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A Comparative Description on the Life Cycles of Five Ommastrephid Squids Fished by Japan: *Todarodes pacificus, Illex illecebrosus, Illex argentinus, Nototodarus sloani sloani and Nototodarus sloani gouldi*

by

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SPECIAL SESSION ON SQUIDS

INTRODUCTION

The short-finned squid (family Ommastrephidae) are widely distributed in the seas of the world. In the waters around Japan, the squid stocks have been utilized in a large scale since the 17th century. The annual catch of Japanese common squid, a major species of squids fished, attained to a peak of 680,000 tons in 1968. Since then, however, the catch had been rapidly decreased to about 300,000 tons, and consequently the market price of short-finned squids showed a substantial increase in late 1970s. With the rise in price, Japanese trawlers began to exploit the squid resources in some foreign waters such as the Northwest Atlantic, Southwest Atlantic and New Zealand waters, and the squid catch from those waters amounted to about 60,000 tons in 1982. Besides, around 100 vessels of squid jiggers entered New Zealand waters and caught about 30,000 tons annually in recent years. On the other hand, several countries, such as Canada, Poland, Korea and Argentina, started the squid fisheries aiming to export the products to Japanese market.

In responce to these exploitations of squid resources, the studies on the biology and population dynamics were started in several waters in the world. However, because of their short life span, complicated life cycle, insufficiency of basic data and inadequate experiance for research, it is difficult to plan and conduct the effective researches.

In this report, a comparative description of life cycles of five short-finned squids is given, though the level of our knowledge on the life cycle is diffefent by species. The authors try to analogize lacked parts in life cycles of some species from those of other species. Follwing five species (including two subspecies), belonged to subfamilies Illicinae and Todarodinae, are examined in this report;

1) Todarodes pacificus, Japanese common squid, Northwest Pacific
2) Illex illecebrosus, short-finned squid, Northwest Atlantic
3) I. argentinus, calamar, Southwest Atlantic
4) Nototodarus sloani sloani, New Zealand arrow squid, New Zealand waters[1]
5) Nototodarus sloani gouldi, Australian squid, Southeast Australian waters.

GROWTH AND LIFE SPAN[2]

Todarodes pacificus : Based on the seasonal changes in length frequency distribution, monthly growth rates were estimated (Araya, 1967; Fig. 1), and the life span of this species was assumed to be one year based on the growth rates and mean mature length[3]. A great many tagged squids have been released in Japanese waters, but no recapture of tagged squid spent more than one year in the sea after release was reported. This fact will support the one-year life span of this species. Furthermore, the growth rate of female is higher than that of male.

Illex illecebrosus : In the same way as Japanese common squid, the growth rate was estimated from the length frequency data, and the life span was assumed to be about one year (Squires, 1967; Amaratunga, MS 1980; Fig. 2). The growth rate of female is higher than that of male. On the other hand, a hypothesis for the life cycle of 1.5 years was presented (Mesnil, 1977). Namely, summer and winter spawning seasons take place and the squid exchange their spawning season from generation to generation. However, it is difficult to fit this hypothesis into actual situation.

Illex argentinus : Also, based on monthly length frequency data, the growth was examined and the life span was estimated to be about one year (Hatanaka, MS 1983; Fig. 3). Female grows faster than male.

1) N. s. gouldi is also distributed in this water, but this subspecies is treated as one population of N. s. sloani in this report for convenience sake.
2) In case of some squid species, it is well known that the majority of squid dies after completing the reproductive activities. "Life span" in this report means a period from the birth to this mass deaths.
3) A mantle length at which 50 % of individuals have spermatophores in the spermatophoric sac for male and have matured eggs in the oviduct for female.

Notodarus sloani sloani : In New Zealand waters, this squid consists of two subspecies. The length frequency distributions of each subspecies show the polymodal form quite often, and this makes it difficult to estimate the growth pattern and life span of this species from the length data. However, Roberts (1983) reported the growth rate of 2.5-4.0 cm per month for smaller squid (18-24 cm) and 1.5-3.0 cm per month for larger squid (24-33 cm) based on the length data in six months from December to May. Taking account of the mean mature length (28 cm for male and 30-35 cm for female) and assuming that the squid die after spawning, the life spans of both subspecies are estimated to be about one year by extrapolating the monthly growth rates reported by Roberts (1983) to a full year.

Nototodarus sloani gouldi : Although no information on age and growth is available in Australian waters, the most prominent mode in length frequency data moved from 17 cm in December to 25-27 cm in March (Machida, 1983), and consequently the mean growth rate is estimated to be 2.0-2.5 cm per month. As the mean mature length is about 23 cm for male and 30 cm for female (Machida, 1983), the life span of this species seems to be approximately one year in the light of the assumptions made on former subspecies.

Summary on growth and life span : As far as the five species examined in this report are concerned, it is considered that their life cycles were estimated to be more of less one year. Generally, females grow faster or larger than males. As a major reason for this phenomenon, it is suggested that the maturation of males begins earlier or at smaller size than females.

MIGRATION BETWEEN SPAWNING AREA AND FEEDING GROUNDS

Todarodes pacificus : As a generally accepted theory, there are three populations around Japan, and each has a different spawning season (winter, autumn and summer), though the spawning areas overlap one another to a large extent (Kasahara, 1982; Fig. 4). These hypotheses were partially supported by the results of larval surveys and tagging experiments in recent years.

Winter spawner, the largest population (at least up to 1960s), has a spawning area extending over the north and central-east parts of the East China Sea, and the main feeding grounds off Hokkaido are far away from the spawning area. Consequently, this population makes a long-range migration between these two areas. The squid in the feeding grounds are generally immature even at the end of feeding season (Nakata, 1984).

Autumn spawner, which spawns in the waters from the southern Japan Sea to the northeastern part of the East China Sea, feeds mainly in the offshore area of the Japan Sea. The distance between spawning area and feeding grounds is shorter than that for winter spawner, and the gonad of autumn spawner develops noticeably when they leave the feeding grounds (Kasahara and Ito, 1972).

Summer spawner appears in several coastal waters from Kyushu to Honshu in summer. They are almost mature at that time and the mature length is considerably smaller than other two populations. The migration is believed to be made on a small scale by comparison.

Illex illecebrosus : In Canadian waters, small squid immigrate onto the continental shelves from late spring to early summer. They feed and grow on the shelves during summer and autumn, and leave there in late autumn. Their gonads, especially in case of female, are seldom matured when they leave. Although no available information on the adult squid in off-shelf waters was obtained, squid larvae were abundantly found along the northern edge of the Gulf Stream in winter. It was suggested that squid spawn in winter in the upper reaches of the Stream off Cape Hatteras to Florida (Hatanaka et al., MS 1982; Fig. 5). Therefore, the population immigrated into Canadian waters seems to be a "long-range migration" type which the feeding grounds are far away from the spawning area, likewise the case of winter spawner of Japanese common squid.

The occurrence of summer spawner in addition to winter spawner is reported in U.S. waters (Lange and SissenWine, MS 1981), but the spawning area is not yet known.

Illex argentinus : The jigging and trawl fisheries for squid start from summer (Feburuary) and autumn (April), respectively. The matured females begin to appear in April and about a half of the females has matured eggs in the oviduct in July and August. Both of the fisheries end in winter (August) because of the decline in CPUE. This is probably due to the behavior that matured squid leave the fishing grounds (viz. feeding grounds) on the continental shelf and its upper slope for spawning. By analogy with the foregoing two species, it could be suggested that a species (or population) having more matured gonad while staying in the fishing grounds has the spawning area in shorter distance from the feeding grounds. Therefore, the major winter spawner in Argentine waters seems to be a "short-range migration" type which the spawning area is situated close to the feeding grounds.

Besides the major population, a minor local population made up of squid matured in smaller size (approximately 5 cm smaller than that of major winter spawner) appears in the coastal waters in summer.

Nototodarus sloani sloani : The spawning season and area are not yet well known in New Zealand waters. However, matured individuals appear throughout the year regardless of the place, and appear in almost all of the fishing grounds regardless of season (Fig. 6). As aforementioned, two subspecies are distributed in New Zealand waters and the bi- or tri-modal forms are commonly observed in length frequency compositions of squid taken. Furthermore, the maturity of gonad is different by size groups. Consequently, it is suggested that several populations exist in the fishing grounds and that they have different spawning seasons and areas from one another. Most of these populations might be the "short-range migration" type because of the occurrences of fully matured squid in the fishing grounds (viz. feeding grounds).

Nototodarus sloani gouldi : As well as the case of former subspecies, spawning season and area are not yet known in Australian waters. However, the length frequency distributions were poly-modal, and matured squid were usually caught within the fishing grounds (Machida, 1983). It is suggested that more than one population inhabit in Australian waters and they are the "short-range migration" type, as those in New Zealand waters.

Summary on migration between spawning area and feeding grounds : The distance of migration between the spawning area and feeding grounds is different from population to population. In case of short-range type, the distance is shorter than a few handred n. miles or both waters might be overlapped to some extent, while the long range type has a distance more than 1,000 n. miles. The squid making the longer-range migration have the less developed gonad when they leave the feeding grounds. As far as the well-known spawning areas are concerned, the areas are located in the upper reaches of the warm current passing through the habitat.

CURRENT SYSTEM AND MIGRATION TYPE OF SQUID

Todarodes pacificus : The Kuroshio, one of the strongest warm currents in the world, flows northwards along the Pacific coast of Japan, while the Tsushima Warm Current derived from the Kuroshio flows into the Japan Sea. The latter consists of three branches. The first branch comming through the eastern channel of Tsushima goes northeastwards along the coasts of Japan, while the second and third branches comming through the western channel of Tsushima flows into the central Japan Sea and goes up north along the coast of Korea, respectively (Fig. 7).

Winter spawner, the "long-range migration" type, is closely connected with the Kuroshio and the first branch of Tsushima Current, while the autumn spawner migrating in smaller scale depends on the second and third branches (Araya, 1967) which are so much weaker than the Kuroshio.

Illex illecebrosus : In the Northwest Atlantic, the Gulf Stream comparable to the Kuroshio flows from south to northeast, and the life cycle of this species seems to be closely connected with the Stream. Based on the information on the distribution of larvae and juveniles (Fig. 5), it is suggested that the larvae are transported by the Stream from the spawning area to the off-shelf waters of northeast U.S. and Canada, and they remain within the Slope Water during a few months (Feburuary to April or May). Then they recruit onto the continental shelves off the northeast U.S. and Canada (Hatanaka et al., MS 1982).

Illex argentinus : In Argentine waters, the Falkland Current (cold current) originated from the Westely Wind Drifts flows northwards and meets with the Brazilian Current (warm current) off Uruguay and northern Argentina (Fig. 8). The coastal water is warmer than the offshore waters throughout the year in Argentine waters.

The information on the spawning area and the distribution of larvae is not available. In spawning season, however, the CPUE of squid drops rapidly, and the spent squid are not found in any fishing grounds on the shelf. Furthermore, young squid recruit onto the northern half of the feeding grounds (north of 45° S) in spring and early summer. Therefore, the spawning area seems to be located somewhere further north. If squid spawn in the upper reaches of warm current as is analogized from the other species, the relations between the major winter spawner and the Brazilian Current and between the minor summer spawner and the warm coastal water are suggested.

Nototodarus sloani sloani : The major current in New Zealand waters is the Tasman Current (warm current). This current collides with the southwestern coast of the South Island and separates into two main branches. A branch goes north along the western coast of South Island (Westland Current), while the other flows to the north along the south and east coasts of South Island and then turns east in the vicinity of Banks Peninsula (Southland Current, Fig. 9).

The current system composed of several warm current may have some relation to the occurrences of several populations. As aforementioned, the populations in New Zealand waters seemed to be "short-range migration" types, and those currents are fairly weak compared with the Kuroshio and the Gulf Stream. The scale of migration seems to be subject to the strength of warm current.

Nototodarus sloani gouldi : The fishing grounds of this species are located around Tasmania, and the East Australian Current (warm current) going down along the east coast of Australia flows into the fishing grounds (Fig. 9). The life cycle of the squid might be closely related to this current.

Summary on current system and migration type of squid : It is suggested that each of squid populations has a life cycle closely connected with a peculiar warm current, and some populations occur in the waters where several warm currents (or branches of a current) flow into. The route and distance of migration seem to be regulated to a large extent by the route and speed of the corresponding current. However, the summer spawner which spawns in the coastal waters warmed up in summer might have little relationship to any currents.

MIGRATION TYPE AND ABUNDANCE

Todarodes pacificus : The annual catch of winter spawner attained to a peak of 680,000 tons in 1968, but since then the catch had decreased rapidly to about 100,000 tons in 1981 (Fig. 10). Especially in the fishing grounds on the Pacific side where the winter spawner related to the Kuroshio is distributed, the annual catch decreased from 480,000 tons in 1968 to 6,500 tons in 1982. The autumn spawner inhabits relatively offshore areas. Late in 1960s squid jiggers began to expand their offshore operations in the Japan Sea. The catch of autumn spawner had increased since then for conpensating the decrease of winter spawner's catch. The catch from this population attained to 200,000 tons in 1972, but decreased to 70,000 tons in recent years (Fig. 10). It is assumed that these fluctuations reflect the changes in abundance of fishable squid population.

There might be some interrelationship between the abundance flucuation and migration type. Namely, the "strong current/long-range migration" type (winter spawner especially on the Pacific side) is usually large in population size, and fluctuates on a large-scale. On the other hand, the population size of shorter range migration type (autumn spawner in the Japan Sea) is smaller and tends to fluctuate on a smaller scale.

Illex illecebrosus : The relative abundance of this species (winter spawner) ranged from 12.7 in 1976 to 0.08 in 1982 in Canadian waters. The abundance in U.S. waters (including summer spawner) also fluctuated on a large scale (NAFO, MS 1982 and MS 1983; Fig. 11). The annual catch in Canadian waters reached a peak of 162,000 tons in 1979 but showed a yearly decrease thereafter. The catch in U.S. waters was stable at the level of 20,000 tons, but this was due mainly to the catch regulation executed by U.S. Government (Fig. 11).

The values of relative abundance mentioned above were estimated from the data obtained by trawl biomass surveys, and consequently they contained some sampling errors. Even so, the extent of the fluctuation in abundance is extremely large. Furthermore, most part of 1979 catch was taken by Canada, while other countries' catches were restricted to the lower level under the national catch quotas. If the catch limits had not been set, the total catch in the year might have been higher. Taking these situations into account, the winter spawner seems to be a large-scale population in size comparable to the winter spawner of T. pacificus in Japanese waters.

Illex argentinus : The substantial squid fishery started in 1978 in Argentine waters, and the total squid catch jumped up to 122,000 tons in 1979, aiming to supply the catch to Japanese market. However, because of the depreciation in market price and a decline in CPUE, the catch was decreased in 1980 (Fig. 12). On the other hand, the annual CPUEs seem to be rather stable in a certain range, though available fishery data series is only a period of recent six years (Fig. 12).

Nototodarus sloani sloani : Japanese squid fisheries in New Zealand waters were started by squid jiggers in early 1970s and by trawlers in late 1970s. In addition, Korea and U.S.S.R. also took part in squid fisheries in recent years. The total squid catch by all countries concerned attained to 50,000 tons in 1976/77 fishing year (the season is from December to June), and since then the annual catch has been on the level of 60,000 -80,000 tons. The mean CPUEs by Japanese jiggers were rather stable on the high level of 3.0-4.0 tons per day (Fig. 13).

The scale of abundance fluctuation of each population is not known. However, the fluctuation (decrease or increase) of each population might be compensated each other, and consequently the annual fluctuation of total populations tends to be rather smaller. This seems to be the main reason that the yearly catch and CPUE of this species are quite stable as a whole.

Nototodarus sloani gouldi : The substantial fishery is not continued in Australian waters. The scales of population size and annual fluctuation could not be discussed at present. However, taking account of the results obtained by Japanese exploratory surveys (Machida, 1983), the squid population could not be so large as that of winter spawner in Japanese waters is.

Summary on migration type and abundance : Each of the "long-range migration" types, such as winter spawners of T. pacificus and I. illecebrosus, has a large-scale fluctuation in annual abundance, and the population size is also large. On the other hand, the "short-range migration" type has small (or smaller) population size, and the abundance seems to be more stable. In the area where several populations inhabit intermingly, the abundance fluctuations of respective populations are supposed to be compensated each other and consequently the annual total catch tends to be stable.

DISCUSSION

The mature lengths and monthly growth rates of five species under consideration are rather similar, and it is also estimated that each of them has a life span of around one year. However, some species, such as Ommastrephes bartrami and Dosidicus gigas, attained to a fairly large size (more than two kg in weight). At the present stage, we could not conclude that all (or most) of the Ommastrephid squids have the one year life span.

The spawning areas of some species are located in the upper reachs of warm current or in the warm water mass (such as a coastal water in summer). Furthermore, the eggs of I. illecebrosus normally developed in the waters warmer than 13° C (O'Dor et al., MS 1981), and a temprature range of 14°-21° C was suitable for the eggs of T. pacificus (Hamabe, 1962). A working hypothesis that squid have the spawning area in the upper reaches of the warm current or warm water mass is useful for detecting the spawning area of little known species.

In the waters where more than one population inhabit, the winter spawner tends to predominate in quantity. It is likely that the winter spawner utilizes the poor season in productivity of ocean as spawning season and the abundant season as growing season. However, further investigations would be necessary for verification of this assumption.

In this report, only an aspect of current system was discussed with reference to the interrelationship between the life cycle of squid and the oceanographic circumstance. However, the current system (especially the warm current) must play the most important role in the migration and abundance fluctuation of the squid. Squid, especially winter spawners whose feeding grounds are located far from the spawning area, are transported by current not only in the planctonic egg and larval stages but also in the young stage. Consequently, their migrations are strongly connected with the current system, and the scale of migration ought to be correlated with the strength of the current. Squid can utilize the wider area of feeding grounds the larger the scale of migration becomes, and consequently the population could become larger in size. On the other hand, the long-range migration (or large-scale current system) brings bigger variations in the conditions for survival in early life stages, and resultantly large-scale fluctuations in the abundance of recruitment occur.

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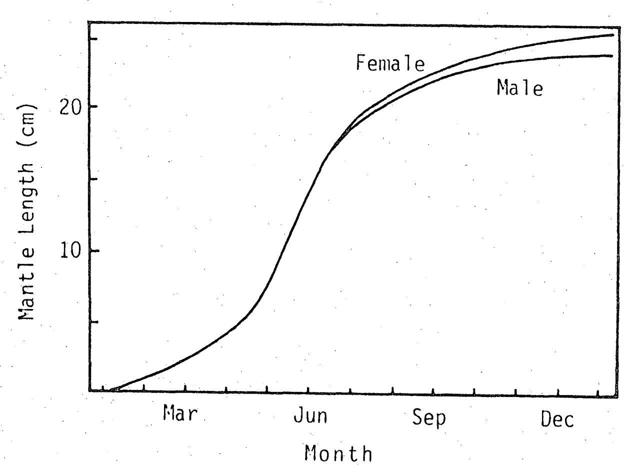
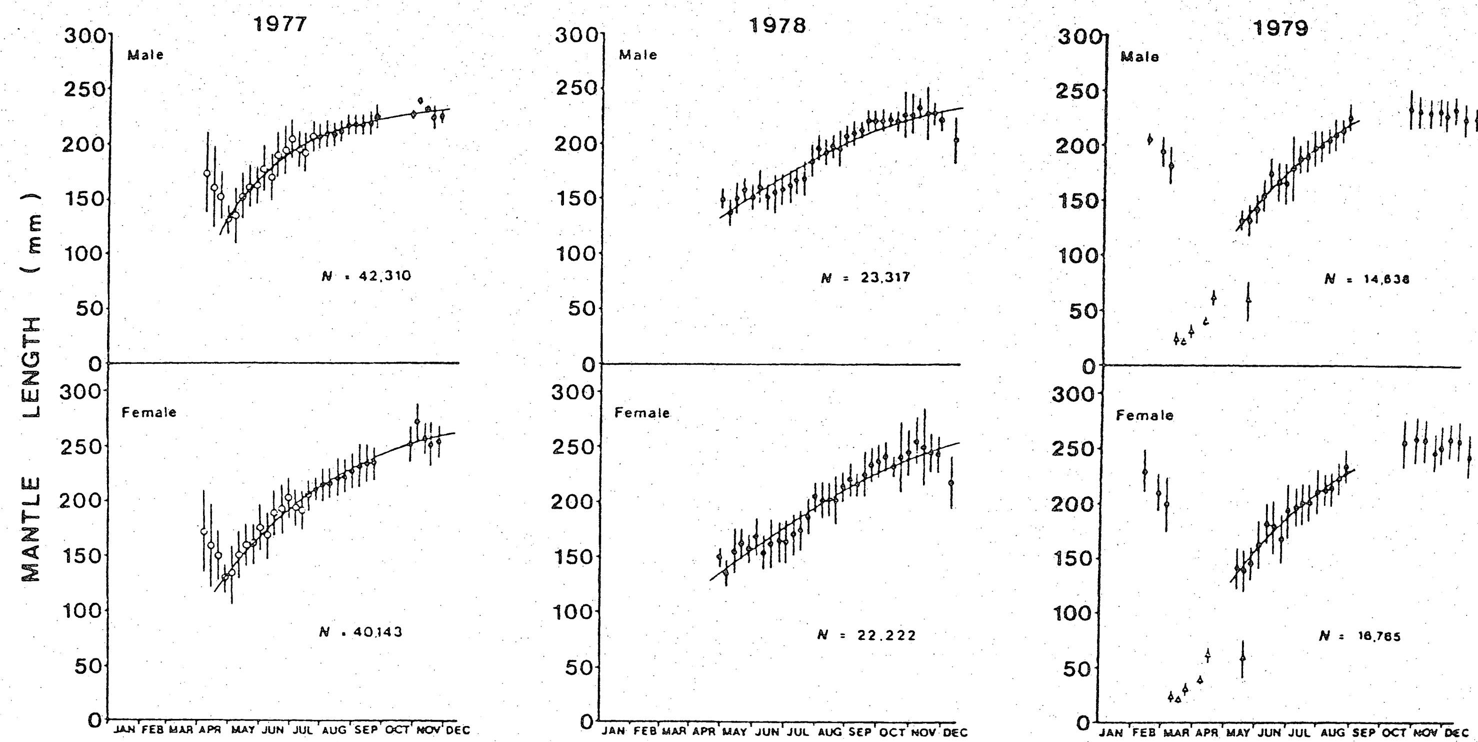


Fig. 1. The growth curves of Todarodes pacificus winter spawner in Japanese waters (Araya, 1967).



Growth curves fitted with von Bertalanffy equation $L_t = L_\infty(1-e^{-Kt})$ to length-frequency data of Illex illecebrosus from 1977, 1978, and 1979 (N.B. O - unsexed; ● - sexed; Δ - samples obtained from Gulf Stream; verticle bars ± 1 S.D.

Fig. 2. The growth curves of Illex illecebrosus in Canadian waters (Amaratunga, MS 1980).

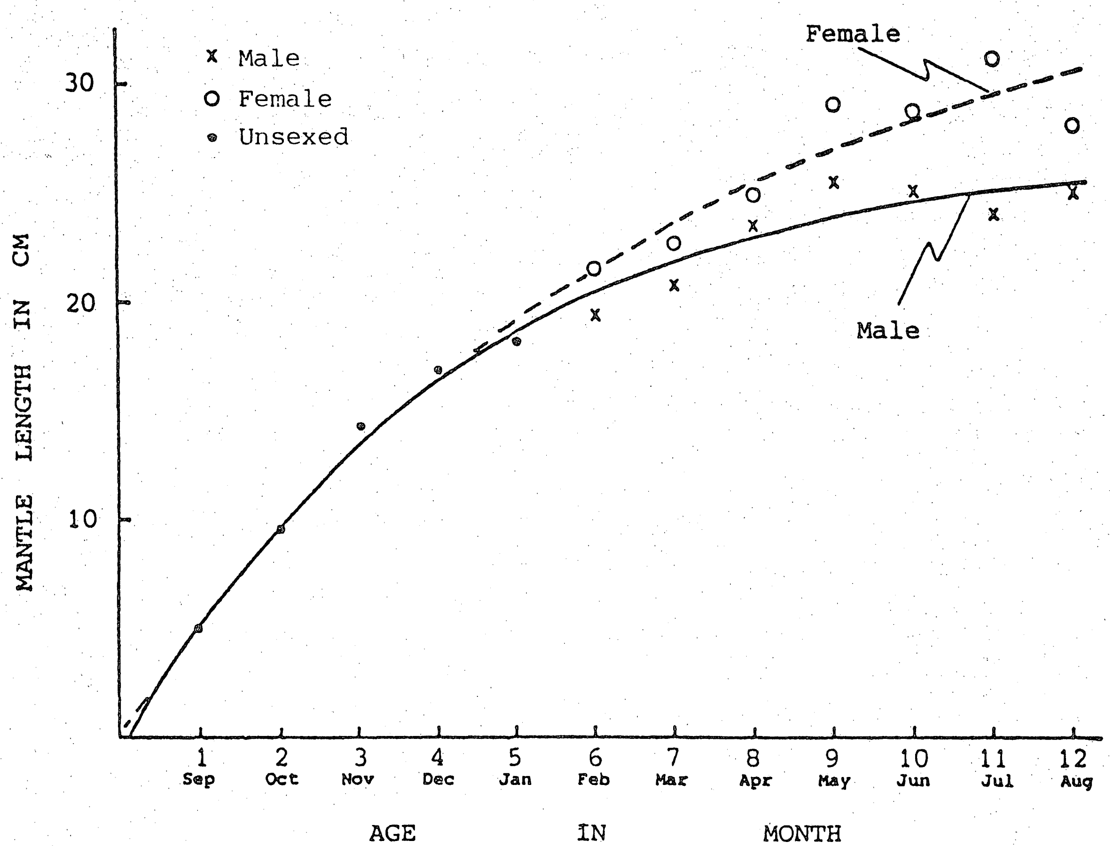


Fig. 3. The growth curves of Illex argentinus in Argentine waters (Hatanaka, MS 1983).

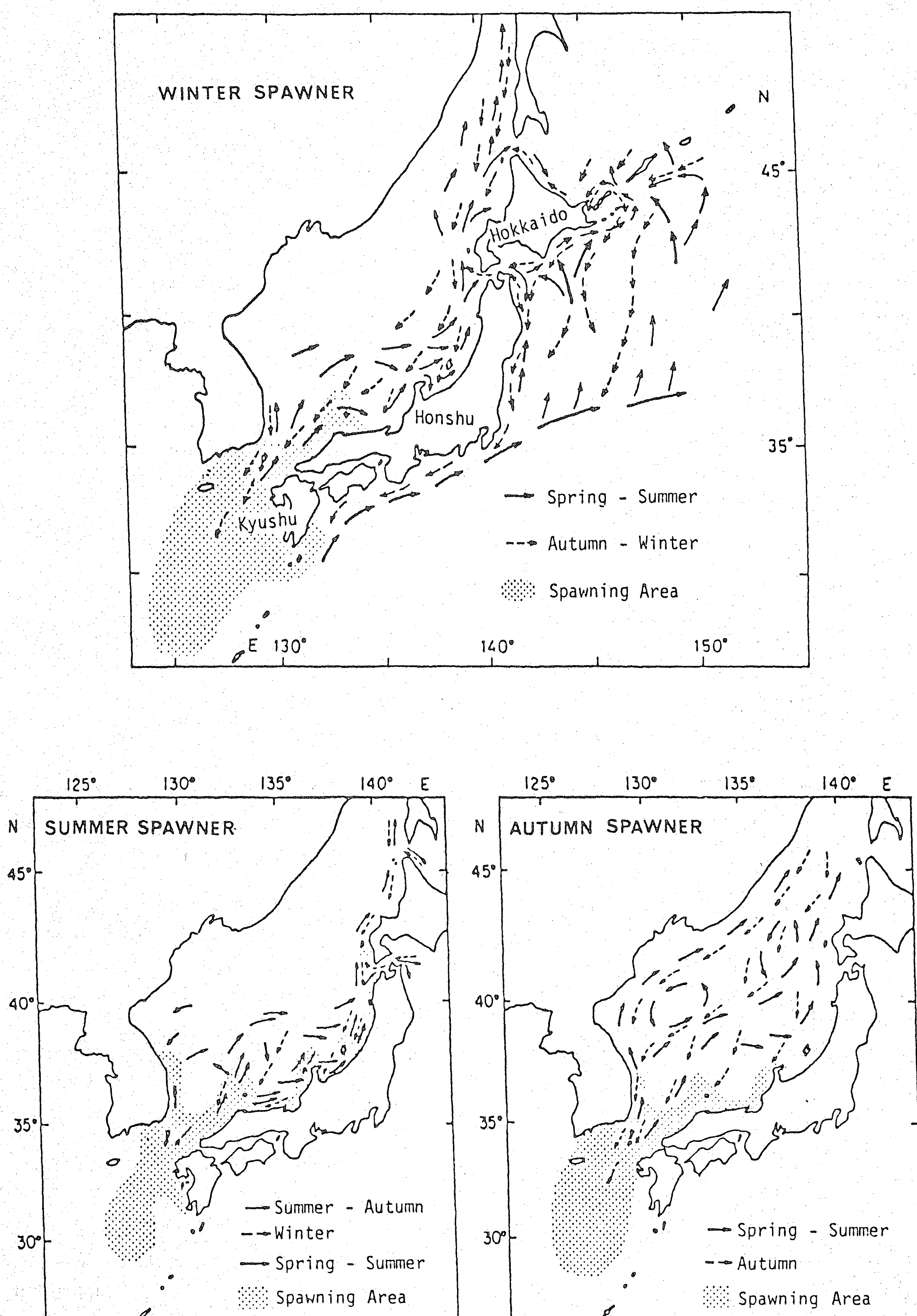


Fig. 4. The spawning areas and migration routes of three populations of *Todarodes pacificus* in the seas around Japan (Kasahara, 1982).

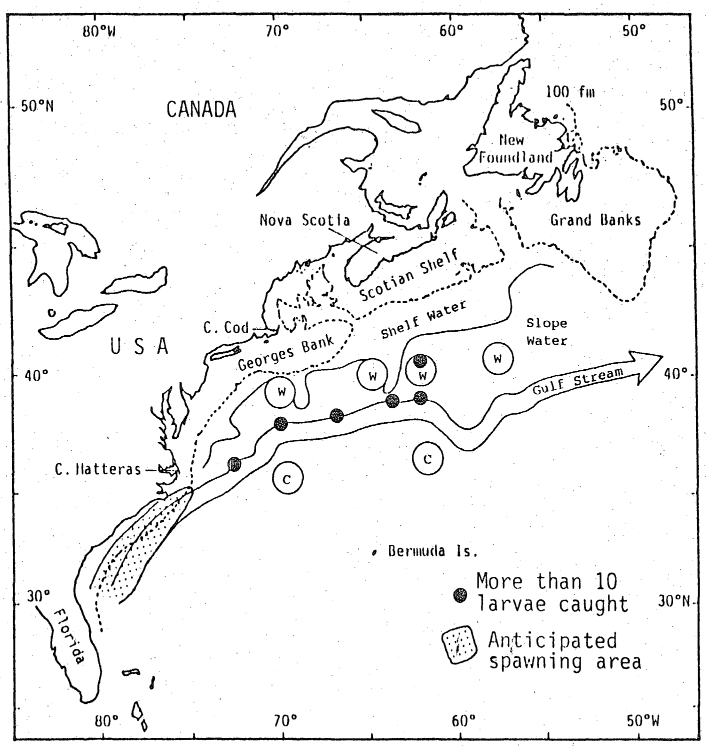


Fig. 5. The larval distribution and anticipated spawning area of <u>Illex illecebrosus</u> (Hatanaka et al., MS 1982).

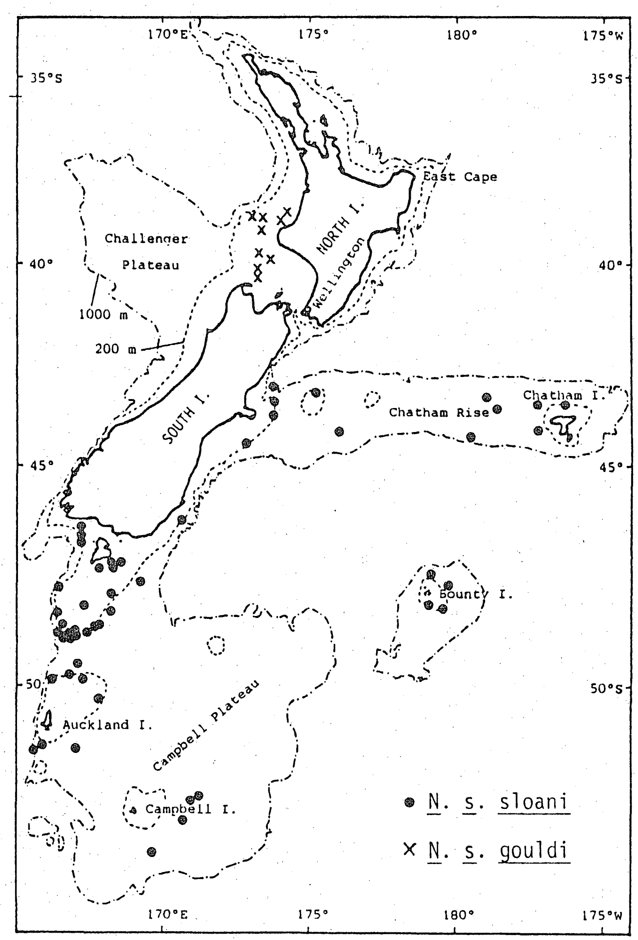


Fig. 6. The distribution of matured specimens of <u>Nototodarus sloani</u>.

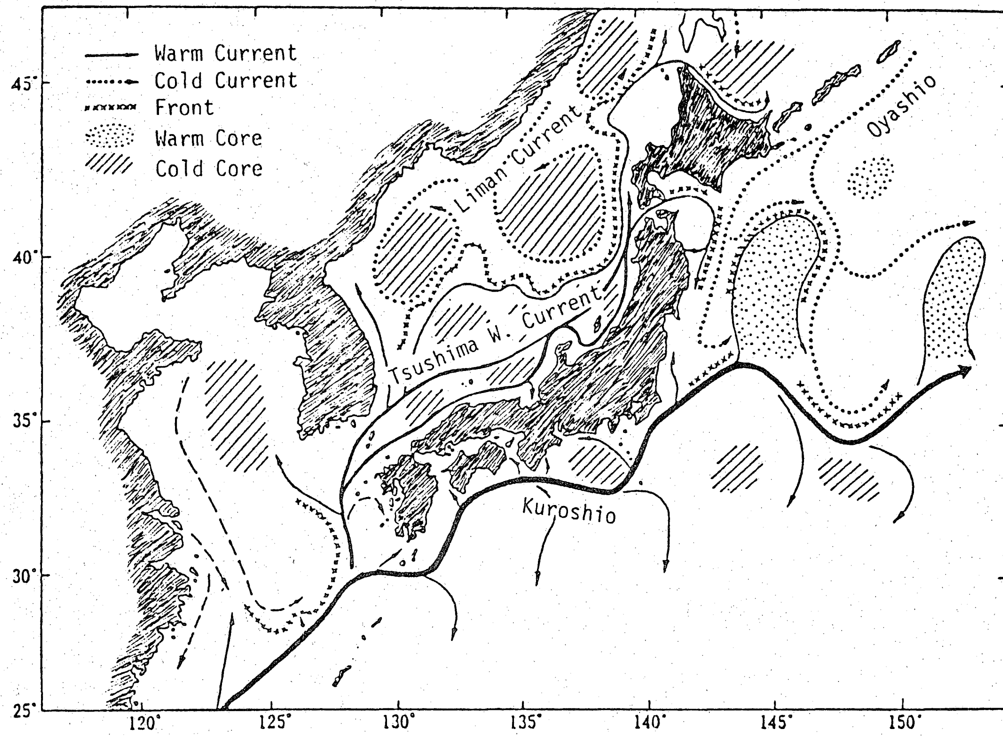


Fig. 7. The schematic figure of current system around Japan (Japan Fisheries Agency, Research Department, 1972).

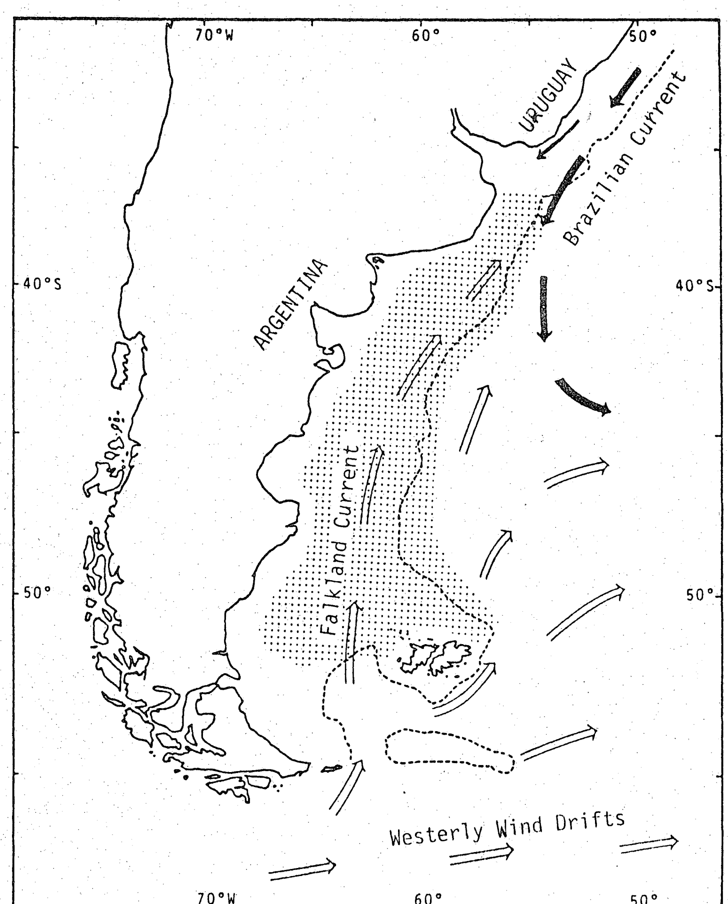


Fig. 8. The schematic figure of current system in Argentine waters (based on Japan Fisheries Agency, 1971). The dotted area is main feeding grounds of Illex argentinus.

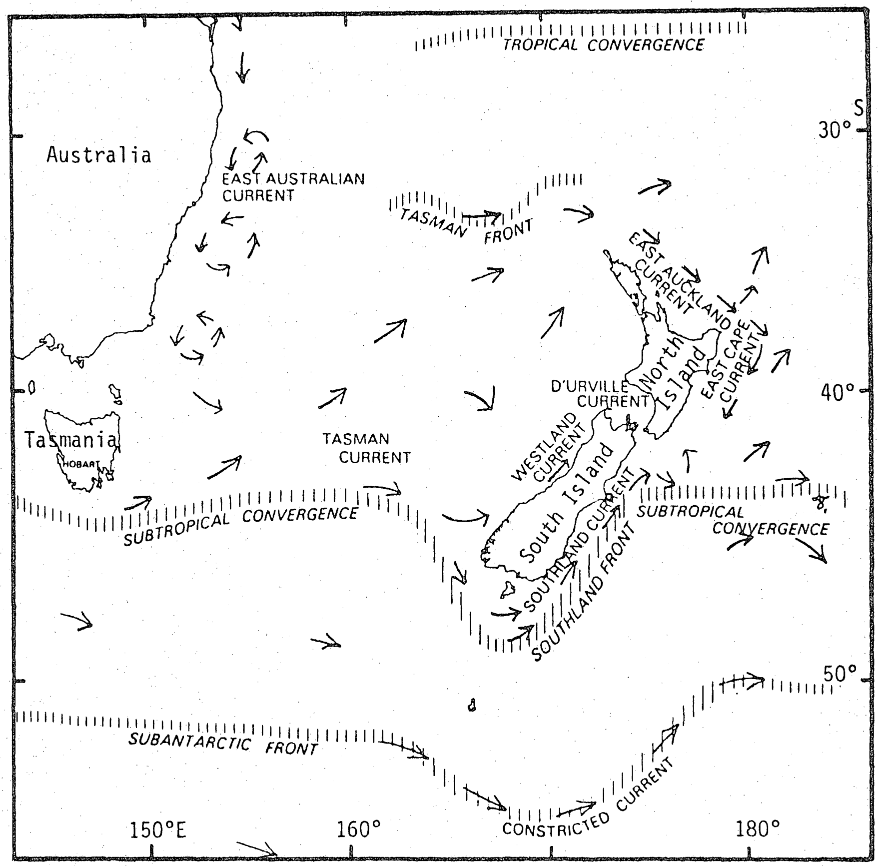


Fig. 9. The schematic figure of current system in New Zealand and East Austlarian waters (Fenaughty and Bagley, 1981).

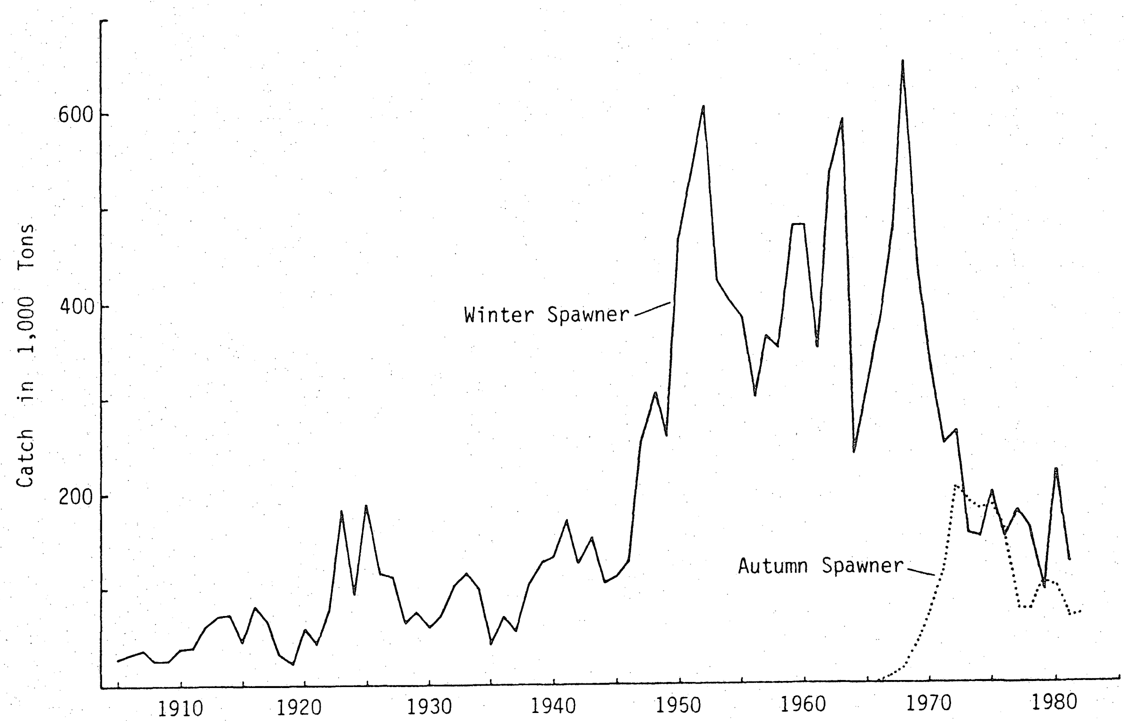


Fig. 10. The annual catches of two populations of Todarodes pacificus in seas around Japan.

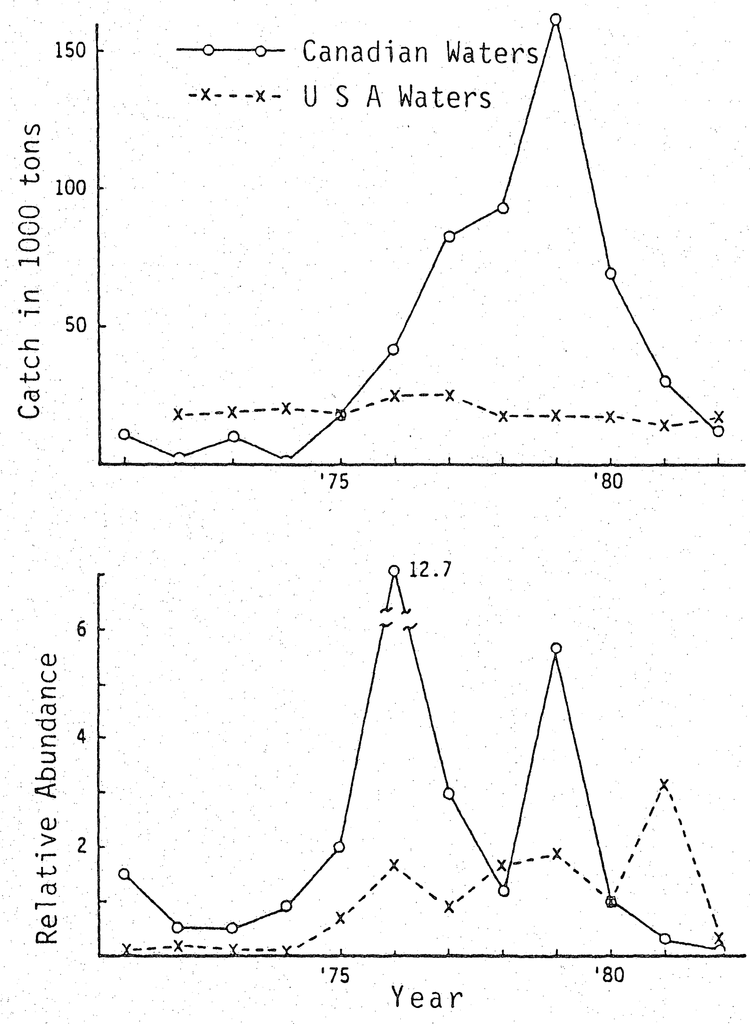


Fig. 11. The annual catch and relative abundance of <u>Illex illecebrosus</u> in the Northwest Atlantic (NAFO, MS 1982 and MS 1983).

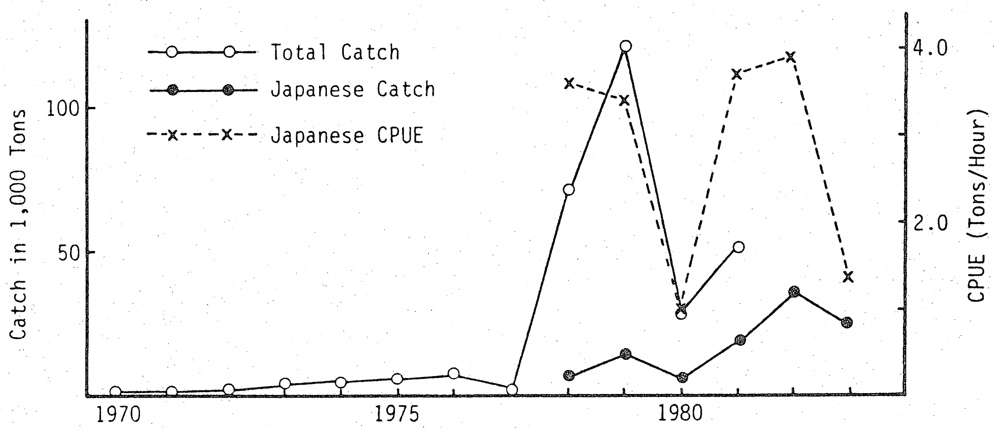


Fig. 12. The annual catch of <u>Illex argentinus</u> and the CPUE by Japanese trawlers (2,500 GRT and over) in Argentine waters.

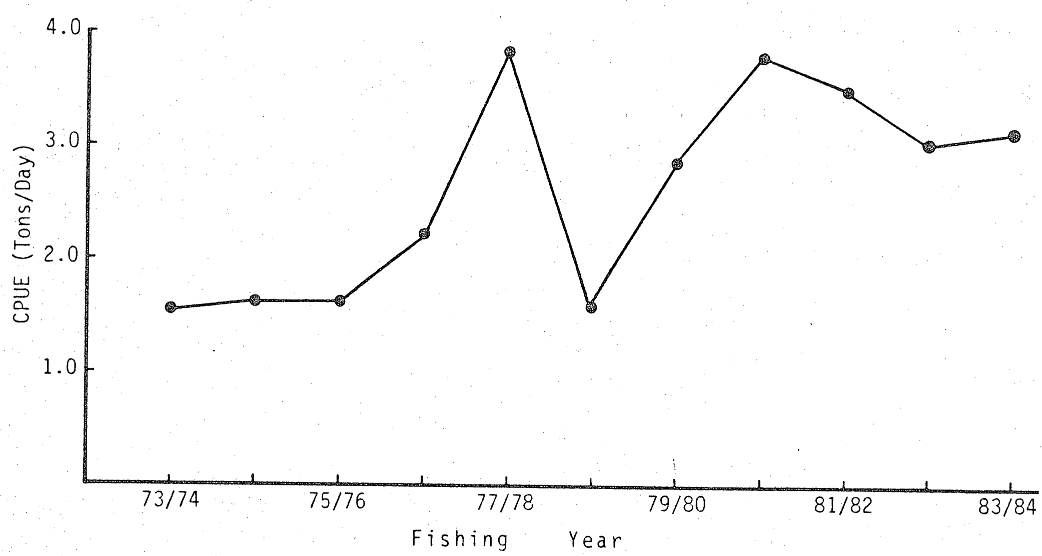


Fig. 13. The annual CPUE of <u>Nototodarus sloani</u> by Japanese squid jiggers in New Zealand waters.