natl. His., 56, 135-143.

Rodhouse, P.G., K. Robinson, S.B. Gajdatsy, H.I. Daly, and M.J.S. Ashmore. 1994: Growth, age structure and environmental history in the cephalopod *Martialia hyadesi* (Teuthoudea: Ommastrephidae) at the Antarctic Polar frontal zone and on the Patagonian Shelf edge. Antarct. Sci., 6(2), 259-267.

Roff, D.A. 1982: Reproductive strategies in flatfish: first synthesis. Can. J. Fish. Aquat. Sci., 39: 1686-

1698.

Roper, C.F.E. and G.L. Voss. 1983: Guidelines for taxonomic descriptions of cephalopod species. In: Proceedings of the workshop on the biology and resource potential of cephalopods. March 1981, edited by Stone, D.M. Mem. Nat. Mus. Victoria, 44, 48-63.

Roper, C.F.E., M.J. Sweeney, and C.E. Nauen. 1984: FAO species catalogue. vol. 3. Cephalopods of the world. An annotated and illustrated catalogue of species of interest to fisheries. FAO Fish. Synop., 125 (3), 277p.

Rosenberg, A.A., G.P. Kirkwood, J.A. Crombie, and J.R. Beddington. 1990 : The assessment of stocks of annual squid species. Fish. Res., 8, 335-350.

Rosenberg, A.A., K.F. Wiborg, and I.M. Beck. 1981: Growth of *Todarodes sagittatus* (Lamarck) (Cephalopoda: Ommastrephidae) from the Northeast Atlantic based on counts of statolith growth rings. Sarsia, 66, 53-57.

Rowe, V. and K. Mangold. 1975: The effect of starvation on sexual maturation in *Illex illecebrosus* (LeSuur) (Cephalopoda: Teuthoidea). J.Exp. Mar. Biol. Ecol., 17, 157-163.

Rowell, T.W., J.H. Young, J.C. Poulard, and J.P. Robin. 1985: Biological characteristics and biomass estimates of the squid (*Illex illecebrosus*) on the Scotian Shelf (Div. 4VWX) in 1984. NAFO SCR Doc., 85/27, 14p.

Saito, R. 1973: Report on industrialization of New Zealand squid fishery for 1972. JAMARC Rep., 12, 126p. (in Japanese).

Saito, R. 1975: Current status of New Zealand squid fishery. Exploitation and Development of World Cephalopod Resources, Fishery Agency, 139-145. (in Japanese).

Saito, R. 1976: The Japanese fishery (jigging) for *Nototodarus sloani sloani* in New Zealand waters. In: Contributed papers submitted to the Expert Consultation of fishing for squid and other cephalopods. (supplement 1 to the report of the expert consultation of fishing of squid and other cephalopods, Tokyo and Hakodate, Japan, 9-13 September 1975). FAO Fish. Rep., 170 Supplement 1, 53-60.

Saito, R., T. Kawakami, M. Hamabe, and Y. Matsushita. 1974: A preliminary note on the ecology of the Ommastrephid squid *Nototodarus sloani sloani* (Gray) in New Zealand waters-III. Studies on the catch by jigs by the Hoyo-Maru No. 51 in 1971 and 1972. Bull. Tokai Reg. Res. Lab., 79, 35-68. (In Japanese with English summary).

Sakamoto, Y., M. Ishiguro and G. Katagawa. 1986: Akaike Information Criterion Statistics. KTK Scientific Publishers, Tokyo, 107-146.

SAS. 1993: SAS/STAAT software: The GENMOD Procedure. SAS Tech. Rep., P-243, 88p.

Sato, T. 1985: Reports on the squid tagging in New Zealand waters. Far Seas Fish. Res. Lab. S series, 14, 1-73.

Sato, T. and H. Hatanaka. 1983: A review of assessment of Japanese distant-water fisheries for cephalopods, In: Advances in assessment of world cephalopod resources, edited by Caddy, J.F. FAO Fish. Tech. Pap, 231, 145-203.

Schaffer, W.M. and P.F. Elson. 1975: The adaptive significance of cariations in life history among local populations of Atlantic salmon in North America. Ecology, 56, 577-590.

Sissenwine, M.P. and A.M. Tibbetts. 1977: Simulating the effect of fishing on squid (*Loligo* and *Illex*) population of the northeastern United States. Int. Comm. Northw. Atl. Fish. Sel. Pap., 2, 71-84.

Smith, P.J. 1985: Distribution of two species of arrow squid (*Nototodarus*) around New Zealand. NZ MAF Fish. Res. Div. Occasi. Publi., 49, 14p.

Smith, P.J., P.E. Roberts, and R.J. Hurst. 1981: Evidence for two species of arrow squids in the New Zealand fishery. N.Z. Jour. Mar. Freshw. Res., 15, 247-253.

Smith, P.J., R.H. Mattlin, M.A. Roeleveld, and T. Okutani. 1987: Arrow squids of the genus *Nototodarus* in New Zealand waters: systematics, biology, and fisheries. NZ Jour. Mar. Freshw. Res., 21, 315-326.

Squire, H.S. 1967: Growth and hypothetical age of the Newfoundland bait squid, *Illex illecebrosus illecebrosus*. J. Fish. Res. Bd. Can., 24, 1209-1217.

Tabert, B.D. and D.W. Coble. 1977: Daily rings in otoliths of three species of *Lepomis* and *Tilapia mossambica*. J. Fish. Res. Board Can., 34, 332-240.

Tung, I. 1978: On the biology and fishing of the squid *Nototodarus sloani sloani* (Gray) in the New Zealand waters. Rep. Ins. Fish. Biol. Min. Econo. Aff. Nat. Taiwan Univ., 111(3), 44-64.

Uozumi, Y. 1988: Status of the Japanese southern trawl fishery and its resources. Gyogyo-Shigen Kenkyu-Kaigi Nishi-Nihon Sokouo Buaihou 16, 10-15. (In Japanese).

Uozumi, Y. 1990: Ommastrephidae. In: Fishes collected by the R/V *Shinkai Maru* around New Zealand, edited by Amaoka, K., K. Matsuura, T. Inada, M. Takeda, H. Hatanaka, and K. Okada. Japanese Marine Fishery Resource Research Center Tokyo, 340-347.

Uozumi, Y. 1994: Efficacy of ageing by statolith microstructure in stock assessment of squid stocks. Report of the 1994 annual meeting of squid resources, and fishing and oceanographical conditions. National Research Institute of Far Seas Fisheries, 22-40. (In Japanese).

Uozumi, Y. and C. Shiba. 1993: Growth and age composition of *Illex argentinus* (Cephalopoda: Oegopsida) based on daily increments counts in statolith. In: Recent Advances in Cephalopod fisheries biology, edited by Okutani, T. O'Dor, R.K. & Kubodera,T. Tokai University, Tokyo, 587-602.

Uozumi, Y. and S. Kawahara. 1991: On the management regime of the *Illex* fisheries in Subareas 3 and 4. NAFO SCR Doc. 91/55, 5p.

Uozumi, Y., A. Yatsu, and D.A. Robertson. 1987: Japan-New Zealand trawl survey off southern New Zealand, April 1983. N.Z. Fish. Tech. Rep., 4. 49p.

Uozumi, Y., E.C. Forch, and T. Okazaki. 1990: Distribution and morphological characters of immature *Martialia hyadesi* (Cephalopoda:

Oegopsida) in New Zealand waters. N.Z. Jour. Mar. Freshw. Res., 25. 275-282.

Uozumi, Y., H. Hatanaka, A. Payne, and J. Augustyn. 1985: Report of the Japan/South Africa joint trawl survey of groundfish resources on the Agulhas Bank in June 1982. Far Seas Fish. Res. Lab. S series, 13, 78p.

Uozumi,Y and M. Kuroiwa. 1990: The growth of *Nototodarus sloanii* based on size frequency data. Cont. Fish. Res. Japan Sea Block, 17, 138-143 (In Japanese).

Villanueva, R. 1992: Interannual growth differences in the oceanic squid *Todarodes angolensis* Adam in the northern Benguela upwelling system, based on statolith growth increment analysis. J. Exp. Mar. Biol. Ecol., 159, 157-177.

Wormuth, J.H. 1976: The biogeography and numerical taxonomy of the Oegopsid squid family Ommastrephidae in the Pacific Ocean. Bull. Scripps Inst. Oceanog., 23, 1-90.

Wormuth, J.H., R.K. O'Dor, N. Balch, M.C. Dunning, E.C. Forch, R.F. Harman, and T.W. Rowell. 1992: Family Ommastrephidae. In: Larval and juvenile cephalopods: a manual for their identification, edited by Sweeney, M.J., C.F.E. Roper, K.M. Mangold, M. Clarke, and S. Boletzky, Smithsonian Cont. Zool., 513, 105-119.

Yamada, H. and K. Hiramatsu. 1991: Bayesian forecast model for the catch of the Japanese common squid in the offshore waters in the Japan Sea. Report of the 1991 annual meeting of squid resources, and fishing and oceanographical conditions. Hokkaido National Research Institute, 61-69. (In Japanese).

Yamada, H. and K. Kattoh. 1987: Report on the arrow squid tagging survey in the New Zealand waters in December 1985 - January 1986. Far Seas Fisheries Laboratory S Series, 15, 47p. (In Japanese with English summary).

Yamada, H., Y. Uozumi, and S. Kawahara. 1989 : On the major squid stocks in the distant waters, III Argentine shortfin squid. Suisan Gijutu to Keiei, 4, 25-31. (In Japanese),

Yang, W.T., R.F. Hixon, P.E. Turk, M.E. Krejci, W.H. Hulet, and R.T. Hanlon. 1986: Growth, behavior and sexual maturation of the market squid, *Loligo opalescens*, cultured through the life cycle. Fish. Bull. US., 84, 771-798.

Yatsu, A. 1986: Feeding habit of *N. sloanii* caught by a bottom trawl. JAMARC, 30, 45-52. (In Japanese).

Yokawa, K. 1994: Allozyme differentiation of sixteen ommastrephid squids (Mollusca, Cephalopoda). Antarct. Sci., 6, 201-204.

XIII. Japanese Summary（日本語抄訳）

ニュージーランドスルメイカ類の漁業生物学的研究

ニュージーランド海域のオーストラリアスルメイカ(*Nototodarus gouldi*)及びニュージーランドスルメイカ(*N. sloanii*)の２種によって構成されるスルメイカ類資源は、1970年代当初より日本漁業によって開発された。このイカ漁業は1970年代中頃より本格化し、1982/83年漁期には、その漁獲は11万トンに達した。それ以降も、1980年代後半まで6-8万トンが漁獲された。この漁獲の6-8割りが日本船によるもので、日本にとって重要なスルメイカ資源の一つとなっている。本研究は、本資源の有効利用に資するため２種類のスルメイカ類の漁業生物学的特性を明らかにすることを目的とした。

使用した資料は、1980年代の日本いか釣船及びトロール船の漁獲統計、これらの一般漁船や日本の調査船（水産庁及び海洋水産資源開発センター所属）によって得られた標本約22,000個体の測定結果、平衡石約1,600個体による日齢査定結果、更に、調査船調査の資料として、ボンゴネット及び着底トロールに付けた稚魚網による卵・稚仔調査結果、コッドエンドに10mm meshの網を用いた中層トロールによる調査結果、そして、計10回行われた日本とニュージーランド協同の着底トロール調査結果である。

ニュージーランド水域では、スルメイカ類はいか釣り及びトロール漁業によって利用されている。いか釣りの漁場は、陸棚上に広く形成される。一方、トロールでは、様々な鰭魚に対する規制の影響を受け、南島南岸及びオークランド島周辺が主要漁場となっている。両漁業ともニュージーランド周辺に発達する陸棚ごとに幾つかに分かれた漁場が形成されている。漁期は南半球の夏季で、いか釣りは1-3月、トロールでは1-5月頃が盛期となる。いか釣りは、水深120m以浅の陸棚上に、トロールでは140-240m付近の陸棚縁辺から斜面上部に漁場が形成され、同水域内でも両漁業の漁場は明瞭に分かれる。

ニュージーランド水域には、現在５種類のスルメイカ亜科の分布が知られている。うち上記２種以外の３種は、主として外洋域に分布し、陸棚及びその縁辺部での漁獲は極めて少ない。これら５種の査定は、外套長40mm以上では、腕の吸盤数で比較的容易に行えるが、この体長以下では、肉眼による形態観察では不可能である。しかし、6-PGDやα-GDHのアイソザイムを用いることで容易に査定できる。本研究では、調査船調査で得られた40mm以下の個体に関しては、可能な限りアイソザイムによる種判定を行った。

ニュージーランド海域における２種の地理的分布は、オーストラリアスルメイカが北島周辺及び南島西岸に分布し、ニュージーランドスルメイカは南島東岸から南岸及び南方の島々の周辺に分布する。両種は、クック海峡及び南島西岸で混在する。今回用いた資料から、これら混在域の種組成は、年及び季節によって大きく変動する事が明かとなった。漁獲統計は種込みで報告されているため、今回用いた統計資料の内、南島西岸域の漁場の東経は種不明のため利用せず、その他の水域については、２種の混在がほとんど無視できるため、両種の地理的分布を基に種ごとの統計値として用いた。

日齢査定の結果、両種とも寿命は約１年で、周年を通じて発生していることが確認された。両種とも、生後200日ごろから成長に雌雄間の差が見られ、それ以降は雌の成長が勝る。生まれ月の異なる個体間の成長パターンに明瞭な差が認められた。この差は、各生まれ月群が過ごす各時期の水温と明瞭な相関が認められた。各時期での成長には明瞭な差が認められるが、最終的にはほぼ同様の最大体長に達する。２種間での成長の差は、発生時期によって異なるが、全体としては大きな差は認められない。各生まれ月毎、雌雄毎に日齢査定結果を基にLogistic curveを当てはめた。

日齢査定結果を基に日齢と成熟の関係を、精巣や卵巣及び付属生殖器官等の重量指数（体重に対する割合）と日齢との相関から分析した。生後200日頃より精巣は急速に発達し、270日頃に最大値に達する。雌の卵巣は、その頃から急速に発達する。卵巣、輸卵管、抱卵線の発達はほぼ同時に起こる。また、交接もその頃急速に行われる。300日頃には、これらの指数はほぼ最大に達する。このような傾向は、２種間で極めて類似するが、オーストラリアスルメイカの方がやや早く成熟するようである。

２種のスルメイカのリンコトウチオン幼生の期間は、日齢査定結果からほぼ生後60日までと推定された。この幼生期の分布はボンゴネット及び稚魚網による調査から、陸棚及びバンク等の浅海域が中心となっていることが明かとなった。また、中層トロールによる調査から、生後90-120日頃の幼イカの分布は、２種とも、成魚の分布域内の陸棚及びバンクなどに広がっているが、その分布は200m以浅に限られる。生後120日以降の分布を様々な時期及び水域で行われたトロール調査結果を基に見ると、両種とも120日以降の個体は調査水域全体に広く分布し、成長に伴う明瞭な地理的分布の差は認められなかった。また、主要な生まれ月群では、各群とも調査水域に広く分布し、地理的分布の明瞭な差は認められない。

生後30日ごとの陸棚上（200m以浅）に分布する資源の割合を着底トロール調査結果から推定した。その

結果、オーストラリアスルメイカは生後４ヶ月頃より陸棚斜面域へ分布を拡大し、その後、８ヶ月頃より再び陸棚上へ回遊する傾向が認められた。ニュージーランドスルメイカでも斜面水域への移動は認められたが、本調査結果からは、高齢個体の陸棚上への回遊傾向は不明瞭であった。しかし、斜面水域には高い熟度指数の個体は認められず、これら成熟した個体が陸棚上のみで観察されることから、本種も成熟に伴い、再び陸棚上へ回遊するものと考えられた。また、オーストラリアスルメイカについては、成熟に伴い、南島西岸から北島西岸への移動の可能性が示唆された。一方、ニュージーランドスルメイカについては、成熟に伴う地域間での移動は認められなかった。

主要餌生物は、甲殻類（ｱﾐ・ｵｷｱﾐ類）、小型魚類、イカ類であり、成長に伴い、甲殻類から魚類、イカ類へと割合は変化する。また、空胃率は、夏低く冬高い傾向が認められた。

各生まれ月群の豊度の比較及び経年変化を見るため、両漁業のサイズ規格別漁獲量及び規格別体長組成から、漁獲物体長組成を求め、日齢査定から求めた各生まれ月の旬別の平均体長とその分散を基にKimura&Chikuni法により体長組成を生まれ月組成へ分解し、各生まれ月群のCPUEを求めた。また、そのCPUEを一般線形化法によって標準化し、各生まれ月群の生後210日及び300日のCPUEの期待値を求めた。この210日のCPUEの経年変化の生まれ月群間の相関関係から、明確な相関はないものの、各水域ごとに比較的類似した豊度変化を持つ2-3の季節発生群が認められた。しかし、水域間の同じ季節発生群どうしの相関は極めて低く、各水域ごとに独立して変動しているものと考えられた。各水域での変動に類似性のないことから、資源変動は、ニュージーランド全体の水温などの変化（El Ninõ）によるものではなく、よりミクロな各水域ごとに独立して変動する環境要因に左右されている可能性が高い。

オーストラリアスルメイカは、少なくとも冬生まれを中心とした２つの発生群が求められた。しかし、観察時期の短さから、夏生まれ等の豊度については不明である。一方、ニュージーランドスルメイカについては、南島東岸、南岸及びオークランド島水域に2-4の互いに比較的独立して変動する季節発生群が認められた。冬から春にかけて発生する群の豊度がやや高い傾向にあるものの顕著に卓越するとは言い難い。

各水域各発生群毎の300日のCPUEと翌年の210日のCPUEから見た親子関係には明瞭な関係は認められず、親の豊度と子の豊度に関係ないことが明かとなった。ニュージーランド海域の２種のスルメイカは、寿命が１年であることから、資源は、毎年完全に入れ替わり、ある年と翌年の資源の関係は親子関係によってのみ繋がるが、その親子関係も極めて不明瞭である。このような特性は、各発生群の厳密な管理が翌年の資源量の安定を約束しないことを意味するものである。

毎年資源は変動し、その変動を親の資源量から予測できないため、漁獲量規制による資源管理は、漁期前の資源量推定を前提とするため極めて困難である。そのため、努力量管理により間引き率をコントロールする方がより現実的である。現在、過去の漁獲水準が加入に顕著な影響を与えた事実はないことから、現時点では、入漁隻数などの大まかな総努力量を設定するといった極めて大まかな管理がより現実的であろう。また、いか釣り漁業は、ニュージーランド海域における各時期で最も豊度の高い漁場を選択する傾向があるし、トロールもイカの豊度が下がると、対象を他の鰭魚へ変更する傾向が認められる。このように、豊度の低い群を執ように漁獲する傾向はなく、漁業には自己管理機能が存在していると考えられる。この漁業の特性も、このような大まかな管理制度の上では有効に発揮できるであろう。もちろん、このような大まかな管理を行うためには、注意深い漁業のモニタリングが不可欠である。

今後は、Delury法などを用いて実際の資源量の絶対値の推定及び漁具効率を推定し、それらを基により適正な漁獲努力量を推定する必要が認められる。

ニュージーランドスルメイカ類の漁業生物学的研究

魚住雄二*

摘　要

ニュージーランド海域における重要漁業資源であるオーストラリアスルメイカ及びニュージーランドスルメイカ2種について、日本のいか釣り及びトロール漁業に関する統計資料, 調査船調査結果及び平衡石を用いた日齢査定結果などを用いて，成長・成熟・移動回遊及び豊度の経年変化等に関する解析を行い，その結果を基に，適切な資源評価及び管理方策について検討した。これら2種は，周年にわたり発生し，幼生期から成熟産卵までの間に若干の深浅移動を行うことを除いて大規模な移動回遊は行わないことが明らかとなった。また，豊度の経年変化から各水域には2-3の季節発生群の存在が示唆された。そして，これらの群は，水域間で独立して変動していることが明かとなった．このような資源構造を持つ資源については，各水域の発生群毎の管理を厳密に行うことは極めて困難で，海域全体での努力量規制を行うことにより，努力量が豊度の高い群へ向かい，豊度の低い群を避けるという漁業の自己管理機能を充分発揮させるような管理が現実であると考えられる．

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Appendix Table V-1. Month class-length key of *N. gouldi* in January 1991 off west coast of the Main Islands. Numeral in each cell shows ratio of a month class in a size class. N denotes number of specimens aged in each size class. * in column N shows that the ratios were extrapolated arbitrarily.

Male	**Month Class**						**Female**	**Month Class**					
DML (mm)	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**N**	**DML (mm)**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**N**
100	-	-	-	-	-	-	100	-	-	-	-	-	-
110	-	-	-	-	-	-	110	-	-	-	-	-	-
120	-	-	-	-	-	-	120	-	-	-	-	-	-
130	-	-	-	-	-	-	130	-	-	-	-	1	*
140	-	-	-	-	1	*	140	-	-	-	-	1	*
150	-	-	-	-	1	*	150	-	-	-	-	1	*
160	-	-	-	-	1	*	160	-	-	-	-	1	1
170	-	-	-	-	1	*	170	-	-	-	0.5	0.5	*
180	-	-	-	-	1	2	180	-	-	-	1	-	1
190	-	-	0.333	0.667	-	6	190	-	-	-	1	-	5
200	-	-	0.455	0.455	0.091	11	200	-	-	0.25	0.625	0.125	8
210	-	0.1	0.7	0.2	-	10	210	-	-	0.167	0.667	0.167	6
220	-	-	0.5	0.5	-	8	220	-	-	0.5	0.5	-	8
230	-	-	0.714	0.286	-	7	230	-	-	0.625	0.375	-	8
240	-	0.333	0.333	0.333	-	3	240	-	-	1	-	-	2
250	-	0.5	-	0.5	-	2	250	-	0.333	0.333	0.333	-	3
260	-	1	-	-	-	1	260	0.167	0.333	0.333	0.167	-	6
270	1	-	-	-	-	1	270	-	0.5	0.5	-	-	2
280	-	-	-	-	-	-	280	-	1	-	-	-	1
290	-	1	-	-	-	1	290	-	-	-	-	-	-
300	-	-	-	-	-	-	300	-	-	-	-	-	-
310	-	-	-	-	-	-	310	-	-	-	-	-	-
320	-	-	-	-	-	-	320	-	-	-	-	-	-
330	-	-	-	-	-	-	330	-	-	-	-	-	-
340	-	-	-	-	-	-	340	-	-	-	-	-	-
350	-	-	-	-	-	-	350	-	-	-	-	-	-
Total						52	Total						51

Appendix Table V-2. Month class-length key of *N. gouldi* in March 1991 off west coast of the Main Islands.

Male						Month Class				Female						Month Class			
DML (mm)	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	N	DML (mm)	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	N
100	-	-	-	-	-	-	0.25	0.75	4	100	-	-	-	-	-	-	-	-	-
110	-	-	-	-	-	-	0.8	-	5	110	-	-	-	-	-	-	0.667	0.333	3
120	-	-	-	-	-	-	0.667	0.333	6	120	-	-	-	-	-	-	-	1	5
130	-	-	-	-	-	-	0.4	0.6	5	130	-	-	-	-	-	0.333	-	0.667	6
140	-	-	-	-	-	-	0.6	0.4	5	140	-	-	-	-	-	-	1	-	5
150	-	-	-	-	-	-	0.8	0.2	5	150	-	-	-	-	-	0.2	0.2	0.6	5
160	-	-	-	-	-	-	0.75	0.25	4	160	-	-	-	-	-	0.5	0.5	-	4
170	-	-	-	-	-	0.444	0.556	-	9	170	-	-	-	-	-	0.333	0.667	-	12
180	-	-	-	-	-	0.6	0.4	-	5	180	-	-	-	-	-	0.5	0.5	-	4
190	-	-	-	-	0.5	0.5	-	-	2	190	-	-	-	-	-	0.857	0.143	-	7
200	-	-	-	-	0.5	0.375	0.125	-	8	200	-	-	-	-	0.2	0.4	0.4	-	5
210	-	-	-	0.167	0.5	0.333	-	-	6	210	-	-	-	-	0.75	0.25	-	-	4
220	-	-	-	-	1	-	-	-	3	220	-	-	-	-	0.6	0.4	-	-	5
230	-	-	0.143	0.286	0.286	0.286	-	-	7	230	-	-	-	0.143	0.429	0.429	-	-	7
240	-	-	-	0.5	0.5	-	-	-	10	240	-	-	-	0.333	0.667	-	-	-	3
250	-	-	0.1	0.5	0.4	-	-	-	10	250	-	-	-	-	0.5	0.5	-	-	2
260	-	-	0.1	0.7	0.2	-	-	-	10	260	-	-	-	0.5	-	0.5	-	-	2
270	-	-	0.5	0.5	-	-	-	-	6	270	-	-	-	-	1	-	-	-	1
280	-	-	0.5	-	0.5	-	-	-	2	280	-	-	0.667	0.333	-	-	-	-	3
290	-	-	0.5	0.5	-	-	-	-	2	290	-	-	-	1	-	-	-	-	1
300	-	-	0.667	0.333	-	-	-	-	3	300	-	-	-	1	-	-	-	-	2
310	1	-	-	-	-	-	-	-	1	310	-	-	1	-	-	-	-	-	1
320	0.5	0.5	-	-	-	-	-	-	*	320	-	-	1	-	-	-	-	-	*
330	-	-	-	-	-	-	-	-	-	330	-	-	1	-	-	-	-	-	*
340	-	-	-	-	-	-	-	-	-	340	-	-	-	-	-	-	-	-	-
350	-	-	-	-	-	-	-	-	-	350	-	1	-	-	-	-	-	-	1
360	-	-	-	-	-	-	-	-	-	360	-	-	1	-	-	-	-	-	1
370	-	-	-	-	-	-	-	-	-	370	-	-	-	-	-	-	-	-	-
380	-	-	-	-	-	-	-	-	-	380	0.5	0.5	-	-	-	-	-	-	2
Total									118	Total									91

Appendix Table V-3. Month class-length key of *N. sloanii* in January 1991 on the Snares shelf.

Male	**Month Class**						**Female**	**Month Class**					
DML (mm)	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**N**	**DML (mm)**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**N**
100	-	-	-	1	-	1	100	-	-	-	-	-	-
110	-	-	1	-	-	2	110	-	-	-	1	-	1
120	-	-	0.25	0.75	-	4	120	-	-	-	1	-	4
130	-	-	0.143	0.857	-	7	130	-	-	0.222	0.778	-	9
140	-	-	0.125	0.875	-	8	140	-	-	0.3	0.7	-	10
150	-	-	0.333	0.667	-	6	150	-	-	0.333	0.583	0.083	12
160	-	-	0.333	0.667	-	6	160	-	-	0.8	0.2	-	5
170	-	-	0.429	0.571	-	7	170	-	-	0.5	0.5	-	4
180	-	-	0.6	0.4	-	5	180	-	0.25	0.25	0.5	-	4
190	-	-	0.75	0.25	-	4	190	-	0.5	-	0.5	-	2
200	-	0.333	0.667	-	-	3	200	-	0.25	0.75	-	-	4
210	-	1	-	-	-	1	210	0.25	0.25	0.5	-	-	4
220	0.25	0.5	0.25	-	-	4	220	-	1	-	-	-	-
230	-	0.5	0.5	-	-	4	230	-	1	-	-	-	1
240	-	0.75	0.25	-	-	4	240	-	1	-	-	-	1
250	-	-	-	-	-	-	250	-	0.5	0.5	-	-	2
260	-	-	-	-	-	-	260	-	-	-	-	-	-
270	-	-	-	-	-	-	270	-	-	-	-	-	-
280	-	-	-	-	-	-	280	-	1	-	-	-	1
290	-	-	-	-	-	-	290	-	-	-	-	-	-
300	-	-	-	-	-	-	300	-	-	-	-	-	-
310	-	-	-	-	-	-	310	-	-	-	-	-	-
320	-	-	-	-	-	-	320	-	-	-	-	-	-
330	-	-	-	-	-	-	330	-	-	-	-	-	-
340	-	-	-	-	-	-	340	-	-	-	-	-	-
350	-	-	-	-	-	-	350	-	-	-	-	-	-
Total						67	Total						64

Appendix Table V-4. Month class-length key of *N. sloanii* in February 1991 on the Snares shelf.

Male	**Month Class**					**Female**	**Month Class**				
DML (mm)	**JUN**	**JUL**	**AUG**	**SEP**	**N**	**DML (mm)**	**JUN**	**JUL**	**AUG**	**SEP**	**N**
100	-	-	1	-	-	100	-	-	1	-	*
110	-	-	1	-	2	110	-	-	1	-	2
120	-	-	1	-	1	120	-	-	1	-	1
130	-	-	1	-	1	130	-	0.25	0.75	-	4
140	-	-	0.667	0.333	3	140	-	-	1	-	4
150	-	0.091	0.818	0.091	11	150	-	-	0.857	0.143	7
160	-	0.118	0.824	0.059	17	160	-	0.176	0.765	0.059	17
170	-	0.25	0.563	0.188	16	170	-	0.3	0.65	0.05	20
180	-	0.412	0.588	-	17	180	-	0.333	0.667	-	18
190	-	0.563	0.438	-	16	190	0.067	0.267	0.667	-	15
200	-	0.222	0.778	-	9	200	0.059	0.235	0.706	-	17
210	-	0.667	0.333	-	9	210	0.083	0.5	0.417	-	12
220	-	0.333	0.667	-	6	220	-	0.429	0.571	-	7
230	0.333	0.333	0.333	-	6	230	0.143	0.286	0.571	-	7
240	-	-	1	-	1	240	-	0.5	0.5	-	4
250	-	0.5	0.5	-	*	250	-	1	-	-	1
260	-	0.7	0.3	-	*	260	-	1	-	-	1
270	-	1	-	-	1	270	-	1	-	-	*
280	-	1	-	-	*	280	-	1	-	-	*
290	-	1	-	-	*	290	-	1	-	-	*
300	-	1	-	-	*	300	-	1	-	-	*
310	-	1	-	-	*	310	-	-	-	-	-
320	-	1	-	-	*	320	-	-	-	-	-
330	-	-	-	-	-	330	-	-	-	-	-
340	-	-	-	-	-	340	-	-	-	-	-
350	-	-	-	-	-	350	-	-	-	-	-
Total					116	Total					137

Appendix Table IX-1. Number of observations (number of the operation days in which the catch by size category are available) for the squid jigging fishery in each ten-day period from 1979/80 to 1990/91 fishing years in the waters off west coast of the North Island.

Ten-day	Month	Fishing Year											
		79/80	80/81	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91
1		-	-	-	-	-	-	-	-	-	-	-	-
2	**November**	-	-	-	-	-	-	-	-	-	-	-	-
3		-	-	-	-	-	-	-	-	-	-	-	-
4		-	-	-	-	-	-	-	-	-	-	-	-
5	**December**	-	-	-	1	2	-	-	-	-	-	-	-
6		-	-	-	13	17	-	-	4	-	-	-	-
7		-	-	-	15	5	1	-	9	6	-	-	1
8	**January**	-	-	-	4	3	-	-	1	-	-	-	-
9		1	-	46	12	12	-	-	-	-	1	1	-
10		1	16	24	15	-	-	-	-	1	-	-	-
11	**February**	7	78	63	2	42	-	-	-	-	-	-	-
12		-	12	30	3	44	-	-	-	11	-	2	-
13		-	16	41	-	-	-	9	-	23	-	17	50
14	**March**	-	4	12	46	2	-	-	-	35	-	11	106
15		24	-	-	134	-	-	4	-	84	1	109	136
16		63	-	5	87	1	-	17	48	72	-	93	60
17	**April**	60	-	52	68	10	5	-	89	48	-	42	13
18		22	-	40	52	37	22	-	32	18	-	-	11
19		-	-	3	52	32	3	1	17	9	-	-	8
20	**May**	-	-	-	51	5	3	-	1	6	-	-	7
21		-	-	-	13	2	8		-	-	2	-	-
22		-	-	-	7	-	-	1	-	-	-	-	-
23	**June**	-	-	-	-	-	-	-	-	-	-	-	-
24		-	-	-	-	-	-	-	-	-	-	-	-
25		-	-	-	-	-	-	-	-	-	-	-	-
26	**July**	-	-	-	-	-	-	-	-	-	-	-	-
27		-	-	-	-	-	-	-	-	-	-	-	-
28		-	-	-	-	-	-	-	-	-	-	-	-
29	**August**	-	-	-	-	-	-	-	-	-	-	-	-
30		-	-	-	-	-	-	-	-	-	-	-	-
31		-	-	-	-	-	-	-	-	-	-	-	-
32	**September**	-	-	-	-	-	-	-	-	-	-	-	-
33		-	-	-	-	-	-	-	-	-	-	-	-
34		-	-	-	-	-	-	-	-	-	-	-	-
35	**October**	-	-	-	-	-	-	-	-	-	-	-	-
36		-	-	-	-	-	-	-	-	-	-	-	-
	Total	178	126	316	575	214	42	32	201	313	4	275	392

Appendix Table IX-2. Number of observations (number of the operation days in which the catch by size category are available) for the squid jigging fishery in each ten-day period from 1979/80 to 1990/91 fishing years on the Snares Shelf.

		Fishing Year											
Ten-day	**Month**	**79/80**	**80/81**	**81/82**	**82/83**	**83/84**	**84/85**	**85/86**	**86/87**	**87/88**	**88/89**	**89/90**	**90/91**
1	**November**	-	-	-	-	-	-	-	-	-	-	-	-
2		-	-	-	-	-	-	-	-	-	-	-	-
3		-	-	-	-	-	-	-	-	-	-	-	-
4	**December**	-	-	-	-	-	-	-	-	-	-	-	-
5		-	-	-	-	-	-	-	4	-	-	-	-
6		-	-	-	-	-	-	1	24	-	1	8	-
7	**January**	-	-	-	-	20	3	172	123	-	2	84	1
8		-	3	-	-	218	84	213	34	3	-	97	2
9		58	6	-	-	229	113	212	108	11	2	16	109
10	**February**	25	-	6	-	248	25	142	86	3	4	17	82
11		77	-	2	-	163	37	103	86	24	10	5	100
12		72	1	-	7	156	29	8	101	19	43	1	55
13	**March**	20	-	4	-	164	48	3	108	5	22	-	13
14		29	23	5	-	236	19	9	81	-	-	-	-
15		17	3	-	-	110	-	-	78	-	-	-	-
16	**April**	13	-	-	-	22	-	-	-	-	-	-	1
17		-	-	-	-	4	4	-	-	-	-	-	-
18		-	-	-	-	16	14	-	-	-	-	-	-
19	**May**	-	-	-	-	-	-	-	-	-	-	-	-
20		-	-	-	-	1	-	-	-	-	-	-	-
21		-	-	-	-	-	-	-	-	-	-	-	-
22	**June**	-	-	-	-	-	-	-	-	-	-	-	-
23		-	-	-	-	-	-	-	-	-	-	-	-
24		-	-	-	-	-	-	-	-	-	-	-	-
25	**July**	-	-	-	-	-	-	-	-	-	-	-	-
26		-	-	-	-	-	-	-	-	-	-	-	-
27		-	-	-	-	-	-	-	-	-	-	-	-
28	**August**	-	-	-	-	-	-	-	-	-	-	-	-
29		-	-	-	-	-	-	-	-	-	-	-	-
30		-	-	-	-	-	-	-	-	-	-	-	-
31	**September**	-	-	-	-	-	-	-	-	-	-	-	-
32		-	-	-	-	-	-	-	-	-	-	-	-
33		-	-	-	-	-	-	-	-	-	-	-	-
34	**October**	-	-	-	-	-	-	-	-	-	-	-	-
35		-	-	-	-	-	-	-	-	-	-	-	-
36		-	-	-	-	-	-	-	-	-	-	-	-
	Total	311	36	17	7	1587	377	863	834	65	84	228	363

Appendix Table IX-3. Number of observations (number of the operation days in which the catch by size category are available) for the squid jigging fishery in each ten-day period from 1979/80 to 1990/91 fishing years on the Canterbury Bight.

		Fishing Year											
Ten-day	**Month**	**79/80**	**80/81**	**81/82**	**82/83**	**83/84**	**84/85**	**85/86**	**86/87**	**87/88**	**88/89**	**89/90**	**90/91**
1		-	-	-	-	-	-	-	-	-	-	-	-
2	**November**	-	-	-	-	-	-	-	-	-	-	-	-
3		-	-	-	-	-	-	-	-	-	-	-	-
4		-	-	-	-	-	-	-	-	-	-	-	-
5	**December**	-	-	-	-	27	-	-	-	-	-	-	-
6		-	-	-	-	2	-	-	5	-	-	51	3
7		-	5	-	-	14	3	-	4	2	50	15	1
8	**January**	2	11	-	-	11	-	-	16	-	87	8	7
9		7	-	11	-	54	2	2	10	4	95	79	1
10		10	-	61	12	1	30	42	13	-	58	67	-
11	**February**	8	-	24	56	3	45	54	7	3	71	7	-
12		50	57	54	99	16	41	126	-	5	13	23	1
13		94	79	59	83	81	13	111	2	26	52	99	1
14	**March**	71	26	92	46	8	58	158	5	36	70	126	-
15		9	65	148	4	124	116	189	42	2	48	39	-
16		-	5	88	-	106	82	79	49	-	38	7	-
17	**April**	2	-	29	14	83	84	60	-	-	21	2	-
18		-	-	25	35	56	46	55	-	-	30	3	-
19		-	-	17	-	46	77	41	-	-	27	-	-
20	**May**	-	-	-	-	84	53	49	18	-	26	-	-
21		-	-	-	-	35	7	12	8	-	10	-	-
22		-	-	-	-	-	-	-	-	-	2	-	-
23	**June**	-	-	-	-	-	-	-	-	-	-	-	-
24		-	-	-	-	-	-	-	-	-	-	-	-
25		-	-	-	-	-	-	-	-	-	-	-	-
26	**July**	-	-	-	-	-	-	-	-	-	-	-	-
27		-	-	-	-	-	-	-	-	-	-	-	-
28		-	-	-	-	-	-	-	-	-	-	-	-
29	**August**	-	-	-	-	-	-	-	-	-	-	-	-
30		-	-	-	-	-	-	-	-	-	-	-	-
31		-	-	-	-	-	-	-	-	-	-	-	-
32	**September**	-	-	-	-	-	-	-	-	-	-	-	-
33		-	-	-	-	-	-	-	-	-	-	-	-
34		-	-	-	-	-	-	-	-	-	-	-	-
35	**October**	-	-	-	-	-	-	-	-	-	-	-	-
36		-	-	-	-	-	-	-	-	-	-	-	-
	Total	253	248	608	349	751	657	978	179	78	698	526	14

Appendix Table IX-4. Number of observations (number of the operation days in which the catch by size category are available) for the trawl fishery in each ten-day period from 1979/80 to 1990/91 fishing years on the Snares Shelf.

Ten-day	Month	Fishing Year											
		79/80	80/81	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91
1	November	-	27	9	-	-	-	-	-	3	15	7	6
2		-	-	-	-	-	-	20	-	-	11	8	6
3		-	-	-	-	-	-	-	-	-	18	4	16
4	December	-	30	63	-	-	-	-	-	-	19	8	2
5		-	52	73	-	-	11	-	-	-	24	-	-
6		-	103	89	24	-	18	43	-	-	50	-	5
7	January	-	44	51	-	33	41	50	18	26	16	14	8
8		-	41	22	9	26	44	41	86	30	26	27	7
9		-	28	15	-	22	61	140	150	43	35	20	9
10	February	-	29	7	33	28	72	113	135	52	33	-	5
11		-	59	63	39	34	75	89	78	86	12	13	15
12		-	53	54	51	78	46	81	82	66	10	-	8
13	March	-	36	78	77	60	65	85	71	54	10	-	8
14		-	40	82	66	100	66	89	87	51	9	-	-
15		-	38	68	94	91	65	30	81	57	22	-	-
16	April	-	36	6	33	78	67	26	61	41	4	-	-
17		-	4	47	13	65	56	53	64	26	-	-	-
18		-	13	7	66	68	83	78	33	29	22	-	-
19	May	-	32	5	56	55	82	49	39	21	17	-	-
20		-	47	38	37	61	61	44	38	32	66	-	-
21		-	77	2	30	95	85	58	36	31	79	-	-
22	June	-	49	37	-	50	57	-	21	-	42	-	24
23		-	49	51	23	38	49	-	18	-	54	-	-
24		-	6	24	-	46	53	-	16	10	7	-	-
25	July	-	22	17	-	28	19	-	-	-	-	-	-
26		-	29	33	19	-	12	1	-	-	-	-	-
27		-	36	44	-	-	-	1	-	-	-	-	-
28	August	-	33	29	-	-	-	-	-	-	-	-	-
29		-	31	8	-	-	-	-	-	-	-	-	-
30		-	41	13	34	21	-	-	-	-	25	44	-
31	September	-	20	-	-	-	25	-	-	-	-	-	-
32		-	-	29	-	-	16	-	-	-	-	6	-
33		-	-	3	-	-	17	-	-	36	-	10	-
34	October	-	-	-	-	-	4	-	-	-	-	6	-
35		41	20	-	-	-	-	-	-	17	-	10	-
36		46	27	-	-	-	52	-	35	18	-	12	-
	Total	87	1152	1067	704	1077	1302	1091	1150	729	626	189	119

Appendix Table IX-5. Number of observations (number of the operation days in which the catch by size category are available) for the trawl fishery in each ten-day period from 1979/80 to 1990/91 fishing years on the Auckland Island Shelf.

Ten-day	Month	Fishing Year											
		79/80	**80/81**	**81/82**	**82/83**	**83/84**	**84/85**	**85/86**	**86/87**	**87/88**	**88/89**	**89/90**	**90/91**
1	**November**	-	-	-	-	-	-	-	-	-	-	-	-
2		-	-	-	-	-	-	-	-	-	-	-	-
3		-	-	-	-	-	-	-	-	1	-	-	-
4	**December**	-	4	-	-	-	-	-	-	-	-	-	-
5		-	2	-	-	-	5	-	-	-	-	-	-
6		-	7	1	-	-	10	-	19	-	-	-	-
7	**January**	-	-	-	-	5	4	-	18	-	3	-	-
8		-	2	-	-	-	6	-	-	-	-	-	-
9		-	1	38	-	11	15	23	-	-	22	-	-
10	**February**	-	-	75	-	50	40	16	-	-	10	-	7
11		-	-	70	50	43	40	48	53	-	56	2	-
12		-	5	40	48	10	30	52	48	-	49	1	-
13	**March**	-	21	20	7	20	43	41	43	-	44	-	-
14		-	21	20	36	-	-	16	16	16	31	-	-
15		-	-	54	5	60	5	70	22	30	66	-	-
16	**April**	-	14	69	35	15	22	47	13	2	75	-	-
17		-	13	57	42	11	40	17	17	8	71	-	-
18		-	21	59	-	35	39	-	21	2	49	-	-
19	**May**	-	12	49	-	4	13	-	9	-	52	-	-
20		-	11	26	22	34	11	7	5	-	12	-	-
21		-	14	66	-	32	15	4	6	-	-	-	-
22	**June**	-	6	20	-	5	9	9	-	-	-	-	-
23		-	7	9	-	3	9	-	-	-	-	-	-
24		-	-	8	-	-	4	-	-	-	-	-	-
25	**July**	-	2	2	-	-	1	12	-	-	-	-	-
26		-	-	-	-	-	-	6	-	-	-	-	-
27		-	-	-	-	-	-	4	-	-	-	-	-
28	**August**	-	2	-	-	-	-	-	-	-	-	-	-
29		-	-	-	-	-	-	-	-	-	-	-	-
30		-	-	-	1	2	-	-	-	-	-	-	-
31	**September**	-	-	-	-	-	-	-	-	-	-	-	-
32		-	-	-	-	-	-	-	-	-	-	-	-
33		-	-	-	-	-	-	-	-	-	-	-	-
34	**October**	-	-	-	-	-	-	-	-	-	-	-	-
35		-	-	-	-	-	-	-	-	4	-	-	-
36		1	-	-	-	-	-	-	-	-	-	-	-
	Total	1	165	683	246	340	361	372	290	63	540	3	7