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A preliminary note on the ecology of copulation of the Ommastrephid squid Illex illecebrosus illecebrosus Lesueur in the Northwest Atlantic

by M. Hamabe, T. Sato, and T. Kawakami

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A Preliminary Note on the Ecology of Copulation of the Ommastrephid Squid *Illex illecebrosus illecebrosus* (LESUEUR) in the Northwest Atlantic

Mototsugu HAMABE, Toshiro SATO,* and Takehiko KAWAKAMI

Abstract: The fact that the sperm bulbs are planted around the mouth, as well as the other characteristics of reproductive behaviour of *Nototodarus sloani sloani* (GRAY) are helpfull in inferring their migration.

Based on the same way of thinking mentioned above, we tried and failed to locate the migrating group of *Illex illecebrosus illecebrosus* on the fishing ground, as we did not know the sperm bulbs were planted on the inside surface of the mantle, not around the mouth of the female.

We would like to study the application of this knowledge that the sperm bulbs are planted on the inside surface of the female's mantle to the fishing development.

As the spermatophores of *Illex illecebrosus illecebrosus* have not been known where they are transmitted and how they play their part at and after the mating, we have reported here the above-mentioned fact as a knowledge about the ecology of copulation of this species.

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* Ocean Fisheries Resources Development Centre, Tokyo. Chiyoda ku, Kioi cho 3 - 4, Postal Code 102.

Introduction.

The Ommastrephid squid Illex illecebrosus illecebrosus (LESUEUR), which is reputed to be widely distributed in the Northwest Atlantic from the region of New York to the coast of Newfoundland in Canada, has provisionally been named the Atlantic surumeika* by the Overseas Squid Fisheries Research and Development Group (Hamabe, Kawakami, Okutani, Nasu, Sasagawa, Nakamura, Saito, Sato and Ichikawa), (see Sato 1974), and this name will be used in this report.

The ommastrephid squids are mostly pelagic animals of the warm water regions but are to be found in a large part of the cold water regions where they go in search of food, afterwards homing to the warm water regions for spawning. During their short life span of about one year they spend the first half year in a migration northwards, and the second half year in a migration southwards. (In the southern hemisphere the directions are reversed, see Naef, 1923, Clarke, 1966 and Hamabe 1965).

They migrate along the surface currents of the ocean and gather together in schools around small eddies in the ocean currents between the tide rip and the socalled deep ocean polar front. This schooling habit makes them easy to p98

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* "Surumeika" is the squid Todarodes pacificus STEENSTRUP.

In this translation I follow the text on the nomenclature of this squid, but refer to the "surumeika family" as Ommastrephidae.
Translator.

catch, and since they are believed to form a major fisheries resource an objective of our biological research on resources has been the behaviour of the ommastrephid squids in both warm surface layers and the colder deep layers of the ocean during the period when they do not school.

The distribution of the principal species of ommastrephid squid throughout the world's oceans is shown in Figure 1. A bold guess suggests that the existing fishing technology could be used to increase the catch of these important species to from five million to ten million tons. The amount caught in the neighbourhood of Japan varies from 300,000 to 700,000 tons and the fishing fleet contains 300 large ships of more than 100 tons, 3000 medium ships of 50 to 100 tons and 30,000 small ships of less than 50 tons. The concentration of fishing in the neighbourhood of Japan is therefore already probably too great, and however large the resource, it would be very difficult to increase the catch.

The five species which have so far been considered by the Overseas Squid Fisheries Research and Development Group are Todarodes pacificus STEENSTRUP, Nototodarus sloani gouldi GOULD, Nototodarus sloani sloani GRAY, Dosidicus gigas d'ORBIGNY, and Illex illecebrosus illecebrosus LESUEUR. An estimate of the possible commercial use of the New Zealand southern squid Nototodarus sloani sloani GRAY was prepared, and two fishing expeditions have been made by Japanese deep-sea fishing boats. The third expedition is being planned.

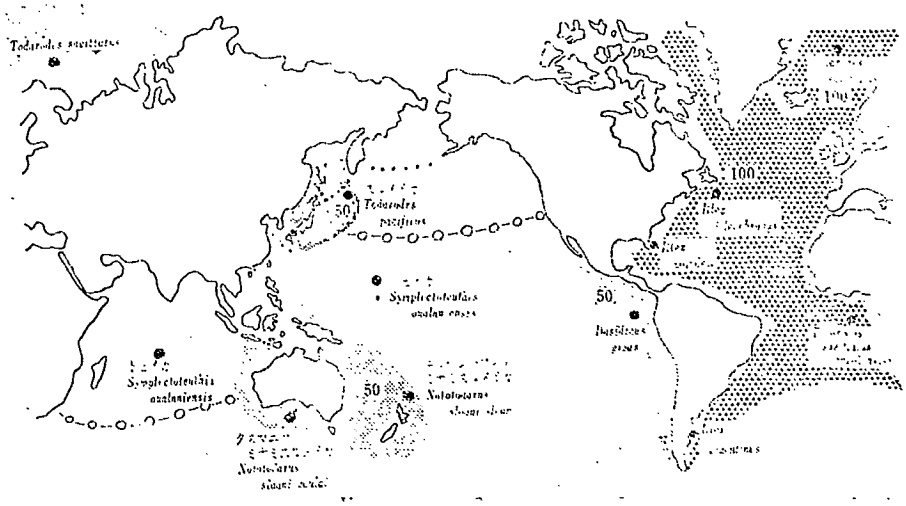

Figure 1.

The world-wide distribution of the principal species of Ommastrephid squids, and the estimated possible catch (in units of 10,000 tons).

Quoted and adapted from the 1968 publication of the Fisheries Agency, investigation and research division, of the Ministry of Agriculture and Forests. (Suisan cho chosa kenkyu bu).

Note. The Japanese characters on the map are the names of the species indicated, and are therefore not further translated. Translator.

The American large squid Dosidicus gigas is found in the Humboldt current on the west coast of South America. According to information informally acquired from the fleet operation carried out by the Soviet fishing fleet in the southern part of the range, (Sato 1972) the northern limit of its range is normally to be found off the Californian peninsular.

It is now thought that the best species for overseas squid fishing development will be the Atlantic surumeika Illex illecebrosus illecebrosus LESUEUR. A number of fisheries reports and biological reports from several countries about this species are to be found in the literature, and it appears that there should be no difficulties beyond those of outfitting the fishing fleet and adapting the techniques of fishing. (Aldrich and Lu, 1968., Bradbury and Aldrich, 1968., Mangold, Lu and Aldrich, 1969., Williamson, 1965., Squires, 1956, 1959, 1966, 1967., Mercer, 1965., Roper, Lu and Mangold, 1969).

We have reports about the catches of New Zealand southern squid, and also the diaries of the earliest squid fishing boats in this area, No. 21 Mizuho Maru and No. 58 Yuko Maru of the Sanyo fisheries, whose headquarters are in the port of Misaki in Kanagawa province (manager Noboru Kasuya). These diaries extend from April to November and from 1970 to 1972. The currents along the Eastern shore of

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North America and Canada from Newfoundland intersect the Gulf Stream in the Northwest Atlantic, to form a polar front which is a favorite fishing ground for species of tuna, and a number of Japanese tuna fishing boats fish in this part of the ocean. These Japanese fishing boats in the North West Atlantic are concerned about the shortage of bait, for which they use surumeika, Todarodes pacificus STEENSTRUP from Japan. The price is high, and the expense of purchasing squid for bait, which amounts to 20 million Yen, is beginning to be the most important factor in the operation.

With this in mind, the tuna fishing vessel Shinnichi Maru (324 tons, Captain Minetaro Mori), registered at the port of Muroto in Kochi province, has engaged in the Atlantic fishery with the objective of being self-supporting for bait.

The Ocean Fisheries Resources Development Centre's research ship has been assigned the task of developing the Atlantic surumeika fishery. An experimental operation was conducted in 1973 by Research Officer Sato (see Sato 1974) and a second investigation has been planned and is now being conducted by Research Officer Ishikawa.

The method that has been used for the promotion of research and development of overseas squid fishing as a utilizable resource has been to collate all the biological information and experience that has been reported about the Japanese surumeika Todarodes pacificus STEENSTRUP, and to

infer from this the probable features and behaviour of the unknown species. In concrete terms this has meant the use of the distinctive characteristics of the reproductive ecology particularly the distinctive implantation of the sperm bulbs on the outer surface of the buccal membranes of the female squid during copulation, to establish the separation between the copulation season and the spawning season. In general, this has given us an effective base on which to infer the features and the behaviour of the squid (Hamabe, 1965,1970,1972). p101

Figure 2 depicts the general distribution of water masses and ocean currents around Japan, and Figure 3 shows an outline of the important points of the life history of surumeika. In the case of the New Zealand southern squid our line of reasoning was applied to the behaviour and ecology of species of squid living in the distribution of water masses and ocean currents around New Zealand shown in Figure 4, and it was thought possible to deduce by analogy that the fishing grounds would be those shown in Figure 4 as K_1, K_2 and D.

Having gained confidence from this example, we supposed that the sperm bulbs of the Atlantic surumeika would be transferred to the female squid and implanted in the outer surface of the mouth bulb in the same way as those of the New Zealand southern squid. However in this species the sperm bulbs are not implanted on the outer surfaces of the mouth

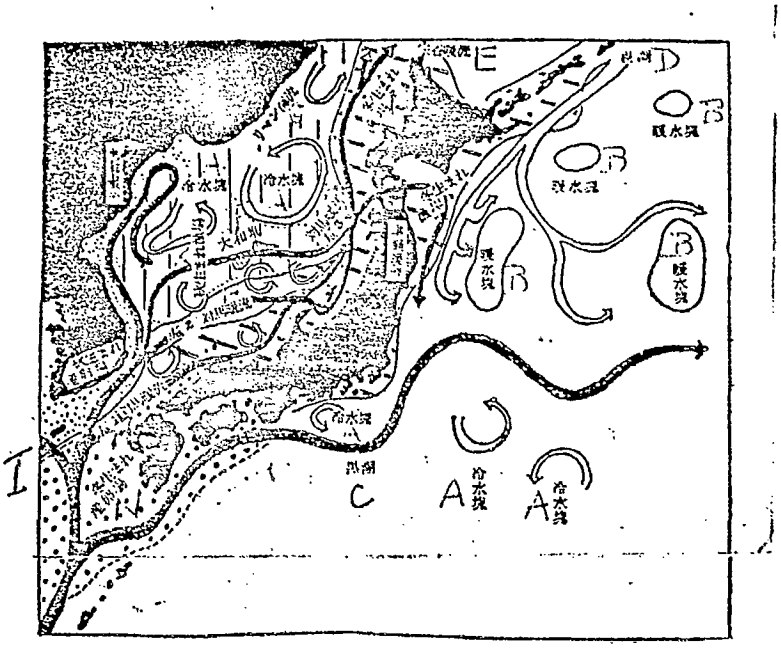
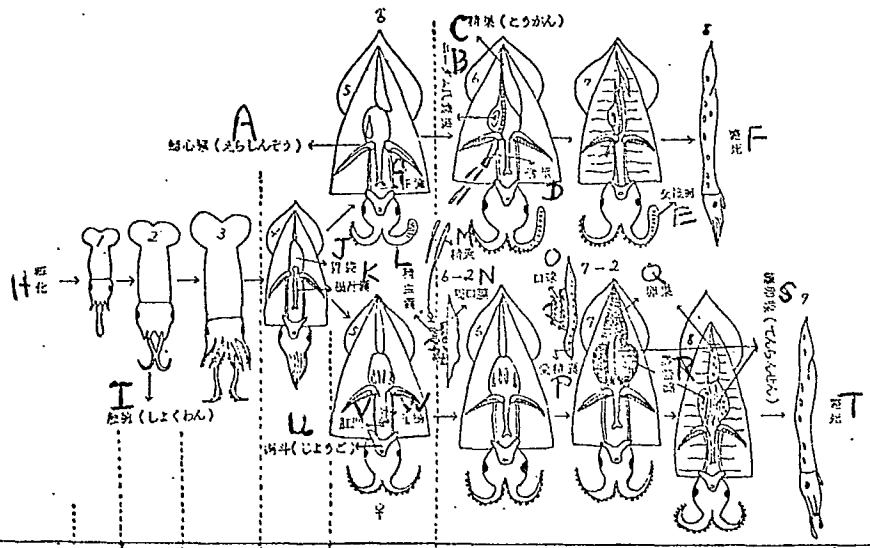


Figure 2.

A general chart of the distribution of the water masses and of the ocean currents surrounding Japan, showing the spawning regions and catching regions for the offshore (autumn born) schools of surumeika, and for the Hokkaido (winter born) schools.
(Quoted and adapted from Hamabe and Kawakami, 1972).

• Spawning place, autumn born schools.
o Spawning place, winter born schools.
Fishing ground, autumn born schools.
Fishing ground, winter born schools.

A. Cold water mass
B. Warm water mass
C. Kurashio current
D. Oyashio (Kurile) current
E. Soya warm current
F. Eastern Korean warm current
G. Riemann current
H. Tsushima current
I. Yellow sea current
J. Yamato bank
K. Autumn born spawning place
L. Autumn born fishing place
M. Winter born spawning place
N. Winter born fishing place.



Body length	1 mm	10 mm	15 mm	5 to 10 cm	10 to 20 cm	More than 20cm. Typically 27 to 30, 25 - 27, 19 - 24cm.
Stage, mode of life	Floating period. Rhynco-teuthion larvae			Seeking food migrates north		< Copulation > period < Spawning --> period Ovulation, southward migration.

Figure 3. An overall diagram of the growth of Japanese surumeika during the first year of life, and of the cyclical migration and other interdependent changes accompanying sexual maturation. (There are variations between the schools born in autumn, winter and summer). (Quoted and adapted from Hamabe, 1972).

A. Gillheart
B. Needham's sac
C. Seminal glands (testicles)
D. Penis
E. Hectocotylus
F. Death
G. Liver
H. Hatching
I. Tentacles
J. Stomach
K. Ink sac
L. Sperm sac or bulb
M. Spermatophore
N. Buccal membrane
O. Mouth bulbs
P. Receptaculum seminis
Q. Ovary
R. Oviduct
S. Nidamental gland
T. Death
U. Funnel
V. Anus
W. Rectum

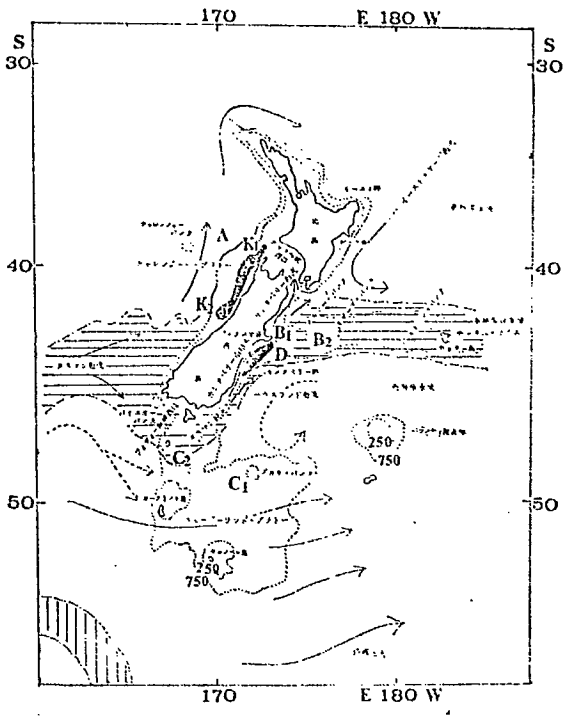


Figure 4.

Overall Map.

The location of the fishing grounds in which the first New Zealand commercial squid fishing expedition of the fishing boat No. 1 Konpira Maru caught surumeika, and of the previous surumeika catches made by the Kaiyo Maru.
(Quoted and adapted from Kawakami, Hamabe, Saito, 1973).

K_1 Fishing ground 28 January 1972 to 9 February 1972. (single-pole fishing (jigging)).

K_2 Fishing ground 10 February 1972 to 24 March 1972. (single-pole fishing (jigging)).

A, B & C Locations in which the trawler Kaiyo Maru took surumeika in mixed catches from November 1970 to January 1971.

D. Suitable locations for the occurrence of a fishery.

Note. The Japanese symbols on the map are geographical names only and are not translated. (Translator).

bulb, and it was found that the method of copulation was implantation inside the body on the inner wall of the mantle. We report here on the effect, from the standpoint of studies of resource biology, of this hitherto unknown difference from the Japanese surumeika Todarodes pacificus STEENSTRUP on the practical development of an overseas squid fishery.

A comparative summary of reports relating to the biology of the Atlantic surumeika Illex illecebrosus illecebrosus (LESUEUR).

1. The four species of the genus Illex in the Atlantic.

The four migratory species of this genus are Illex illecebrosus illecebrosus (LESUEUR), Illex illecebrosus coindetii (VERANY), Illex illecebrosus argentinus (DE CASTELLANOS), and Illex oxygonius (ROPER, LU & MANGOLD). The first three occupy, in the given order, the Northern, Central, and Southern portions of the Atlantic Ocean, and the last is reported to be found between Cuba and the Florida peninsula (Mangold, Lu and Aldrich, 1969; Roper, Lu and Mangold, 1969).

2. A general description of the northern form, Illex illecebrosus illecebrosus (LESUEUR).

This species ranges from Iceland southwards past Greenland, Hebron Harbour, Labrador and Cape Hatteras to the Gulf of Mexico and is also commonly to be found in the Caribbean Sea. As can be deduced from this range, this species is the cold-water variety of the four species, and is found when the range of water temperature is 0° to $15^{\circ}C$, with a breeding water temperature range of 7° to $15^{\circ}C$. In comparison with the other species, it grows and matures

slowly. In the cold northern waters it assumes a large form, and becomes smaller towards the south as the water becomes warmer, but even in the southern waters Illex illecebrosus illecebrosus (LESUEUR) is to be found throughout a wide range of water temperature (Roper, Lu and Mangold, 1969). It is reported (Squires, 1967) to live for two years, during the first of which it remains close to the coast, going out to the deep ocean to spawn and die in the winter of the second year.

3. The separate ecology of Illex illecebrosus illecebrosus (LESUEUR) in Newfoundland waters.

This species has been named the "short-finned squid" (Mercer, 1965) or, because of its use as bait in the long-line cod fishery, the "bait squid" (Squires, 1967). While it remains close to shore, it principally preys on the small Osmerid fish capelin (Mallotus villosus MULLER) and when it goes out to sea it feeds mostly on Euphausia. It is selectively sought out and devoured in large quantities by the Odontocetid pilot whale Globiocephala melaena (Squires, 1967). Various aspects of the swimming behaviour and fin movements and of the ways in which a jigger hook is attacked have been observed (Williamson, 1965), and similar behaviour has been seen in the pursuit and catching of capelin (Bradbury and Aldrich, 1969).

It is present on the Grand Banks during the offshore migration in May, and around June schools of squid suddenly appear and enter the waters of the continental shelf. A similar well-known schooling occurs in Japan (the Oki islands). During the period from June to October the squid continue to swim offshore and are caught by jigging at a water depth of about 30m. The quantity caught on the Grand Banks around Newfoundland, was about 4536 tons in 1953, 6800 tons in 1954, 6800 in 1955, 7700 tons in 1956, 2700 tons in 1957 and 907 tons in 1958. Around November they leave the shelf for the deep waters in order to spawn, and it is believed that they die there after spawning. At this age, some of them may live through the winter in the adult form (Squires, 1965).

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4. The copulatory ecology of Illex Illecebrossus Illecebrosus (LESUEUR).

It is known that there are differences between the sexes in the individual rates of growth and that in general the females grow more quickly (Mercer, 1965). The hectoclytus may develop from a ventral arm on either the left or right side, whereas it has been found that the hectoclytus does not develop from the right ventral arm of the Japanese surumeika.

The sexual maturity necessary for reproduction occurs when the body is mature, amd in the male squid this is reached when the mantle length is 20 to 25cm, the largest mantle length being 27cm. Although the length of the mantle

in the mature female is not certain, the largest mantle length is known to reach 31cm (Roper, Lu and Mangold, 1969); (Squires, 1956).

In addition to the report by Squires (1956) on the necessary conditions for reproduction, there is a detailed report on a comparative investigation of the morphology of the sperm bulbs by Roper, Lu and Mangold (1969), in which the main theme is morphological taxonomy rather than reproduction.

These writers describe the course of sexual maturity in the following way. A ventral arm of the male squid begins to grow when the mantle length is about 20cm. The seminal glands of the male develop rapidly around September to October, and in rare cases a large male may then already possess sperm bulbs ready for transfer and implantation. It is believed that the male squid normally arrives at maturity only after migration to the deep ocean. In exceptional cases males have attained maturity in May with spermatophores completely developed, and a large number of spermatophores have passed through the penis and are dispersed around the funnel, so that some of them are believed to leave the funnel and to be discharged.

Specimens of female squid with a mantle length of 28cm have been found to be approaching maturity in May. In these female squid the length of the orange coloured nidamental gland is found to reach 7.6cm, and it thickens as

it secretes the gelatinous material needed for wrapping the eggs at the time of spawning. The ovary contains eggs from 0.83mm to 1mm, and the egg mass is seen to have a pale yellow colour. Such a large female squid will probably produce eggs during the summer of the coming year. In general it appears that the development and maturation of the female squid proceeds slowly and gently and that there is no sudden change of condition.

The writers quoted show pictures of the distinctive features of the spermatophores of the four species Illex oxygonius, Illex illecebrosus, Illex coindetii and Illex argentinus (see their Figure 10). The distinctive features of the spermatophores by which the four species of Illex may be distinguished are the long or short taper of the pointed end of the outside of the spermatophore, the exact shape of the socalled "spearhead shaped" part of the tunic, the shape of the conical protrusion and the constriction where this protrusion touches the long shaft. The complete shape of the spermatophores of Illex oxygonius is shown in the photograph in their Figure 5. Since it was reasonable to assume that Illex illecebrosus illecebrosus (LESUEUR) would greatly resemble this typical example of the morphology of the genus Illex this photograph was carefully inspected. It was found that the general structure of the spermatophores was very much the same as in other Ommastrephidae, but that there were some

small differences. A particular difference was the occurrence of an accumulation of a twisted skein of a string or fibre on the outermost tip of the spear-head shaped portion which has already been mentioned.

The reports of the genus Illex which have here been quoted contain no information about the copulatory behaviour or about the fate of the spermatophores.

A preliminary note on the ecology of copulation of Illex illecebrosus illecebrosus (LESUEUR).

In his investigations from May to November 1973 of the experimental fishing grounds whose extent is shown in Figure 5, Research Officer Sato studied the locations of fishing grounds for the Atlantic surumeika and the behaviour and conditions of the schools of squid which were present. In contrast to the state of maturity of the male squid, the female squid appeared to be all unmated, since there were no sperm bulbs implanted on the outer surfaces of the buccal membranes. Since it was scarcely possible that these schools could contain only females which had failed to mate, it was supposed that they were immature schools which were migrating north in search of food. This was of course a mistaken view of the ecology of copulation, and when an anatomical investigation was made in the laboratory, it was found that,

Figure 5.

The locations between New York and Newfoundland in which T. Sato in No. 51 Hoyo Maru searched for and caught the Atlantic surumeika Illex Illecebrosus illecebrosus (LESUEUR) between May and November 1973.

Range of experimental exploitation.

Location of Fisheries.

as shown in Figure 6, the sperm bulbs had been implanted on the inner wall of the mantle, to the left and right of the base of the gills.

The number of individual females showing these internal traces of copulation was small, and the number of mature male squid and of immature female squid used for comparison was also small, but the overall results could not be doubted. By means of a great amount of work at sea, it has been shown that the spermatophores of the Atlantic surumeika Illex illecebrosus illecebrosus (LESUEUR) illustrated in the report by Roper, Lu and Mangold (1969) are discharged and transferred, and that an arrangement of sperm bulbs is implanted on the inner surface. The accumulation of twisted fibres is perhaps wrapped around them like a sock. There are variations in the ecology of copulation of squid, in particular in the manner of copulation, and this difference between the Atlantic surumeika and the Japanese surumeika is thought to be similar to that described by McGowan (1954) for the reproductive ecology of the Myopsid squid Lologo opalescens (BERRY) in the sea near California and that illustrated by Drew (1911) for the squid Loligo pealei (LESUEUR). On the basis of the results of the second series of experimental investigations, we hope to be able to investigate the way in which this external evidence of copulation of the Atlantic surumeika can be used to establish the location of fishing grounds.

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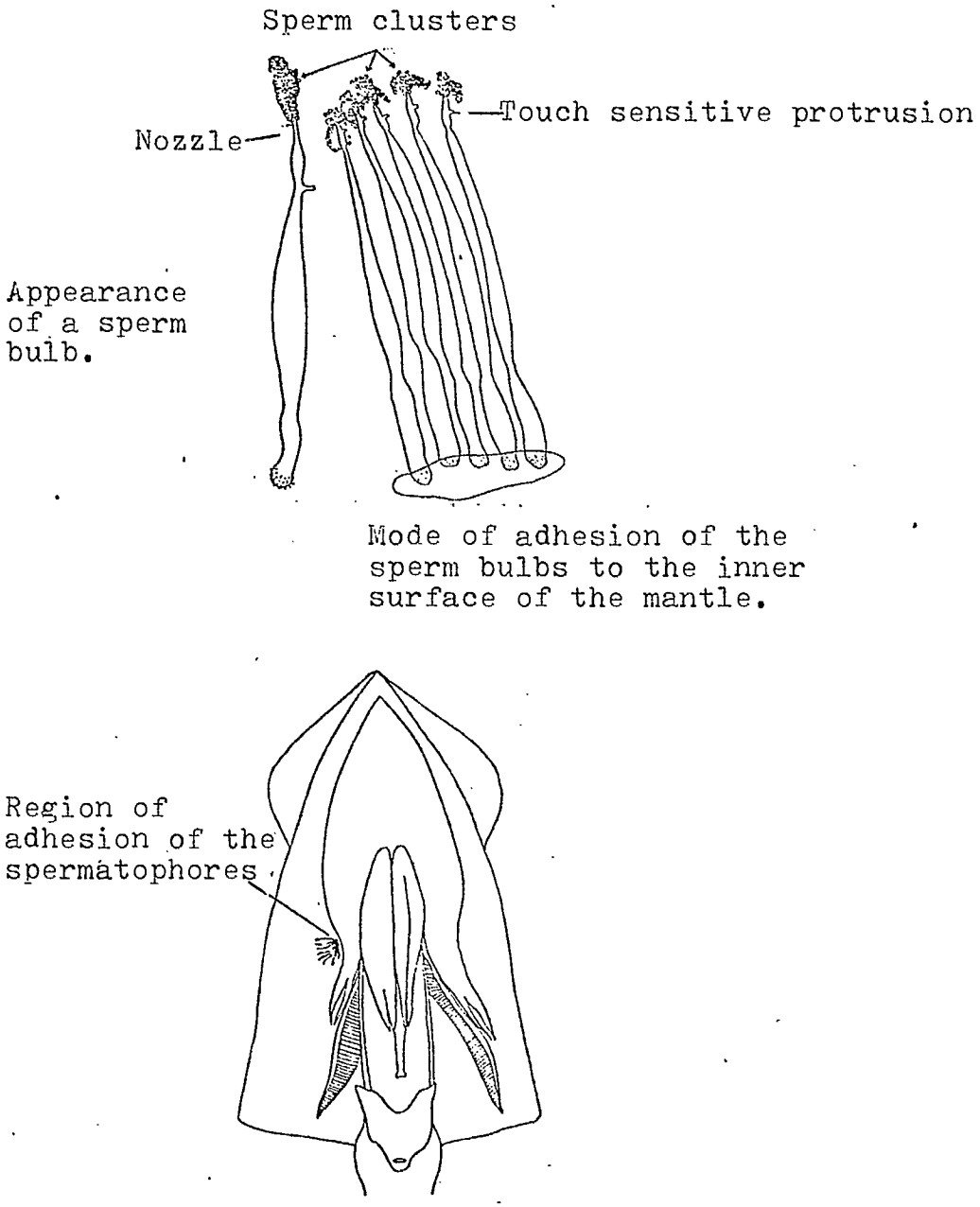

Figure 6. The implantation of sperm bulbs near the base of the gills, as shown by the dissection of a mature female Atlantic surumeika Illex illecebrosus illecebrosus (LESUEUR) of mantle length 19.7cm and weight 157g caught on 11 July 1973. The sperm bulbs are attached by adhesive hooks to the inner wall of the mantle, and clusters of sperm, resembling scraps of cloth are discharged from the orifice of the nozzle. The length of the sperm bulb is 7 - 8mm, and the diameter of the thickest part is 0.2 to 0.3mm.

Conclusions.

1. It was assumed that the distinctive features of the reproductive ecology of the Japanese surumeika, in particular the distinctive implantation of sperm bulbs on the outer buccal membranes during copulation, could be used as a pointer in finding schooling locations of the New Zealand southern squid.

2. The same assumptions were made about the Atlantic surumeika Illex illecebrosus illecebrosus (LESUEUR) but in this squid the sperm bulbs are never implanted on the outer surfaces of the buccal membranes, and are found to be implanted to the left and the right of the base of the gills on the inner surface of the mantle.

3. The existing reports about the reproductive ecology of the Atlantic surumeika contain no information about the location or method of implantation of the sperm bulbs at the time of copulation.

4. The results of experiments to be made in the fishing grounds during 1974 will be investigated to determine whether the internal evidence of copulation in the Atlantic surumeika can be used in the development of a fishery.

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