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Studies on the propagation of the scallop,
Patinopecten yessoensis (Jay), in Mutsu Bay

By Gotaro Yamamoto

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By Gotaro Yamamoto

1. Introduction

The Japanese scallop, Hotategai, Patinopecten yessoensis (Jay)*, was first established as a new species in Jay's report (1856). Specimens of this species were found in Hakodate, Hokkaido.

In the Japanese literature, P. yessoensis was first reported by Terahashi (1716) who observed that this scallop ran like a sailboat and therefore named it "Hotategai" (hotate means sailing, and gai means a clam). A similar description of Hotategai was also given later in the Arakida's "Atlas of the Shell-Fish".

The scallop fishery in Mutsu Bay, Aomori Prefecture, started as early as mid-18th century, and the adductor muscle from the scallop was one of the marine exports to China which contributed much to the financial status of the feudal government. Thus, the scallop fishery at that time was under the strict control of the government.

Although not many reports were published on the methods of scallop fishing at that time, it appears that the methods were quite primitive and that scallops were caught by a single net.

Early in the Meiji era, on April 28, 1886, Aomori Prefecture issued a proclamation forbidding the use of certain types of nets for the scallop fishery in Mutsu Bay for a period of 3 years. It is of interest to note that this was the first prefectural policy for the protection of the scallop fishery. In 1893 and again in 1895 the marine reserve areas were further extended in order to protect the propagation of the scallop. In 1895 the prefectural administration also asked Dr. K. Kishigami to carry out investigations on the protection of the scallop fishery in Mutsu Bay. After a two-week study he urged the administration to issue a stern policy prohibiting indiscriminate fishing of scallops (Kishigami, 1896).

Since then, until 1940, there was only one, as far as the author knows, report concerning the propagation of scallops in Mutsu Bay (Aomori Prefecture Marine Experimental Station Report, 1930). During this period,

* Masuda recently claimed that this species was different enough from the North American scallop, P. caurinus, and, therefore, classified it as Mizuhopectin yessoensis (1963).

however, a few basic studies were carried out on the biology of the scallop (Nomura, 1918; 1932; 1933).

In 1940 the Aomori Marine Experimental Laboratory of the Research Institute of Agriculture, Tohoku University, was opened in Aomori City, and a study of the propagation of the scallop in Mutsu Bay was initiated by Mr. U. Nishioka (later Professor at Mie University), Mr. S. Nagamine of the Mutsu Bay Branch of the Prefecture Marine Experimental Station and myself. However, the beginning of the Second World War did not allow us to continue the project in a satisfactory manner. After the war, in 1948, Drs. S. Nomura and S. Kokubo of Tohoku University set up an investigation to study the development of the marine resources in Aomori Prefecture with financial support from the prefectural administration. The study of the propagation of scallops in Mutsu Bay was also re-started with much vigor and help, and this study became one of the major research projects of a branch office (later became Aomori Prefecture Mutsu Bay Marine Propagation Research Institute) of the Prefectural Marine Experimental Station which was newly opened at Ominato in Mutsu City in 1949.

During the long course of this investigation, the author has been conscious of his indebtedness to many people who have offered valuable help in countless ways. Their co-operation is gratefully acknowledged and, in particular, I should like to express my sincere gratitude to Professors I. Motomura and M. Kato of Tohoku University for their expert criticism and advice on the ecological aspects of the study, and to Professor T. Imai of Tohoku University for his criticisms and suggestions. Also, I wish to thank the following persons for their willing technical assistance: Mr. U. Nishida (ex-professor Tohoku University); Mr. S. Nagamine; Mr. I. Etô (present at Ishikawa Prefecture Marine Experimental Station); Messrs. S. Sato, J. Hasegawa, K. Tanaka and T. Sekine (all at Aomori Prefectural Bureau); Mr. M. Usuki (present at Niigata University); Mr. H. Fukushi (present at Protein Institute of Osaka University); Mr. Y. Amauchi (present at Gengakukun-sha Publishing Co.); Mr. T. Kato (present at Nikko Fishery Nursery Station of National Marine Bureau); Messrs. B. Tsubata, K. Takeda, and B. Sugano (all at Aomori Prefecture Mutsu Bay Marine Propagation Research Institute).

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2. Scallop fisheries of the world

It is reported that New Bedford, Massachusetts, U.S.A. has the largest scallop fishing industry in the world and that the annual catch reached approximately 10,000 tons (Olsen, 1955). However, this amount is far less than that recorded in Hokkaido for 1934 - 91,545 tons, or in Mutsu Bay for 1928 (Fig. 5). The scallop commercially caught in New Bedford consists mainly of Aequipecten irradians Lamarck (Bay scallop) which lives between Nova Scotia and Tampa, Florida, U.S.A. The densest population of this species is seen in the sea between Cape Cod (New Bedford) Massachusetts to Bogue Sound, N.C., U.S.A., and the largest annual catch between these two points reached 16,710 tons (Gutsell, 1930). The bay scallop usually inhabits shallower water near an inner bay or island. According to recent studies, bay scallops living in the States of Massachusetts and Maine are different from those in the States of Florida and North Carolina. Thus, the former has been classified as A. i. irradians, while the latter as A. i. concentricus. A. i. irradians spawns in the middle of June (Belding, 1910), whereas the spawning of A. i. concentricus has been reported to take place in August (Sastry, 1963).

The scallop, Placopecten magellanicus, which lives further northward, has also been fished commercially. An amount of 840 tons for the maximal annual catch was recorded in 1936-1937, while the minimum was 16.4 tons in 1921-1922. The second largest annual catch of 382 tons was obtained in 1945-1946. The amount for the average annual catch during the recent years is approximately 100 tons. This species inhabits the deep water, has a large size and, thus, is called the giant scallop, large sea scallop or Digby scallop. It is distributed from New Bedford to Northumberland, Nova Scotia, but the centre of its fishery lies off Digby, in the Bay of Fundy, Nova Scotia (Dickie, 1955; Dickie and Medcof, 1963).

Patinopecten caurinus which is akin to the Japanese scallop P. yessoensis, is a large-sized scallop and is found near Juneau, Alaska. This species has been reported in abundance in 34-42 fathoms off Cape Fairweather, 39-44 fathoms in Ice Bay, and 54-56 fathoms off Cape Saint Elias (Rathjen et al., 1963; 1964).

In Europe Pecten (Chlamys) opercularis is the most common scallop, and the annual catch reaches 1300 to 2000 tons in the Isle of Man, and in Firth of Forth, southern Scotland. The centre of the fishery is Bantry Bay in Ireland. This species is called the Queen (or Common) scallop in southern England, Clam in Scotland, and Zamborina in Spain. Another large scallop, Pecten maximus L., found in the English Channel is called Scallop, Escallop or Great Scallop in England and Vieira in Spain. It has been sometimes fished near Plymouth, England, though the amount of the haul is small (Dakin, 1909).

The Tasmanian scallop, Notovola meridionalis is widely distributed in the seas of the southern hemisphere, and has been commercially caught

in amounts of 200 tons (Olsen, 1955). This species is found from Newcastle (N.S.W.), Australia, through Bass Strait to Port Lincoln (S. Aus.) and Tasmania. In these areas N. meridionalis, Equichlamys bifrons and Mimachlamys asperinumus have also been commercially caught in small quantities.

There are at present approximately 300 species of scallops. All of them are distributed in the cold sea of higher than 35° north or south latitudes. In England the shell of the scallop is called the St. James shell and has been used as a sacred symbol. At Compostella in northwestern Spain it was worn by pilgrims to show they had visited the shrine of St. James. In France it has been acclaimed by many people as Coquille Saint Jacques. Also, it is well known from Botticelli's famous painting "The Birth of Venus" where Venus (Aphrodite) was born in a scallop shell. The scallop which was held as a sacred symbol for centuries is reported to be Pecten maximus (Cox, 1957).

3. Life cycle of the scallop, P. yessoensis, in Mutsu Bay, and its fluctuations and abundance

(1) Life cycle

a. Type of sexuality and time of spawning. Although the scallop is a dioecious animal, one can very rarely see a monoecious individual. In this case the base of the gonad is male and yellowish white, the other half near the tip is female and orange red. Sometimes the female gonad is interwoven with the male gonad, forming a mosaic pattern (Fig. 1). It appears that the scallop was originally ambisexual like other Pelecypods. Many closely related species distributed in North America and Europe, such as P. (Chlamys) opercularis in England; P. maximus, P. varius and P. glaber in the English Channel; Aequipecten irradians and P. gibbus along the Atlantic coast of North America, have a monoecious type of sexuality, and only one species, P. tenuicostatus, is dioecious.

Spawning of scallops in Mutsu Bay usually takes place from the end of March to the middle of May. In recent years it was observed that spawning frequently starts as early as the beginning of March. This early spawning of scallops does not appear to be due to an early rise in water temperature but to other factors, since the water temperature at the sea bottom in early March during this period has been 4 - 5°C which is far less than the optimum temperature for spawning, 8.0 - 8.5°C. Eggs spawned under such conditions could not complete their growth. Although no information is available on the growth of scallop larvae developed from eggs which were spawned earlier than usual, it should be kept in mind that the number of trocophores and fully-grown larvae has shown a considerable decrease in recent years.

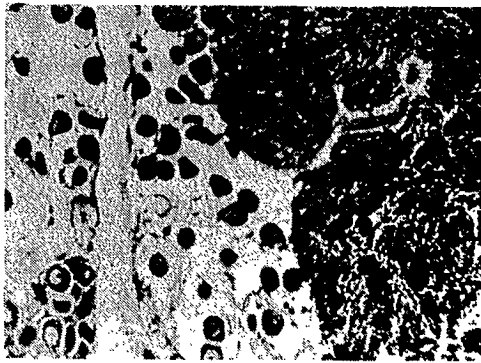


Fig. 1. Microscopic photograph of the gonad from a monoecious scallop. Both ovary and seminal vesicle can be seen. $\times 50$.

b. Process of development. The spawned ova are released in the sea and then fertilized, and soon after the eggs start to divide as shown in Fig. 2 and Table 1. Several characteristic features of the development of the scallop egg are: (1) cytoplasm of the egg contains carotinoid pigments. Because of the presence of these pigments the egg has a characteristic colour. This colour disappears by the time the embryo develops to the veliger stage. The pigments sometimes appear in the ligament, and as a result the ligament shows an orange-red colour which fades away upon exposure to sunlight (Kobata et al., 1950). (2) Cytoplasm also contains numerous non-transparent yolk granules, the presence of which makes it difficult to observe the development of the cell lineage in unstained living specimens. One can usually trace the development up to the 16-cell stage. (3) When the first cleavage division takes place, the polar lobe is formed (Fig. 2, from d to g'). Drew (1906) observed that the polar lobe in Pecten tenuicostatus was formed each time the first and second polar bodies were formed and when the first and second cleavage division took place. However, this has not been observed in Patinopecten yessoensis. (4) The embryo develops to the blastula stage after 40 hours at water temperatures of 8 - 9°C (Fig. 2, k). A few flagella are formed at several areas on the outside cell membrane, and the embryo starts to move by rotation. (5) The embryo reaches the trochophore stage 4 days after fertilization and starts to float in the surface water and to swim freely. Several apical cilia are formed at this stage, but they disappear by the early veliger stage. (6) The formation of the velum follows, then the embryo grows to the veliger. It usually takes 5 to 6 days after fertilization to reach this stage. A further one or two days are required to form the complete pair of D-shaped shells. At this stage the body and the shell of larvae do not contain any spots or pigments and are fairly transparent. No flagellum is formed on the velum. In this respect Patinopecten yessoensis differs from either P. opercularis, P. tenuicostatus or P. irradians. (7) Fifteen to sixteen days after fertilization, when the shell length of the larva is approximately 120 μ , the shell starts to increase in size. This is the beginning of the umbo stage of development. As shell growth continues, the growth rate of the left shell exceeds that of the right; which results in the formation of an asymmetric bivalve shell. When the larva has a shell length of approximately 300 μ and starts to adhere to other objects, it is fully developed. Usually the right side shell of fully-grown larvae attaches to the substratum by byssus. Occasionally the larva cuts its own byssus and starts to secrete a new byssus in order to attach to other substratum. (8) Within 12 hours after the larva has adhered to substratum, the characteristic spat shell is formed. At first a thin and transparent chonchioline membrane is formed (Fig. 2 - q, r), later calcium carbonate is deposited, and then the membrane becomes non-transparent. (9) sometime after a fully-grown larva has started to adhere to substratum, degeneration of the anterior adductor takes place and a remarkable development of the posterior adductor begins.

There are a number of factors which affect the embryonic development of the scallop. It is well known that of these, water temperature

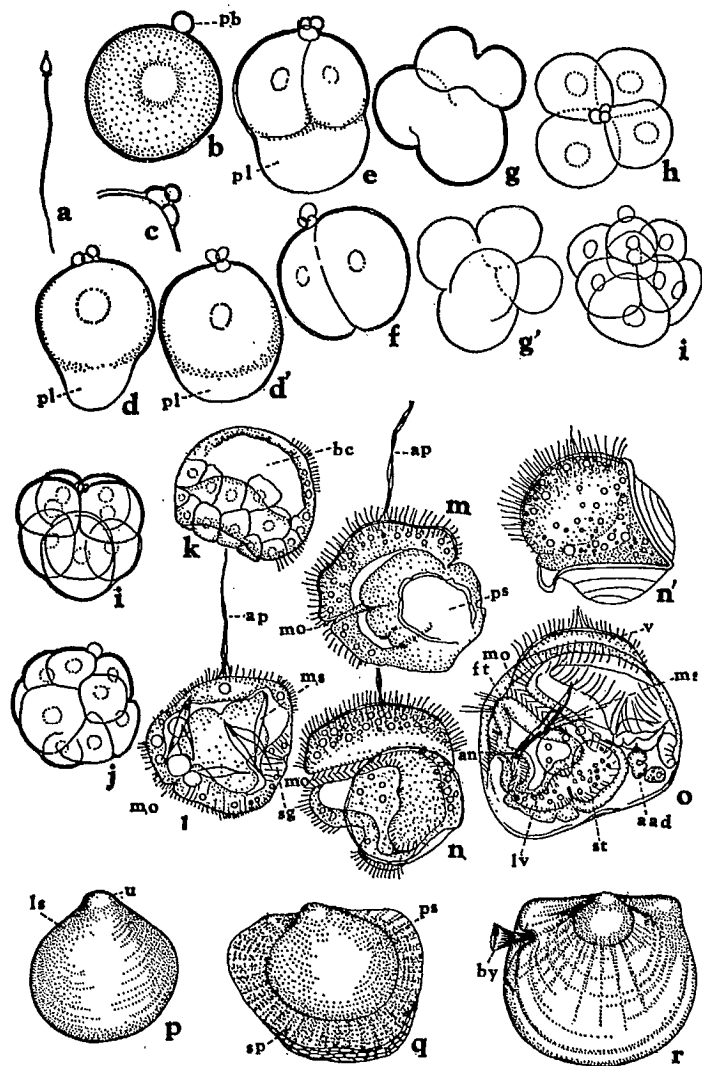


Fig. 2 (see p. 8 for caption).

Fig. 2. Development of the scallop, Patinopecten yessoensis.

- a) Sperm with granular middle pieces.
- b) After the first mitotic division. The part attached to the polar body denotes the animal pole. The egg nucleus is in the centre of the egg, and zona pellucida is at the outside.
- c) A part of the animal pole. Three polar bodies are formed by the second mitotic division.
- d) Before the first cleavage division the first polar lobe is formed.
- d') In some eggs the polar lobe is quite small.
- e) Formation of the cleft of the first cleavage division. The cleft does not enter the polar lobe at the vegetal pole.
- f) 2-cell stage. One large and one small daughter cell.
- g) Preparation for the second cleavage division.
- g') The second polar lobe appears (seen from the vegetal pole).
- h) 4-cell stage.
- i) 8-cell stage.
- i') 8-cell stage, seen from the side.
- j) 16-cell stage.
- k) Blastula. A few flagella appear on the outside membrane, and a rotation movement of the embryo can be seen.
- l) Trochophore. The mouth appears.
- m, n and n') Early veliger stage. Velum is formed, and the shell starts to be formed. n' is the frontal view of n.
- o) Veliger. The shell covers the whole body.
- p) Shell of prodissoconch larva. The surface of the left-side shell is shown.
- q) Shortly after the 'adhesion' period, the spat shell is formed except in the top part of the prodissoconch shell.
- r) The spat shell characteristic of this species is formed, and many typical signs of the dissoconch shell appear.

Magnification factors are: a - approximately 500; b - o, approximately 320; p - 70; q - 60; and r - 30.

aad - anterior adductor; an - anus; ap - apical cilia; bc - blastocoele; by - byssus; ft - foot; ls - left shell; lv - liver and pancreas (mesoderm); mo - mouth; ms - muscle; pb - polar body; pl - polar lobe; ps - prodissoconch shell; sg - shell gland; sp - spat shell; st - stomach; u - umbo; v - velum.

(Yamamoto and Fukushi, unpublished)

and salt concentration play a primarily important role. The optimum water temperature for the embryonic development has been reported to range from 10 to 15°C, the median being 12°C. At higher temperatures than the optimum, abnormal development has been frequently observed, whereas at lower temperatures the normal development has been delayed (Nishioka et al., 1949; Yamamoto et al., 1950). The effect of temperature on the rate of the embryonic development has been extensively studied in many other marine animals, and the case of P. yessoensis falls into the category (Patiria-Urechis type) described by Chase (1935).

The optimal salt concentration for embryonic development of the scallop varies from 30.0 to 40.0 ‰, the median being 37.0 ‰. This concentration is higher than that of sea water.

Table 1. Development of the scallop, Patinopecten yessoensis.

Stage	After fertilization	Optimum water temperature °C
Formation of the first polar body	5 hours	8.5 - 9.5
Formation of the second polar body	6	8.5 - 8.7
2-cell stage	8	7.8 - 8.0
4-cell stage	10	7.0 - 8.0
8-cell stage	16	7.0 - 8.0
16-cell stage	20	7.8 - 8.7
Blastula	40	7.5 - 8.3
Formation of blastocoele	2 days	8.0 - 8.9
Trochophore	4	7.8 - 9.2
Veliger, D-shaped larva		
72 × 58 μ	5 - 7	7.3 - 9.5
Ditto 104 × 87 μ	8 - 10	7.5 - 8.0
Ditto (second prodissoconch larva)	15 - 17	7.8 - 9.5
Umbo larva 118 × 104 μ		
Umbo larva 180 × 168 μ	22 - 28	9.0 - 13.0
Umbo larva 200 × 180 μ	30 - 35	11.5 - 13.7
Umbo larva (full-grown larva) 313 × 325 μ	40	12.2 - 14.2

c. Conversion from juvenile to adult life. The fully-grown larva undergoes a number of morphological changes during its juvenile life (the period of adhering to substratum) which usually lasts between 40 and 60 days. In Mutsu Bay the juvenile life starts at the beginning of June and ends at the end of July. By the end of this period the shell length reaches 6 to 10 mm. In other words, the shell length increases at a rate of 100 to 150 μ daily. This rapid growth is certainly aided by rising water temperature. From the end of July until the beginning of August, the fully-developed larvae fall down to the sea bottom and begin their adult life there. This change is accompanied by a number of physiological alterations, and accordingly the mortality rate during this conversion period is the highest of the whole life cycle.

Although a few scallops show mature gonads by the beginning of winter, most of them remain sexually immature until one year old. The author observed that the number of sperm found in the gonads of 6 one-year-old scallops with shell-lengths of 5.2 - 6.8 cm, was far less than that of adult scallops which were more than two years old.

The growth rate of scallop is shown in Fig. 3. The growth curve for the shell length levels off after three years, while that of the body weight becomes flattened after 4 years.

Before going into further discussions on the title of this booklet, I would like to define certain terms for a clear description of the different developmental stages of the scallop. The embryo before the veliger stage is called the Developing Embryo. Then the stage which has D-shaped shells and the one which has an elongated umbo are called D-Shaped Larva and Umbo Larva, respectively. This separation is not only based on morphological differences in the shell shape but also on the chemical composition of the shell between the two (Watabe and Yuki, 1952; Watabe, 1956). Up to this stage of development, the larva is planktonic and, therefore, is called Plankton Larva.

The larva which adheres to substratum is called Adhering Larva; the one which comes down to the bottom of the sea but is still less than one year old, Bottom-Living Larva; the one which is more than one year old but less than two years old, Juvenile Scallop; and the one which is older than the juvenile scallop, Adult Scallop.

(2) Formation of injury ring

When one examines the shell surface of scallops, the presence of conspicuous annual rings is easily recognized, particularly on the right shell. This ring is an 'injury ring' brought about by disturbances of shell growth. The injury ring is formed during the summer in Mutsu Bay (from June to September) when shell growth stops.

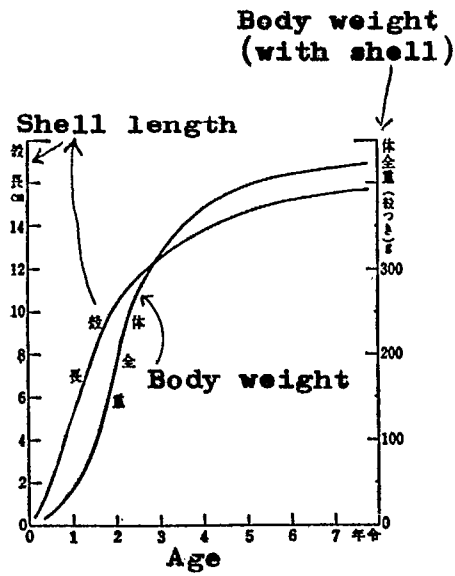


Fig. 3. Growth of the scallop, *P. yessoensis*.
The curves of logarithmic phase are seen for both shell length (up to 3 years old) and body weight (up to 4 years old). Thereafter both curves show a stationary phase.

On the other hand, in Hokkaido bottom-living larvae have been reported to stop growth at the end of November and to resume growth in May after the ice has melted away (Kinoshita, 1936; 1949). Therefore, formation of the injury ring takes place in summer in Mutsu Bay, while it occurs in winter in the coastal area of Hokkaido facing the Sea of Okhotsk. This difference is not quite as strange as one assumes, if one takes into consideration that the optimal temperature zone for normal life of this animal is rather limited.

Studies on the effect of temperature on the relative crawling speed of Mutsu Bay scallops showed that the relative speed increased with increasing temperature from 5 and 20°C; the movement was markedly reduced at temperatures lower than 4°C or higher than 22°C; the movement of flagella came to a complete halt at 0°C and irregular movements were frequently seen at 23°C (Yamamoto, unpublished data). These facts may explain some of the causes of the seasonal differences in the formation of the injury ring between Mutsu Bay and Hokkaido.

The injury ring is formed as a result of the presence of seasonal physiological rhythms in the life of the scallop. However, the formation of the injury ring is often brought about by drastic environmental changes. In Mutsu Bay the technique of "transplantation" has been used quite often as a means of propagating scallops. This is usually carried out by two methods: larvae of about 6 mm shell-length are raised in a nursery pond for approximately 4 months until they grow to 2 - 3 cm, then they are sown on the the sea bottom. Or a dense population of juvenile scallops of 5 - 7 cm shell length can occasionally be found on the sea bottom 40 to 60 m deep. They are collected and re-sown on the bottom of a more suitable area. In these cases the presence of conspicuous injury rings are always observed on the shell surface of the scallops when harvested (Fig. 4). As a matter of fact, in Mutsu Bay the formation of the injury ring in transplanted scallops has been used as a marker as to whether the transplantation had been successfully carried out.

(3) Variation of annual catch in the scallop fishery

It has been repeatedly reported that the annual scallop catch shows quite a wide variation from one year to another. Kishigami's report stated "an abundant population of scallops was found in Nobeji Bay about 35 years ago, though no detailed information could be obtained. But it is said that good catches lasted for only a few years. Also, good catches of scallops observed off the coast of Kawauchi village in the early Meiji era were reported to be reduced to almost nil within 3 years. A large quantity of scallops of about 2 years old was again found at a spot 78 fathoms deep and one mile off the coast of Nobeji village in 1890. A fishery for the scallops started in 1891, but in 1892 no significant catch was recorded. No evidence was given to show the presence of a sizeable colony of scallops off the coast of Aomori City until 1885

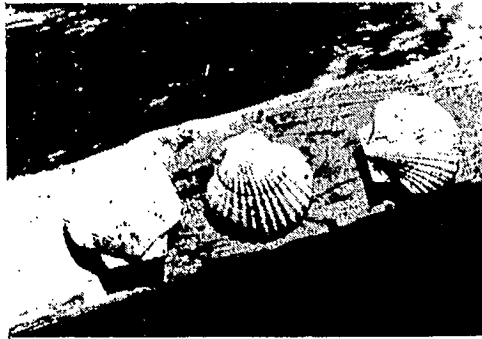


Fig. 4. Injury ring of shells from transplanted scallops. The scallops were transplanted at ages of 12 - 15 months, and were harvested one year later. The specimens were obtained at Nobeji, Aomori Prefecture.

when a large population of small-sized scallops was seen there. The Aomori Prefectural government immediately prohibited fishing of these scallops for a period of three years, and excellent growth was reported. Upon termination of the closed period in 1889, the scallops were allowed to be fished and the annual catch for that year reached 10,000 tons. In 1890 the harvest was sharply reduced, and in 1892-1893 specimens of large scallops were rarely seen". Frequent occurrences of this wide fluctuation in the annual scallop catches in Mutsu Bay are shown in Fig. 5. The sharp rise and fall in the annual catch is ascribed to indiscriminate fishing for scallops (Kishigami, 1896). Nishioka (1943), however, pointed out that there was a cyclic up and down in the annual catch, the duration of one cycle being 18 years.

A close examination of Fig. 5 reveals several interesting points: an extremely large catch reaching more than 10,000 tons a year occurs very suddenly, followed by a small annual catch ranging from 200 to 300 tons for many years and that after 1950 the annual catch has maintained a minimum of 1000 tons. This improvement in the minimal annual catch was apparently due in part to a voluntary refrain from fishing and also to progress in artificial propagation techniques.

The sudden rise in the annual scallop catch is believed to be a result of an explosive 'abnormal overproduction' or 'abnormal development' of this animal by several unknown factors. An abundant accumulation of the resources aided by abnormal overproduction is rapidly consumed by both large scale fishing and high natural mortality.

The wide variation in catch in the scallop fishery is by no means unique for Mutsu Bay but has also been observed for the Hokkaido district (Table 2). A similar pattern to this has been shown in the Hokkaido herring fishery and in the round clam fishery of Awaji Island. On the Atlantic coast of America the largest annual catch of Aequipecten irradians was recorded as 16,700 tons. However, in a poor year the catch is as low as 300 tons a year. On the Atlantic coast of Canada, the annual catch of Placopecten magellanicus has been reported to vary from 16.4 to 840 tons (Gutsell, 1930; Dickie, 1955), whereas in England that of Chlamys opercularis ranges from 200 to 1300 tons (Dakin, 1906).

(4) Factors influencing the amount of resources available for the fishery

As described in the previous chapter, one of the main causes of an extremely large annual scallop catch is the abnormal development of this animal in that year.

Mr. Koderu (personal communication), after his trip by a bathyscaphe to the sea-bed in 1956 told me, "It was an unbelievable sight to observe, millions of scallops were piling up on each other on the bottom of the sea as if there had been an invisible fence around them, and living

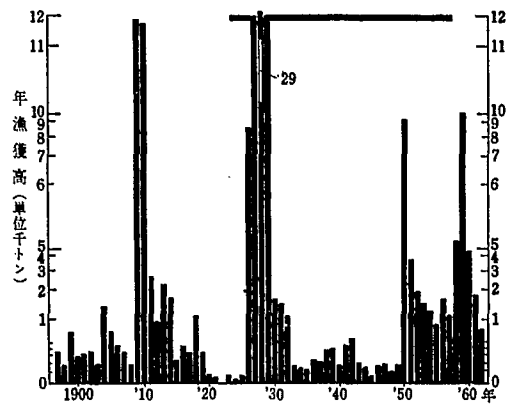


Fig. 5. Variation in annual scallop catch of Mutsu Bay (from Statistical Table of Aomori Prefecture). The ordinate shows the annual catch in 1000 tons, while the abscissa denotes the year. The annual catch in 1928 is marked on the upper part of the closed bar in numbers.

Table 2. Annual catch of scallops in Hokkaido in tons.
(Data provided by the courtesy of Mr. T. Wakui)

Year	Sea of Okhotsk	Coast of Nemuro City	Sea of Japan	Pacific coast	Total
1910	11,783	295	179	6	12,263
11	8,972	55	794	24	9,845
12	12,997	323	432	24	13,776
13	11,174	747	514	112	12,547
14	18,179	1,588	2,233	105	22,105
1915	37,359	7,793	244	158	45,554
16	5,693	1,557	926	169	8,345
17	1,873	...	1,202	609	3,684
18	2,738	1,028	1,299	182	5,247
19	1,225	1,262	10,732	303	13,522
1920	8,660	364	4,910	190	14,124
21	9,166	1,069	1,619	7	11,861
22	13,629	1,137	609	234	15,609
23	9,582	1,583	424	105	11,694
24	16,116	9,221	943	164	26,444
1925	24,029	11,727	658	111	36,525
26	17,997	9,914	69	142	28,122
27	17,979	9,831	150	111	28,071
28	20,726	5,502	226	110	26,564
29	15,903	8,739	797	105	25,544
1930	8,042	22,792	5,285	100	36,219
31	14,904	15,181	1,029	156	31,270
32	11,140	8,057	1,241	135	20,573
33	30,922	9,025	319	126	40,392
34	68,272	10,102	176	124	78,674
1935	59,587	8,270	41	114	68,012
36	35,914	8,984	115	182	45,195
37	31,675	10,954	47	164	42,840
38	13,803	10,529	328	78	24,738
39	18,195	4,716	3	141	23,055
1940	41,345	5,184	6	38	46,573
41	13,956	3,007	3	54	17,020
42	58,533	4,174	3	65	62,775
43	39,378	4,109	..	25	43,512
44	14,324	1,863	..	2	16,189
1945	918	84	..	6	1,008
46	8,279	1,604	..	5	9,888
47	7,216	1,845	..	126	9,187
48	5,602	1,572	15	187	7,376
49	13,650	279	..	142	14,071
1950	9,759	10	1	208	9,978
51	5,296	16	..	190	5,502
52	6,502	2,707	..	277	9,486
53	9,226	1,895	1	198	11,320
54	13,134	3,245	..	403	16,782
1955	10,115	4,198	..	242	14,555
56	7,215	3,754	105	547	11,621
57	11,838	2,920	..	499	15,257
58	12,912	1,599	..	406	14,917
59	9,017	1,633	..	891	11,541
1960	7,651	1,642	..	805	10,098
61	7,789	864	..	380	9,033

like a single giant creature having billions of small moving units on the surface of the body". This huge accumulation of scallops on the sea bottom was a result of abnormal development.

There are three possibilities to explain these abnormal developments: (a) abnormally large scale spawning, (b) production of extremely large quantities of adhering larvae, and (c) an unusually high survival rate of bottom-living larvae. I shall now present some experimental data to substantiate each one of these three possibilities.

It is conceivable there is an extremely wide variation in the production of spawn by scallops in Mutsu Bay, since a large fluctuation in the number of planktonic larvae has been observed. In order to investigate a possible cause of the variation of spawning of scallops, the number of ova or sperm held by the gonad was counted by the method of Belding (1910) (Table 3). A two-year-old female scallop holds approximately 1×10^8 ova in the ovary, whereas the ovary of five-year-old scallop contains 1.7×10^8 ova. If one assumes that one female scallop spawns 1×10^8 ova and that these ova develop to full-grown scallops without any loss, the total weight of all these adult scallops after 3 years will reach 20,000 tons. The largest annual catch of scallops recorded in Mutsu Bay was 30,000 tons. This amount could be produced by less than two female scallops, using the above assumption! The fact that an astronomical number of ova is held by a single female scallop certainly indicates the high potentiality of this animal for reproduction. Needless to say, however, this high potentiality is continuously being depressed by unfavourable environmental conditions which lead to a high mortality rate of the spawned ova. Therefore, the presence of large numbers of ova in the ovary of this species may also indicate inherently the presence of a high mortality rate during the various developmental stages.

It is quite possible that a large number of factors will affect the number of adhering larvae, such as inorganic environmental conditions during the developmental stage of planktonic larvae, quantity and quality of the food available for planktonic larvae, the number of planktonic larvae which are taken out of the bay due to sudden changes in the direction of tidal currents, quantity and quality of substratum, geographical location of substratum, etc.

It has already been pointed out briefly that the mortality rate of bottom-living larvae is the highest of any stage particularly in the early developmental stage, since the larvae undergo various physiological alterations during this stage. Since it seems that this last point plays a particularly important role in the variation of the annual scallop catch, it will be described in detail in a later chapter.

Table 3. Number of ova or sperm contained in a single ovary or seminal vesicle of the scallop, Patinopecten yessoensis.

Age	Sex	Shell length (mm)	Total body weight including shell weight	Gonad weight	Number of ova or sperm
2	♀	122	211 g*	39 g*	11,440 × 10 ⁴
2	♀	108	162	29	8,448
2	♀	111	191	37	11,000
3	♀	137	294	43	12,584
3	♀	127	282	40	11,704
3	♀	131	299	45	13,200
3	♀	126	288	44	11,088
4	♀	148	367	53	15,488
4	♀	156	352	59	17,248
4	♀	138	330	52	15,224
4	♀	142	341	61	17,864
5	♀	148	359	60	17,600
5	♀	149	381	62	18,128
6	♀	151	392	59	17,248
6	♀	152	420	64	18,744
2	♂	121	199	23	3,708 × 10 ⁹
3	♂	148	368	52	8,307
4	♂	156	381	56	8,928

* Fresh wet weight

4. Stimulation of spawning

(1) Annual change in the gonad of scallops

a. Structure of gonad. The sexuality of the Mutsu Bay scallop can be macroscopically determined by the colour of the visceral sac at about the middle of December. However, this becomes difficult from the end of May toward June. At this time the size of the visceral sac is only $1/4$ to $1/5$ of that in winter. The gonad of the scallop spreads all over the visceral sac, and the intestine runs through the gonad. At the peak of the breeding season the gonad extends toward the back and sometimes covers a part of the midgut gland.

The gonad consists of numerous elastic small vacuoles, each of which is made up by flat germinal epithelium and base membrane. Each vacuole is surrounded by loose connective tissue. No partition wall dividing the gonad into a left and right portion, is seen at all. However, the vacuole has an outlet duct which leads to a left and right renal duct. Thus, the products released from the vacuoles located in the left (right) side of the visceral sac will be brought into the left(right) renal duct. Discharge of the reproductive products is aided by a rapid opening and shutting movement of the shell.

b. Oögenesis and spermatogenesis. Appearance of a primary oöcyte in the ovary of the Mutsu Bay scallops takes place between the end of January and the beginning of February. In other words, the appearance of the characteristic sex colour of the visceral sac occurs when the ovum has attained more than half of its growth period. A period between early February and late March can be called a preparatory period for spawning, although no marked morphological change takes place during this period. In mid- to late May, several ova are always observable in the ovarian vacuole. Spawning of the Mutsu Bay scallop is completed by the end of May at latest.

A period of 5 months between June and October corresponds to the rest period of oögenesis. During this period the visceral sac shrinks and the ovarian vacuole becomes completely empty. The epithelial cell of the vacuole starts to show a rapid multiplication (cell division) from late October to early November, and oögonium can be seen in close contact with the epithelium. The oögonium is a large round cell and contains a nucleus which occupies a greater part of the cell. The nucleus contains chromatin granules that are located adjacent to the base membrane. The development of the oögonium starts with a thickening of the membrane at the base where it is in contact with the epithelium. This membrane is microscopically structureless and is palely stained with aniline blue. At this stage of development the stalk is formed at the base of oöcyte, and the stalk is filled with many small ducts. It is believed that nutritional materials are carried into ova through these ducts. A fully developed primary oöcyte

is separated at the stalk from the epithelium, becomes round, and is then dropped into the vacuole. Since a single vacuole is usually packed with many oocytes, each oocyte takes a polygonal, instead of round, shape due to pressure from adjacent oocytes.

The formation of sperm takes place at the same time as that of the ovum. In November the vacuole of the seminal vesicle is filled with spermatogonia, then in mid-January to early February fully-developed sperm are seen in the gonad. When the sperm are released into sea water at this time, they seldom show any activity. Activity of the sperm is demonstrable only after March (Yamamoto, 1943).

Under normal circumstances, fertilization takes place 40-50 days (30 days in case of sperm) after the ovum has become microscopically mature. Unfortunately, no study has been undertaken to examine any morphological changes accompanied by physiological changes occurring during this post-maturation period.

(2) Experiments on the stimulation of spawning

Artificial parthenogenesis is rather difficult to carry out in animals belonging to lamellibranch molluscs such as Tapes philippinarum, clam (Venus mercenaria), and scallop, but is easy only in Ostrea gigas. In the case of Tapes philippinarum, the main difficulty is that a small percentage of mature ova are available for fertilization. However, in the case of the scallop, when the ova from the ovary are placed in sea water, a majority of the immature ova (primary oocytes) undergo cytolysis. As a result, the sea water becomes contaminated with the contents of the ova, and this severely inhibits the processes of both fertilization and embryonic development.

On the other hand, in Ostrea gigas, when the ova are placed into sea water they change their shape from polygonal into round, and at the same time the first mitosis sets out. When the metaphase comes, the mature ova are ready for acceptance of the sperm. The easy onset of mitotic division of the ova observed in this species of animal does not occur in other shellfish.

In order to study the early embryonic stages of the Mutsu Bay scallop, attempts were made to establish a satisfactory method for artificial propagation.

a. Artificial propagation. When the ovary was cut and the ova were placed in sea water, most of the immature ova underwent cytolysis as described earlier. However, a sediment of a few mature ova was always recognized at the bottom of a container. This suggested that the specific gravity of the mature ovum was larger than that of sea water. As a matter of fact, determination of the specific gravity of the mature ovum gave a value of 1.028 at 15°C. Then, the ova were placed in sea water containing 5 - 10% distilled water. The mature ova quickly settled at the bottom of

a container and were easily collected by decanting the container. The matured ova obtained thusly were washed, and when sperm was introduced, 10 - 15% of the ova were fertilized.

The technique of artificial propagation, originally applied by Loeb in 1899 to sea-urchin, has been successfully employed on a variety of animals. Inaba (1936) induced spawning in Ostrea gigas by the use of 1/10 N NH₄OH. Also, the use of sea water containing ammonia has been tried with success for artificial spawning of Pinctada martensi (Wada, 1942), Tapes philippinarum and Venus mercenaria (Hatanaka et al., 1943). A solution of urea has been reported to be effective in Tapes philippinarum and Venus mercenaria (Motomura, 1934).

The ova of Patinopecten yessoensis were treated for 30 minutes with sea water containing $5 - 7 \times 10^{-4}$ N NH₄OH, then washed with normal sea water. When the washed ova were mixed with sperm, approximately 60% of the ova were fertilized (Table 4).

Table 4. Fertilization rate of the ova of Patinopecten yessoensis by treatment with sea water containing various concentrations of NH₄OH. The experiments were carried out from Apr 4 to May 10, 1943.

Concentration	Duration of treatment (min.)					
	10	20	30	40	50	60
1×10^{-4} N	10%	10%	28%	22%	23%	31%
3 x "	13	22	65	71	56	48
5 x "	11	19	63	72	50	45
7 x "	17	27	65	29	49	40
9 x "	20	25	50	81	29	52
10 x "	12	39	41	31	29	47

Strong bases such as NaOH could be used, instead of NH₄OH. However, in order to secure a high fertilization rate, either a high concentration of NaOH or a long duration of treatment had to be employed. This difference in the effect on artificial propagation is possibly due to a dissimilarity in the permeability into the ovum between the two bases.

b. Stimulation of spawning. The method of artificial spawning described in the previous chapter offers a convenient way to obtain larvae, but has several disadvantages. One of these is that intricate manipulation is required for a successful technique. Second, a complete washing of

chemicals used for treatment is mandatory, since both the ovum and larva of Patinopecten yessoensis are very susceptible to the action of chemicals. Last, it is well known that this method is not suitable for obtaining large quantities of larvae.

It has been reported that a rise in water temperature stimulates spawning in the female and male oysters, Ostrea virginica and O. gigas, that spawning in the female is further stimulated by the presence of a small amount of sperm from the same species and that spawning in the male is accelerated by the presence of ova not only from the same species but also from distant species (Galtsoff, 1930; 1938a; 1938b; 1940). Stimulation of spawning in the male oyster, Ostrea gigas, has also been reported to be induced by green algae such as Ulva (Miyazaki, 1938). Kinoshita et al. (1943) reported that spawning of female scallops Patinopecten yessoensis, was markedly stimulated by a combination of raising pH with NaOH and increasing temperature by 5°C. It was found later that the temperature treatment alone was quite effective in inducing spawning in both male and female scallops (Yamamoto, 1950a; 1951a; 1951c). A similar effect on spawning of female Aequipecten irradians has been reported (Sastry, 1963). A repeated sudden increase in temperature has been successful in stimulating the spawning of male and female Anadara broughtonii (Kanno, 1962). Not only the temperature treatment but also the following various agents have been employed for the stimulation of molluscs: KCl, electric stimulation, NH₄OH, NH₄Cl in female Mytilus edulis (Iwata, 1948a; 1948b; 1949; 1952); injection of NH₄OH into the ovary of Tapes philippinarum and Venus mercenaria (Sagara, 1958); and kraft mill effluent (sulfate process pulp mill waste) in female Mytilus edulis (Breese, 1963). Lubet (1956) has proposed a hypothesis that spawning of female Mytilus edulis and Chlamys varia is controlled by both outer and inner factors. His hypothesis was based on the observation that spawning was induced after the removal of the cerebroid ganglia. The ganglia probably secreted substances that inhibited spawning (this, he defines as the inner factor). The removal of the ganglia eliminated the inner factor, so the animal would have responded to the outer factor. It is not quite clear how the effect of temperature on spawning of certain species of molluscs can be explained by his neurosecretion theory.

The many agents used for the stimulation of spawning will be classified into two categories - physical and chemical. Because of a high susceptibility of the ova of Patinopecten yessoensis to chemical agents, the author has put the emphasis on the use of the physical method (temperature treatment) for the stimulation of spawning in this species. It cannot be denied that the addition of NH₄OH to the temperature treatment certainly increases the effectiveness. However, it has been observed that NH₄OH also increases the incidence of abnormal development of the embryos.

The author's method for the stimulation of spawning of the Mutsu Bay scallop will be summarized as follows: first, the female scallop should be close to the breeding period, and this can be judged easily

by an orange-red colour of the ovary. Both female and male scallops, 10 to 20 each, are kept at least for one-half day in a tank, water temperature of which varies from 4 to 9°C.

Then the scallops of both sexes are transferred into another tank where water temperatures are kept between 9.5 and 13.0°C. In order to avoid a decrease in temperature, a drop in pH resulting from respiration of the scallops and a lack of soluble oxygen, a large and shallow tank should be chosen.

After several hours under these conditions, spawning of ova and sperm is induced. Spawning of ova proceeds with the maturation of primary oocytes, then their transport into the oviduct, and spawning finally takes place (Yamamoto, 1951c). Development of a cloudy stream of light pink ova released from the mother scallop into sea water can be seen. Several spawnings (sometimes up to 10) occur from a single female scallop at intervals of 1 to 3 minutes. Spawning of sperm slightly precedes the spawning of ova. The occurrence of 60 spawnings from one male scallop at intervals of 40 to 50 seconds was recorded.

High percentages of fertilization ranging from 50 to 70% have been obtained. Within 20 - 30 minutes after fertilization, mucus and feces are filtered off, then the eggs are washed several times with clean sea water and transferred into breeding ponds containing clean sea water. Incomplete washing of the eggs often leads to contamination of the water with remnants of sperm and degradation products of the ova and to the development of Cyclidium, and both conditions are detrimental to the growth of planktonic larvae.

c. Maturation of ova by temperature treatment. A sudden increase in water temperature of 0.5 - 5.0°C causes spawning of ova in the female scallop and also promotes mitotic division of the oögonia, as described previously. This chapter will describe in detail other phenomena occurring at the same time.

In Mutsu Bay, February is the month that the ovigerous alveoli of Patinopecten yessoensis are full of primary oocytes and the seminal vesicles are full of sperm. Yet spawning ova and sperm are not normally observed until late March.

Why spawning of male and female scallops does not take place in early February is not known but may be due to some unfavourable environmental conditions or to unreadiness of certain physiological mechanisms involved in spawning. In order to explain this, a few observations were made on the optimum spawning temperature for scallops in Mutsu Bay. In Mutsu Bay the sea water temperature of the area where scallops normally inhabit is between 3 and 5°C during the month of February. In early February small portions of the ovary were cut out of scallops which had been kept at water temperatures of 4.5 - 5.5°C and immediately transferred

into heat-sterilized sea water, maintained at 7.8 - 10.6°C. After 2 to 24 hours the pieces were fixed with Bouin, Bensley or Carnoy solution, sliced and microscopically examined after Delafield-Eosin and Mallory triple staining. As early as two hours after heat-treatment in one ovary, 7% of the ova showed mitotic division, whereas none of the ova in the control ovary displayed mitosis (Table 5). Certain ova formed themselves into spheres and were brought into the ductules. At the same time, however, a small number of ova in ovigerous alveoli showed signs of degeneration (Fig. 6). No change in the pH value of sea water was observed.

Table 5. Stimulation by heat-treatment of mitotic division of the ova from Patinopecten yessoensis.

The observations were carried out on Feb. 8-Feb. 9 at Ohminato, Aomori Prefecture.

Duration of stimulation	2 hr	4 hr	5 hr	Control
Temperature	7.8-8.4°C	8.2-9.8	8.6-10.6	4.5
pH	8.2 ₅ -8.2 ₀	8.2 ₅ -7.9 ₅	8.2 ₅ -7.9 ₅	8.2 ₅
Animal No.	1	0.0%	7.1% *	0.0%
	2	2.2	2.7	0.0
	3	0.0	2.4	0.0
	4	2.7	0.0	0.0
	5	7.1 *	3.2	0.0
	6	2.3	0.0	0.0
	7	3.1	8.2	0.0
	8	6.6 *		5.7 *
	9	2.7		
	10	0.4		
	11	0.0		
	12	2.0		
	13	0.0		
	14	2.8		

* Degeneration of the ova was noticed

A similar observation was again made in early April. This time both Ringer solution for marine invertebrates (NaCl 2.5%, KCl 0.26%, CaCl₂ 0.23%, MgCl₂ 0.16%, NaHCO₃ 0.007%) and Duval's culture medium for marine invertebrates (1924) were used, in addition to heat-sterilized sea water. Ovarian pieces collected from female scallops that had been kept at water temperatures of 7.2 - 8.0°C, were transferred into the test solutions, temperatures of which were maintained at 13.0 - 13.6°C. After 2 hours of this treatment, 7 - 9% of the ova were shown to be in the process of mitotic division in all the media tested.

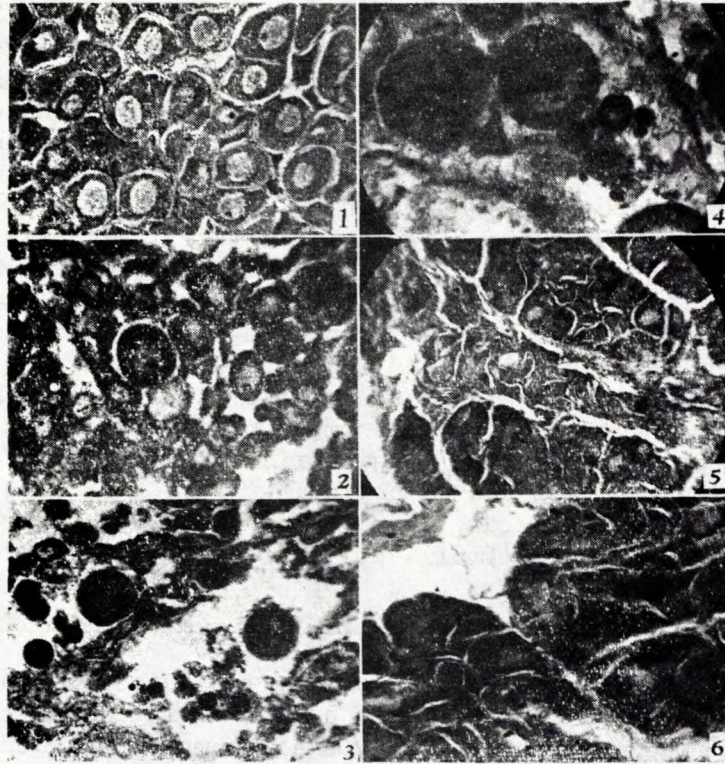


Fig. 6. Microscopic photographs showing mitotic division, ovulation and degeneration of ovarian tissue from Patinopecten yessoensis.

1. Before heat-stimulation (control), ovary containing primary oocytes. x ca 150
2. After 2 hours of heat-treatment, mitotic division starts. Ova form themselves into a sphere, and flows of cytoplasmic granules can be seen. x ca 150
3. Two ova are shown to be in the process of mitosis. x ca 150
4. Two ova after mitotic division flow into oviductules. x ca 200
5. Ovigerous alveoli displaying degeneration. x ca 100
6. Destruction of ova and the presence of pycnosis and large cytoplasmic vacuoles are seen. x ca 150

From the results of these two experiments, it has been concluded that (1) a water temperature of 8.0 - 8.5°C appears to be a critical regulating factor for the spawning of ova, as described by Kinoshita (1934), (2) a sudden increase in the water temperature promotes both maturation of the ova and ovulation. The effect can be recognized within a few hours after the heat-stimulation, (3) raising the pH value of a medium is not necessarily essential for maturation of the ova and ovulation, (4) neither nervous nor humoral factors are involved in maturation of the ova, since isolated ovarian pieces have responded to the temperature-stimulation (for discussion, See Wright, 1945; Kawamura & Motonaga, 1950; Kawamura & Ohtsuka, 1950, (5) spawning of female scallops is controlled by both physiological periodicity of the ovary and the environmental condition. However, if environmental conditions are met in accordance with requirements, spawning is possible even when the ovary is not physiologically in the spawning-time, and (6) degeneration of the ova has been accelerated also in the Duval's medium by temperature-treatment, and no difference has been observed in the number of destroyed ova between the centre and the periferal part of the ovarian piece used. Therefore, degeneration of the ovum was caused neither by a lack of oxygen nor by an accumulation of carbon dioxide. Each ovigerous alveolus probably responded differently to the stimuli applied (Yamamoto, 1951c).

(3) Variations in spawning in female scallops and environmental conditions

Ecological studies carried out by the author on spawning of Mutsu Bay scallops since 1941 have revealed a wide variation in the number of planktonic and adhering larvae. Only small numbers of both types of larvae were detected in 1942-1943, while extremely large numbers were observed in 1946-1948.

Although possible causes for this variation in the quantity of these larvae are quite complex to analyze, a primarily important factor would be the size of spawning by the female scallop, and a secondary factor may be a variety of developmental and environmental conditions which the larvae will be subjected to later.

There are possibly three controlling conditions which determine the size of spawning. The first one is the optimum water temperature for spawning. This has been found to be 8.0 - 8.5°C. The second is a rapid rise in water temperature. It was observed that a gradual increase in water temperature failed to effectively stimulate spawning, even though the stimulation was carried out during the peak of the breeding season (March to early May). In this case no single spawning was observed during the season, and a majority of the ova held by the ovary were quickly destroyed, absorbed then excreted in late May. The last condition is that a rapid rise in water temperature should occur during a period between March and early May. If the rise comes after that period, it will not effectively stimulate spawning.

The relationship between the change in water temperature and the quantity of planktonic and adhering larvae (Fig. 7), observed in Mutsu Bay during a period between March and May from 1945-1960, appears to offer supporting evidence to prove the validity of these three conditions. Appearance of large numbers of planktonic larvae was recorded in 1948, 1952, 1956 and 1957, whereas that of adhering larvae was detected in 1948, 1952, 1954, 1956, 1957 and 1960. The years of 1948, 1952, 1956 and 1957 are characterized by a rapid increase in water temperature above the optimum spawning temperature during the month of April. It is also seen that these years generally correspond to the years when large quantities of adhering larvae were observed.

These results may indicate the possibility that the quantity of planktonic larvae can be predicted by the shape of a rising curve of water temperature for a particular year. The quantity of adhering larvae may also be forecast by the temperature curve but with less accuracy than that of planktonic larvae, since it depends on both the long growing conditions of planktonic larvae and the delicate environmental conditions at the time of adhesion, both of which are much less predictable than the conditions required for spawning. It seems that further studies along this line will be required to increase the accuracy of prediction.

Amirthalingam (1928) reported the presence of a lunar periodicity in the reproductive cycle of the English scallop Pecten (Chlamys) opercularis. However, no such phenomenon has been found in Patinopecten yessoensis in Mutsu Bay (Yamamoto, 1952).

5. Feeding and breeding planktonic larvae

Recent rapid progress in the studies of breeding useful marine invertebrate larvae has not only aroused the interest of many marine biologists but also attracted considerable attention from commercial enterprises as a useful means of marine propagation. Since an excellent study on the English oyster Ostrea edulis by Bruce et al., (1940), a number of reports have been published on this subject on a variety of marine invertebrates, such as Crassostrea virginica (Loosanoff & Davis, 1950; 1963), Ostrea gigas, O. edulis, O. lurida, Spisula (Pseudocardium) sachalinensis, Notohaliotis discus and Stichopus japonicus (Imae et al., 1942; Imai & Hatanaka, 1949; Imai et al., 1950; Imai & Sasaki, 1961). Although the author has also been trying to establish a method for rearing scallop larvae Patinopecten yessoensis (Yamamoto, 1950a; 1950b; Yamamoto & Eto, 1950), it is felt that the method is still imperfect and that further studies will be required to improve it to the extent of being applicable on a large scale. Some results of experiments carried out in 1948 will be presented here, since no report has been available yet on the present subject.

a. Experiments on feeding larvae, done in 1948. The prerequisite to the successful feeding of larvae is to secure large quantities of

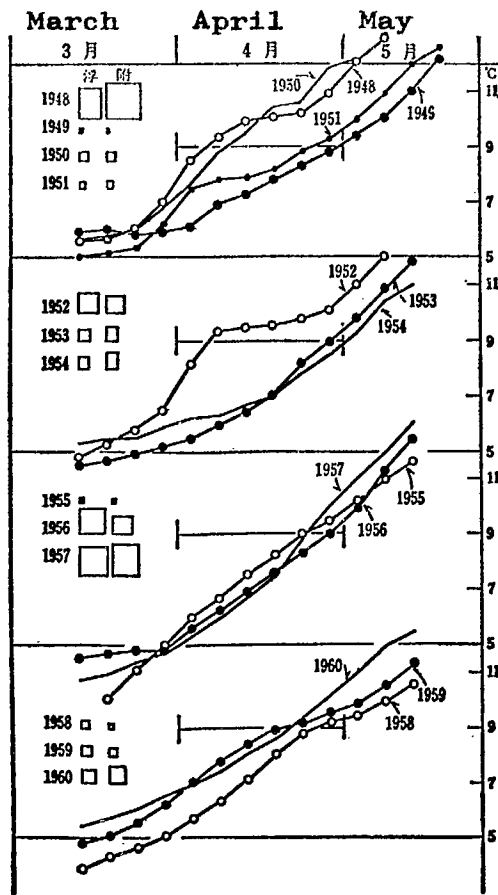


Fig. 7. Relationship between a rise in water temperature and the quantity of planktonic and adhering larvae of Patinopecten yessoensis.

The ordinate denotes the coastal water temperature at surface and the abscissa indicates a breeding season. The optimum temperature for spawning is marked by a horizontal line present at the centre of each figure. This surface temperature of 9°C has been corrected for the difference due to the depth of the sea.

The size of the open squares at the left side of each figure shows the relative quantity of planktonic (left square) and adhering (right square) larvae detected in a particular year.

(The data presented were obtained from Etoh, 1953; Sato, 1954, 1961; Kato, 1962; and a Report of Aomori Prefecture Mutsu Bay Marine Propagation Research Institute).

developing embryos preferably by the temperature-treatment described earlier. The developing embryos thus obtained were washed several times with filtered sea water and transferred into a concrete tank, 3 (length) × 2 (width) × 1.3 (depth) m. The proper number of embryos was found to be 2 - 5 per 10 ml sea water. Therefore, one tank of this size held 2 - 2.5 million embryos. No sea water was changed during the breeding period of 40 days except that a small quantity of fresh water was added from time to time in order to supplement the quantity lost due to evaporation. Tank water was stirred several times a day to supply oxygen and to hasten the decomposition of metabolic products from the embryos.

Selection of a proper food for the larvae was found to be the most difficult task of the whole experiment, since the larvae need microorganisms as food and since the quantity of the microorganisms reproduced did not meet the amount demanded by the larvae. After a long trial and error period, it was finally decided that the microorganism that appeared predominantly in an Erdshreiber's culture medium at 10°C, was fed every 2 to 3 days at a rate of 10,000/ml of tank water. This organism was distinctly different from the one, Monas sp., that Imai & Hatanaka (1949) used for feeding Ostrea gigas larvae. It was a perfectly round flagellated Protozoa with pale blue-green pigments in the body. Since it appeared to belong to the Protomonad, it has been called here Protomonad sp. When it was kept at room temperatures of 10 - 20°C in a culture flask facing a north window, a dense population of 200,000 to 500,000/ml was easily obtained. Contamination of tank water with organisms other than Protomonad, probably due to an incomplete filtration of tank water, was the source of constant worry, and the development of diatoms was often observed. In order to discourage their development, the tank was covered with a simple roof. A shortage of Protomonad in tank water was another source of trouble, and one time a small amount of rice-bran was wrapped in a piece of gauze cloth which was hung in the tank water in the hope that this might stimulate the reproduction of the Protomonad. However, this led to the disastrous result of increasing the quantity of organic contaminants. On another occasion, numbers of scallop larvae were eaten by the larvae of Aedes togoi which developed in the tank water.

Due to a number of difficulties, the number of larvae in the tank decreased rapidly, and after 30 days of feeding only 30,000-50,000 larvae of 200 μ shell-length were counted in one tank. At the end of the feeding experiment, however, 10-20 adhering larvae with a typical spatshell were found.

b. Possibility of artificial breeding. Further developments of the 1948 experiment into artificial breeding of Mutsu Bay scallops on a large scale had to be given up, unfortunately, due to lack of funds. Considering the current interest shown by the marine industry in this type of development around the world, it seems quite appropriate here to quote the statement made by Loosanoff & Davis (1963), that the fishery originally started with "hunting" (fishing), is now entering into the last stage of its development, the era of "cultivation" (breeding).

Although there will be many approaches to this problem, the primary step should be to secure ample supplies of fertilized eggs or developing embryos. Large numbers of experiments have been carried out on this problem, and there will be no difficulty in achieving a good result in this regard. The next step is to search for a suitable food for the growth of larvae. The recent review article of Hirano & Ohshima (1963) on this topic certainly will be beneficial to those who are interested in the subject. Protomonad sp. used by the author in the 1948 experiment is a mixotrophic food but, similar to Monas sp., rather strongly saprozoic. If Protomonad sp., along with its culture medium, is added into a tank, a large amount of organic metabolites will be released into tank water; which in turn may hinder the normal growth of larvae. Therefore, care must be taken that no culture medium but only protozoa is added to the tank water. Davis & Guillard (1958) studied the relative value of 10 genera of microorganisms as food for larvae of Ostrea virginica and Venus mercenaria and concluded that both Isochrysis galbana and Monochrysis lutheri equally provided the best value, that a combined feeding of these two microorganisms with Platymonas sp. and Dunaliella euchlora resulted in better growth than a single feeding, that Prymnesium parvum and Stichococcus sp. produced toxic substances to the growth of oyster larvae, that these two had almost no value as food for clam larvae, that flagellates which had no shells were excellent as food for oyster larvae during the early developing stage and that both Isochrysis and Monochrysis never produced toxic substances even at an extremely dense population. The sizes of Isochrysis and Monochrysis are $5.5 \times 3 \times 2.5 \mu$ and $7 \times 3 \times 2.5 \mu$, respectively. They also reported that the culture of these microorganisms was successfully carried out under 500 watts white fluorescent light at 19.0 - 23.0°C in sea water containing NaH_2PO_4 , NaFeEDTA , NaNO_3 , a trace amount of heavy metal salts and various vitamins. The best feeding results were obtained, when 100,000/ml of the microorganisms were fed to the spat up to 6 days old, then the number of organisms was gradually increased and finally 400,000/ml were given to 14-day-old larvae. In this case the number of larvae used in the tank was 10-15/ml of feeding water.

Also, Chaetoceros simplex var. calcitrans Paulsen isolated from a Skeletonema colony has been employed for sea-ear and clam larvae with great success (Umebayashi, 1961). This microorganism was cultured in a similar way to Isochrysis or Monochrysis: 6-7 millions/ml were obtained within 7-10 days under 10 watts white fluorescent light (500-1000 lux). If air was passed through the medium at a rate of 5 ml/min/l of culture, the culture could be grown much quicker than when no air was used. Some of the results described above should be taken into consideration if one attempts to carry out any experiment on breeding scallop larvae. It seems that the most urgent problem to be resolved is a choice of the most suitable microorganism as food for scallop larvae.

Next, the control of the inorganic environmental conditions of the feeding water has to be considered carefully, since scallop larvae are known to be very sensitive to changes in these conditions.

The fourth step is to provide facilities on a large scale for both breeding larvae and raising food organisms. Mere expansion of experimental arrangements will be insufficient in carrying out the industrial enterprise. Also, the establishment should be in a favourable situation. Uninterrupted supplies of female scallops, abundant supply of sea water and selection of a sheltered location are the minimal requirements for a successful industrial breeding of scallops.

6. Ecology of planktonic and adhering larvae

(1) Appearance of planktonic larvae and variation in their quantity.

In Mutsu Bay planktonic larvae of Patinopecten yessoensis can be collected usually between late March and late June, but the largest quantity is seen from late April to late May. The water temperature during this mid-season varies from 9 to 13°C. This temperature range coincides with the range of the optimum temperature for the development of the embryos (Fig. 7). The proper growth of larvae depends not only on the inorganic environmental conditions such as water temperature, but also on the quantity and quality of food (Protozoa). However, reproduction of these protozoa is also dependent on water temperature. Therefore, a small quantity of planktonic larvae in a year of low water temperature is probably the result not only of improper conditions for spawning but also a suppression of reproduction of protozoa such as Protomonad sp., dinoflagellates and diatoms. According to Negoro (personal communication), a large number of protozoa, more than 100 times the number of plankton represented by various shellfish larvae, are found in lakes, and the greater part of these protozoa belong to the class, diatom and Euglena. Therefore, under normal circumstances, it is quite conceivable that there are numerous types of plankton in the sea, and most of them serve as food for scallop larvae.

The relative quantity of planktonic larvae detected in Mutsu Bay for the last 10 years shows a wide variation: the years of large quantities of larvae are 1952 (2752/m³), 1956 (3800) and 1957 (4600), whereas the years of small quantities of larvae are 1953 (735/m³), 1958 (200) and 1960 (174) (Sato & Kodera, 1958; Sato, 1961; Kato, 1962). However, even the densest quantity observed in 1952 is far less than that found in 1935 at Lake Saroma in Hokkaido (1262/100 l) (Kinoshita, 1949).

(2) Horizontal distribution of planktonic and adhering larvae and its ecological implication.

In Mutsu Bay a dense horizontal distribution of planktonic larvae of Patinopecten yessoensis was spotted off the coasts of Kawauchi, Ohminato and Hamaokuchi (Fig. 8). In some years this dense population extends southward to the coast of Nobeji or westward into the Tsugaru Straits. Another large population is often found in an area west of the Natsutoma Peninsula, but the quantity detected in this area shows a very wide yearly variation (Yamamoto, 1950a; 1950b; 1950c; 1953a; 1953b; Sato & Kodera, 1958).

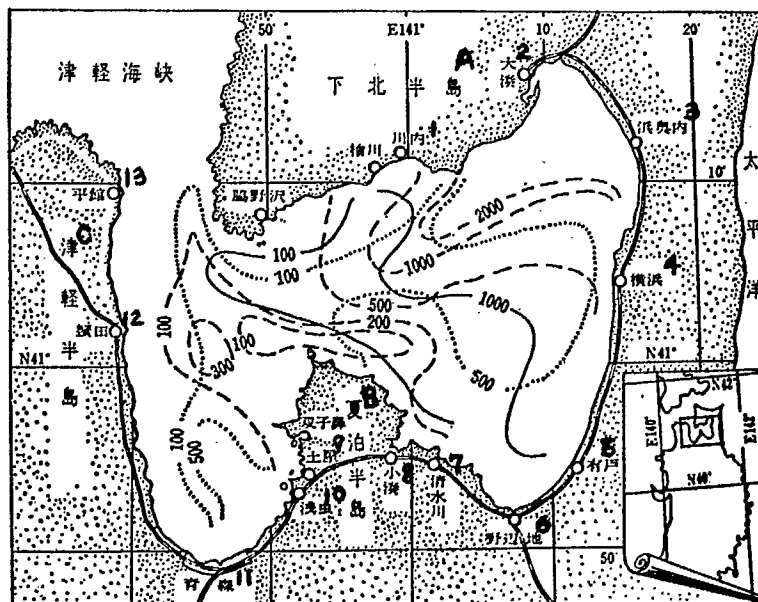


Fig. 8. Equivalent curve showing the number of planktonic larvae of Patinopecten yessoensis obtained by vertical hauls with a plankton net and by horizontal hauls with a wing pump during the months of April and May in 1948, 1950 and 1951.

The number of the larvae was computed per 1 cubic m sea water. The straight, dotted and interrupted lines denote the equivalent curve in 1948, 1950 and 1951, respectively. (A portion of the data was taken from Eto's report in 1953.)

A Shimokita Peninsula B Natsutoma Peninsula
C Tsugaru Peninsula

- | | |
|----------------|-------------|
| 1 Kawauchi | 2 Ohminato |
| 3 Hamaokuchi | 4 Yokohama |
| 5 Arito | 6 Nobeji |
| 7 Shimizugawa | 8 Kominato |
| 9 Futagonana | 10 Asamushi |
| 11 Aomori City | 12 Kanita |
| 13 Hiradate | |

It is of some interest to note here that a large quantity of adult female scallops are usually found off the coasts of Kawauchi, Nobeji and Yokohama and also around Natsutoma Peninsula. These planktonic larvae start to adhere to the substratum after 30 - 40 days. Therefore, quantitative distribution of full-grown planktonic larvae and adhering larvae does not necessarily correspond to that of all planktonic larvae. As a matter of fact, a large variation has been noticed in Mutsu Bay not only in the annual quantity of adhering larvae but also in their yearly geographical location.

The primary prerequisite condition for the transformation of planktonic into adhering larvae is, needless to say, that the planktonic larvae must be physiologically ready for adhering. This readiness is usually judged by shell length. As already described, planktonic larvae of 300-320 μ shell length are considered to be ready for setting.

The concentration of copper ion was reported to play a certain rôle in the setting of Crassostrea virginica (Prytherch, 1934). However, this did not hold true for Ostrea gigas (Imai & Hatanaka, 1949). In the case of Patinopecten yessoensis, copper does not appear to play any role because of an extremely low tolerance of this species to salts.

The author (1954) observed a large number of adhering larvae in the spot where a swirling movement of sea water was occurring or where a current was slowing down. In this context, it is of some interest to note the method which has been used for many years for catching clams. The method is simply to dig a trench at the base of a shoal and to collect clams after a certain period at the bottom of the trench. The principle of this method is probably to create a spot where the current slows down and/or where water runs in a swirling motion. If this is true, a good catch will be obtained by placing a net at favourable spots where these conditions of water movement are met. Also, the author often observed from a bathyscaphe a large colony of marine animals at an area where river water flows into the sea.

Of possible ecological significance for the transformation of plankton larvae into adhering larvae are physical conditions such as movement by current. This cannot be over-emphasized in view of the fact that in Mutsu Bay there is a wide geographical variation in the distribution of adhering larvae. For example, not many adhering larvae are found along the coast of Kawauchi where large numbers of adult scallops are caught yearly. On the other hand, large numbers of adhering larvae are caught along the coast west of Aomori Bay and yet hardly any number of adult scallops have been seen here. The consistent good catches of adult scallops year after year off the coast of Kawauchi may be due in part to the presence of numbers of large stones on the sea bottom which tend to create a slow and swirling movement of water, to difficulties in setting nets on the bottom and also to ample supplies of substratum.

Further analyses of the points discussed above certainly will lead to the establishment of an efficient way to collect larvae and will avoid the occurrence of a poor annual catch of nearly no adhering larvae due to indiscriminate use of nets all over the Bay.

(3) Mortality rate and physiological characteristics of bottom-living larvae.

Transformation from planktonic into adhering larvae occurs usually from late May to early June in Mutsu Bay. When the adhering larvae develop to 6-10 mm shell length, which occurs between late July and early August, they start to settle down on the sea bottom.

During the period of their adhering life, larvae are not permanently attached to a single substratum but repeatedly change the substratum according to their requirements, by simply cutting their byssus. During a period of three months, starting from August until late October, after the larvae have begun a bottom-living life, large portions of the larvae die. According to our observation (Yamamoto & Eto, unpublished), the survival rate of bottom-living larvae for the first two-month period was found to be only 5-10% off the coast of Nobeji. This low survival rate was later observed not only in the Nobeji district but all over Mutsu Bay (Yamamoto, 1954; 1955). In one district, Hamaokuchi, a completely zero survival rate was recorded. Such a drastic loss in the number of larvae during the early growing stage has been universally observed among other species of molluscs, such as Tapes philippinarum (Ito & Kogiso, 1954), and certain species of clams (Hiroshima Prefecture Marine Experimental Station Report, 1952; Hokkaido Marine Experimental Station Report, 1953; 1954).

Although the cause of this high mortality rate of bottom-living larvae of Patinopecten yessoensis during the early developmental stage is not known, the following facts may be of some importance. First, during the 3-month period between August and October when transformation of adhering into bottom-living larvae takes place, the water temperature is the highest of all year, and the temperature of the sea bottom 20-30 m deep where the bottom-living larvae ordinarily inhabit, is 20°C and sometimes reaches 23-24°C. Measurements by the method of Nomura & Tomita (Nomura, 1932; Nomura & Tomita, 1933) of the relative speed of ciliary movement at various temperatures showed that temperatures between 5 and 20°C were optimal for movement, that the mechanical activity of cilia stopped at about 0°C and that the activity was markedly inhibited at temperatures between 20 and 23°C. Although one cannot deduce the general physiological condition of an intact individual animal from the results of such simple experiments, the results appear to indicate that the time of transformation falls in a period of unfavourable environmental conditions.

Then, in order to examine the tolerance of bottom-living larvae to various environmental factors, the effect of several of these factors on the relative creeping speed (taken as a measure of physiological function) of the larvae was studied. Bottom-living larvae of 10-19 mm shell length and 2-year-old adult scallops of more than 100 mm shell length were used in the experiments (Yamamoto, 1956b; 1957a).

1. Effect of suspended silt. Air-dried silt obtained from the sea bottom, in concentrations of 0.05 to 3.5% at intervals of 0.5%, was suspended in sea water (17.00 cl‰, temperature 16.2 - 18.0°C, pH 8.3), and the creeping speed of small pieces (approximately 3 × 5 mm) of foot cut from scallops was measured in this suspended silt. The results were expressed as relative speed; i.e., the time required to cover a known distance at 0% silt concentration was taken as 100% (Fig. 9).

Creeping of larvae of 17-19 mm shell length came to a complete halt in a silt concentration of 0.05%. In this case the surface of the foot was completely covered with aggregates of about several hundred microns which were formed with silt and mucus. Larvae of 25-27 mm shell length showed a considerable degree of tolerance against silt. A similar experiment was also carried out on Crassostrea virginicus by Loosanoff et al. (Loosanoff & Engle, 1947; Loosanoff & Tommers, 1948) who observed a 95% reduction in the filtration rate of sea water and a nearly complete inhibition in the amount of soluble oxygen consumption at a silt concentration of 0.3 g/l.

2. Effect of low oxygen tension. Sea water was boiled for 1.5-2 hours then covered with liquid paraffin and allowed to cool. Oxygen tension of this sea water was measured by the Winkler method and found to contain only 1.5-1.7 ml, oxygen/l. Control sea water (17.00‰, temperature 13.5 - 16.0°C and pH 8.3) gave a value of 6.26 ml/l. The relative creeping speed of larvae 11-18 mm shell length in this low oxygen-tension water was 50% of that of adult scallops of 120 mm shell length, and the movement came to a complete halt after 20-30 min (Table 6).

Table 6. Effect of low oxygen tension on creeping of three different developmental stages, of scallops, Patinopecten yessoensis.

Development, shell length (mm)	Relative speed after 15 min	Time required for a halt of creeping (min)
11-18	21.7(15.4-28.0)* %	20(13-37)*
23-27	43.3(38.7-48.0)	30(22-34)
120	40.0(38.2-41.9)	45(36-53)

* 95% confidence limits

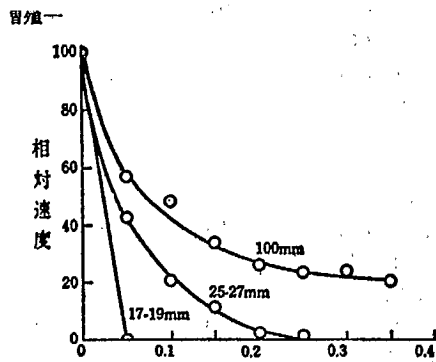


Fig. 9. Effect of suspended silt on the relative creeping speed of small pieces of the foot from scallops, *Patinopecten yessoensis*, of three different developmental stages (shell length 17-19 mm, 25-27 mm and 100 mm).

The ordinate indicates the relative speed and the abscissa shows concentration of suspended silt (dry weight) in percentage.

Studies on the oxygen consumption by scallops Patinopecten yessoensis (Yamamoto & Eto, 1950) showed that the consumption by spat was three times as much as that by adults and the consumption by adults decreased rapidly at oxygen tensions less than 0.34 ml/l, while the decrease occurred at tensions less than 2.52 ml/l in spat. These results clearly indicate a very low tolerance to low oxygen tension by scallop spat compared with adults.

3. Effect of sudden temperature change. Experiments were carried out in both February and September. In the former case, scallops were kept initially at 5°C, while in the latter experiment at 20°C (Table 7). In the September experiments, the relative speed of adult scallops was 16% of the control when the water temperature was decreased by 5°C, whereas that of spat showed only 3% of the control under the same condition. Then when the temperature was suddenly decreased by 10°C, the speed by the adult was 12% of the control, but crawling nearly halted in the spat. This table indicates a low tolerance of spat to sudden temperature changes.

Table 7. Effect of sudden temperature changes on the relative creeping speed of two different developmental stages of scallops, Patinopecten yessoensis.

Initial temperature	Experimental temperature	Adult scallops 110-140 mm shell length		Spat 10-13 mm shell length	
		100%	125%	100%	125%
5°C*	5°C	100%	100%
"	10	16.2	17.3
"	15	11.0	11.6
"	20	10.0	7.9
20°C**	5	11.7	9.2	0.0%	0.1%
"	10	12.0	11.9	0.8	0.6
"	15	16.0	16.4	3.4	3.0
"	20	100	100	100	100

* February experiments

** September experiments

4. Effect of other factors. Determinations of oxidation-reduction potentials of scallops showed the presence of a significant difference in the rH value (at pH 7.0) between spat (14.3 for larvae of 11-18 mm shell length and 8.9 for larvae of 23-27 mm shell length) and adult scallops (5.7 for scallops of 100-120 mm shell length).

All these data clearly indicate a very low tolerance of the scallop spat to a variety of environmental conditions, as compared with the adults. It seems that scallop spat are inevitably destined to a high mortality rate in order to survive, to acclimate themselves and finally to become adults.

7. Methods for rearing scallop spat

Artificial rearing of scallop spat under more favourable conditions than the natural environment might result in a reduction of this high mortality rate of spat during the early developmental stage. We have been investigating this topic for some time, and the results will be shown here, though the investigation has not been completed yet.

(1) Rearing in tanks and pools

Nishioka, et al. (1949) carried out an interesting experiment in an attempt to propagate scallop spat transported from Lake Saroma in Hokkaido to Mutsu Bay. A shallow metal cage (48 × 63 × 42 cm), the bottom of which was made of concrete, was placed at the base of a pool. The pool was a cave hollowed in a reef and was 0.6 m deep at ebb tide. Two outlets were provided which were flush with the low tide line so that the inside water could be exchanged freely with the outer sea water at the time of flood tide or in rough seas. Ten scallop spat of 10 mm shell length were kept in this pool for a period of 10 months. Of 20, 5 died, but the remainder grew to spat of an average shell length of 47 mm.

This result prompted us to carry out feeding experiments of scallop spat in tanks. Concrete tanks of 1.8 × 2.7 × 1.5 m deep, the capacity of which was approximately 7 tons of sea water, were provided for rearing 10,000 spat of an average shell length of 5 mm per tank. Into each tank 1 ton of sea water was poured every 3 hours with a pump. The tank had a discharge outlet at the top, opposite to the pump, therefore, water ran freely inside the tank. However, excreta from the spat, food remnants and silt were deposited at the base of the tank particularly the four corners, at the end of a 4-month period.

Again selection of the proper food for the spat was a difficult problem, since controversial opinions exist in this respect. For example, Kinoshita & Hirano (1935) discovered diatoms and phytomastigina in the contents of the stomachs of scallop spat Patinopecten yessoensis. However, it is well known that these phytoplankters are quantitatively not important as food for molluscs such as the oyster Ostrea edulis under natural conditions (Korringa, 1949). On the other hand, Sawano & Hasegawa (1954) concluded from their histochemical studies that chlorophyll in the compressed juices of white clover was taken up by phagocytes of the digestive system of scallop spat.

Therefore, the following comparative studies were carried out to determine a possible best food for scallop spat. The spat in tank 1 were

fed sediments of Chaetoceros sp. and Rhizosolenia sp., both of which were caught by horizontally towing a net in Ashizaki Bay in Ominato, and Skeletonema and Nitzchia, both of which were cultured in our laboratory, in total quantities of 450-500 ml. In tank 2, 500 g of white clover juice was added. No substance but sea water was poured into tank 3. Analysis of sea water pouring into the tanks contained approximately 200 ml of sediments per ton of water, which consisted of broken plankton and detritus. Tank 4 served as a control, into which sea water was poured through double layers of calico filter. However, since a majority of the spat in tank 4 died within a week of the experiment, the use of this tank was discontinued, and tank 3 was employed then as a control.

After 4 months, the spat grew to sizes of 20-25 mm shell length (Fig. 10), and the survival rates of the spat in tanks 1, 2, and 3 were found to be 84.5%, 92.9% and 64.2%, respectively. It is of particular interest to point out here that the survival rate of the spat in tank 3 (control) was very high (Yamamoto, 1955). Further studies along this line might bring an efficient method for rearing scallop spat under natural conditions.

Further experiments were carried out to examine the possibility of breeding in a pool. The pool selected for the experiments was the same as used by Nishioka and his colleagues in their report (1949). The pool had an area of 48 m², and the depth of water at flood tide was 1.5 m. The base was covered with sand and detritus. In late July, 1500 scallop spat, 3.2 mm shell length, were added to the pool, and daily feeding of 1.0-1.5 Kg clover juice was begun. During the months of July and August the pool was covered with marsh-reed screens to cut down the amount of direct sunlight, so that the inside water temperature of the pool was nearly the same as that of the sea.

The spat grew very well in the pond and in late September an average shell length of 9 mm (the largest one was 14 mm) was obtained. However, one day in late September the district was struck by a typhoon which introduced cloudy dirty sea water into the pond and also stirred up the bottom silt. The results were indeed destructive; nearly all the spat died, the outlet-inlet pipes of the pond were partially destroyed, and the experiments had to be abandoned. Unfortunately, we were not able to repeat the experiments. However, it is my strong belief that successful rearing of scallop spat in tanks and ponds is feasible. There are, of course, a few problems to be answered before the goal is attained.

First of all, facilities for breeding spat on a large scale have to be carefully contemplated. Recent progress in the science of marine engineering will eventually be able to resolve seemingly incompatible requests of having free and ample supplies of plankton from the sea and at the same time not having the deleterious effects from the sea, such as stirring of the tank or pond water due to storms.

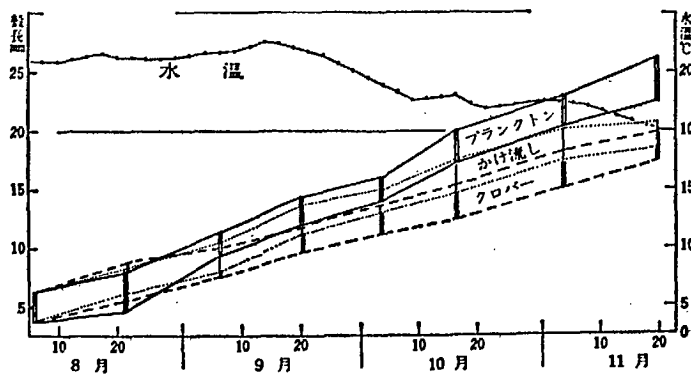


Fig. 10. Growth (represented by shell length) of the scallop spat, Patinopecten yessoensis, bred in tank. See text for details.

The left and right ordinates show shell length in mm and water temperature, respectively. The abscissa denotes the calendar month, starting August to November. The vertical lines indicate the lower and upper limits of shell length measured at a particular time. The columns enclosed by solid, interrupted and dotted lines represent the experiments in tank 1 (plankton), tank 2 (clover juice), and tank 3 (control), respectively.

Next, an ample supply of food for spat should be procured. Two different kinds, natural and synthetic foods should be available. Rapid expansion of our knowledge of the biochemistry of algae has made it possible to culture large quantities of natural food. Also, recent developments in animal nutritional physiology will render it feasible to manufacture synthetic foods. However, the role of the synthetic food will be in supplementing any shortage of natural food, whenever this occurs, and complete reliance for feeding spat on synthetic food may not be necessary.

In connection with feeding, it is of some importance to select a way in which the food will be effectively utilized by the spat. According to our experiments which were carried out to determine whether there was a diurnal variation in food intake by scallop spat, using the Cole & Hepper (1954) method of measuring filtration rate, the filtration rate (taken as the food intake) of both spat and juvenile scallops started to increase toward evening, reached a maximum at about midnight (Fig. 11), and showed the lowest rate during daytime (from 9:00 to 13:00). The filtration rate of Patinopecten yessoensis measured by this technique, the daily maximum value being 0.032 ml/hr/g soft body weight of spat, appeared to be approximately 1/20 of that reported on Pecten irradians by Jørgensen (1949). From these results the recommended time for feeding appears to be any time after dusk.

(2) Breeding basket

Kodera et al. (1958) first tried using hanging baskets similar to those employed in culturing pearl-oysters, for rearing scallop spat. Adhering larvae immediately prior to their transformation into bottom-living larvae were placed in a basket that was then hung in the sea. When the benthos grew to shell lengths of 2-3 cm, they were released in the open sea. The original basket was made of wood, 90 x 60 cm, 30 cm deep. The bottom and both sides were covered with Saran screens, 1000 denier, 16 meshes. The basket was filled with 1000-3000 spat, fixed at a position just under the sea surface, and left there for several months. Later the wooden frame was replaced with a vinyl pipe frame then with iron bars of 6 mm diameter and pearl net. Also, the surface setting was changed to a hanging setting. These changes certainly reflected an improvement in the breeding results. In 1954 when the experiment was initiated, an average gain in shell length during three months of rearing was 17 mm and the survival rate was approximately 50%, whereas in 1959 an average shell length of 22 mm, and survival rates varying from 60 to 94% were obtained (Kodera et al., 1961).

Spat reared in baskets were then released into the open sea in late November. Although no detailed report has been made available on the growth and the survival rate of these released spat, a considerable number of them appeared to be dead by next spring, but in certain favourable sheltered spots a survival rate of approximately 50% was recorded (Yamamoto & Tanaka, unpublished data). Thus it appears advisable to release the spat in sheltered areas to ensure their good growth. After several months, they may be released into any fishing area.

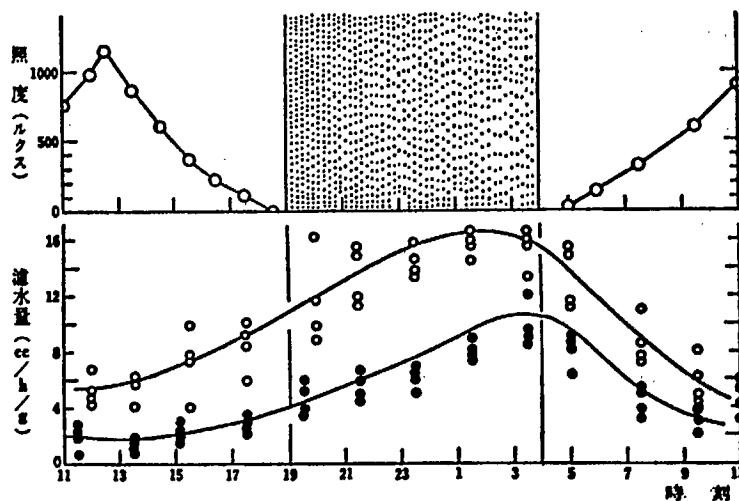


Fig. 11. Diurnal variation of the filtration rate of the scallop Patinopecten yessoensis.

The upper figure shows changes in illumination (in lux), while the lower figure shows the filtration rate in ml/hr/g soft body weight of spat or scallop. The abscissa indicates the time of the day on the basis of 24 hours. In the lower figure, the closed circles demonstrate the filtration by juvenile scallops of 4.2-6.6 cm shell length, whereas the open circles denote that by spat of 1.0-2.5 cm shell length. The water temperatures for the juvenile scallops and for the spat varied daily from 16.3 to 18.3°C and from 14.5 to 17.9°C, respectively.

(3) Breeding under natural conditions

As pointed out repeatedly, relatively large numbers of bottom-living scallop larvae have been frequently recorded in certain areas of Mutsu Bay. Therefore, if scallop spat are seeded in these favourable areas without rearing in tank or pool, these spat might grow to such an extent that they may be later transplanted into the main fishing grounds or they may be harvested later in the year. One might expect to avoid the high mortality rates of spat by this means. The author has tentatively called the method "Natural Rearing". Studies on the practicability of natural rearing were initiated by us in 1952 at the districts of Nobeji and Kawauchi. In early August, adhering scallop larvae which had just started their benthic life, were placed in baskets that were then sunk on to the bottom of the sea. Submarine observations were made after 2 months to count the number of spat surviving in the baskets. A maximum survival rate of 18% was obtained in Nobeji district.

This experiment was later repeated twice. In one experiment, the marker indicating the location of the baskets was lost, and in another experiment all the spat in the baskets suddenly disappeared at the end of August. It is not known whether all of them died or escaped from the baskets.

8. Favourable habitats for scallops and problems of transplantation

(1) Distribution of marine benthic fauna and favourable habitats for spat and adult scallops

a. Distribution of fauna. Nishioka and Yamamoto (1943) reported after their surveys on the distribution of Patinopecten yessoensis, geology of the sea-bed and fauna of submarine benthos at 87 different spots of Mutsu Bay, that the distribution of scallops was limited to the coastal areas, that scallops inhabited the sea-bed at 6-30 m depth and the bottom of the areas where scallops were found in large number consisted of gravel containing less than 30% of silt, the diameter of which was smaller than 0.1 mm. They, however, cautioned that the geological composition of the sea bottom was not necessarily a deciding factor for the distribution pattern of scallops. Similar surveys were later carried out on 24 more spots, and Mutsu Bay was divided into four faunal districts based on these observations (Fig. 12). These divisions were made, on both the number of each benthic animal species per 1/4 m² detected at a particular area and the frequency of appearance of the same species of animal in all the Bay area, using the methods of Motomura (1935) and Kato & Toriumi (1950).

District I occupies the entrance of Mutsu Bay and is characterized by the predominant appearance of Dentalium makiyamai and D. octangulatum (both 22%), followed by Telepsavus sp. (14%). Also, the presence of the

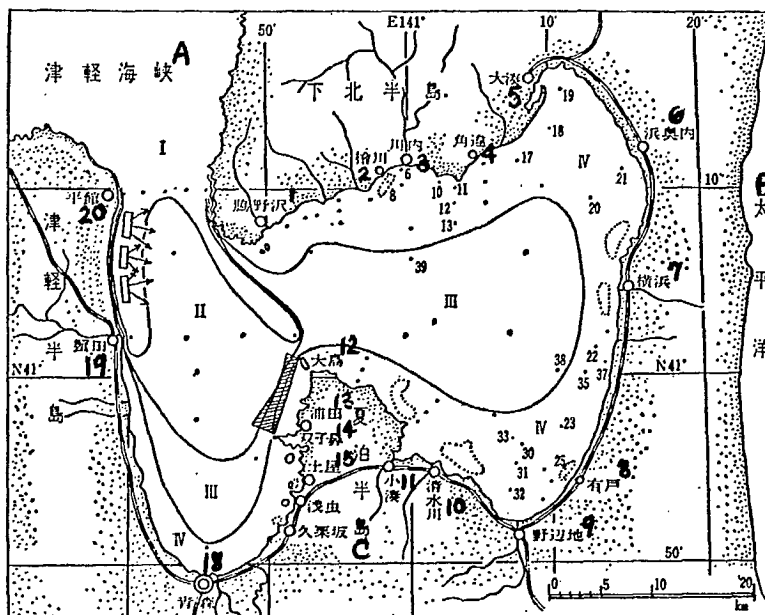


Fig. 12. Map of Mutsu Bay divided into 4 faunal districts, determined by the frequency of appearance of benthic animals.

District IV (coastal area) is considered to be a primary living site of Patinopecten yessoensis. Along the coast between Tairadate and Kanida (District I), transplantation of scallop spat failed; which is shown by the arrows in the map. Certain areas of District IV are enclosed by dotted lines. Judging from the distribution pattern of both Pepidopleurus assimiles and Echinocardium cordatum (see later part of text), these areas are considered to be the site where a large number of spat are likely to survive. The shaded area located off the coast of Ohshima down to Futagonana, is noted by the frequent occurrence of abnormal development (for example 1956).

A	Tsugaru Straits	B	Pacific Ocean	C	Natsutoma Peninsula
1	Wakinozawa	2	Hikawa	3	Kawauchi
4	Kakuchigai	5	Ohminato	6	Hamaokuchi
7	Yokohama	8	Arito	9	Nobeji
10	Shimidzugawa	11	Kominato	12	Ohshima
13	Urata	14	Futagonana	15	Tsuchiya
18	Aomori City	19	Kanida	20	Tairadate

following molluscs is the feature of this district: Chama reflex, Cyclocardia ferruginea, Carditellopsis toneana, Anodontina stearnsiana, and Turcica coreensis. The submarine fauna of the district is rather complex and appears to be oceanic. The district has a sandy bottom and the depth varies from 60 to 70 m.

A greater part of submarine animals in District II is Dentalium makiyamai (53%), followed by Telepsavus sp. (24%) and Maldane sarsi (12%). A small number of Dentalium octangulatum, Axinopsida subquadrata, Acesta goliath, and Nuculana yokoyamai are also found in this area. The fauna of this district is relatively simple. The sea-bottom in the district is completely covered by fine silt (less than 0.1 mm diameter), and the depth of the district varies from 50 to 60 m.

District III shows the simplest fauna in Mutsu Bay; it is composed of Maldane sarsi (80%), Ophiophragmus japonicus and O. mirabilis (2%), and small numbers of Modiolus difficilis, Modiolus elongatus and Montacuta oblongata. It occupies a large area at the centre of the eastern Bay, and abnormal development is sometimes found in a part of this district adjacent to District II. The nature of the bottom of this district is mainly (70-90%) fine silt, and the area is approximately 40 m deep.

District IV is the coastal area of the Bay, and the fauna is quite diverse; i.e., Ophiura sarsii (22%), Telepsavus sp. (17%), Echinocardium cordatum (14%), and various molluscs such as Pillucina pisidium, Wallucina lamyi, Lucinoma annulata, Saxidomus purpuratus, Theora lubrica, Acropagia subtruncata, Macoma tokyoensis, M. incongrua, Fabulina minuta, Raeta pulchella, Anisocorbula venusta, Cantharidus jessoensis and Patinopecten yessoensis. Scallops occupy about 0.7% of the fauna of this district. The bottom is composed of sandy silt, gravel, or sandy silt containing pieces of broken shells. Certain areas of this district are characterized by a very slow current (Yamamoto, 1950c; Yamamoto & Habe, 1958; 1959; 1962).

Although no single factor can be attributed to the formation of such benthic fauna, it is of interest to point out the presence of certain differences in the salt concentration of the water at the bottom among the four districts. This was found out by six different surveys carried out between 1947 and 1948. The concentrations in Districts I, II, III and IV were found to be more than 32.60 ‰, 32.40-32.60, 32.00-32.40 and less than 32.00, respectively (Yamamoto, 1950). However, it appears that the formation of the fauna districts is dependent on physico-chemical factors resulting from convection of oceanic and coastal water rather than the salt concentration of sea water.

b. Detection by transplantation of favourable habitats for scallops.
It has already been noted that District IV offers the best sites for scallops. This was confirmed not only from the fact that scallops have been caught in large numbers in this district but from the following transplanting experiments of scallop spat.

Large numbers of one-year-old scallop spat of 4-6 cm shell length found off the coasts of both Futagonana and Nobeji were transplanted into various parts of Mutsu Bay. During several surveys conducted to examine the survival rate of these transplanted spat, several problems were brought to our attention. One of them concerned the adherence of Balanus trigonus upon the shell of the spat. It was argued that this marine animal might compete with the spat for food. However, later observations revealed that in many cases this adherence was not permanent but temporary. A majority of the spat transplanted into Districts I, II and III was either lost or dead, and only in District IV did they survive and grow in a satisfactory manner (Yamamoto & Eto, 1951; Yamamoto, 1951b).

The results of these surveys indicate the importance of the need for careful consideration of the adaptability of a transplanted animal species to a new environment. If the animal belongs to a member of the animal community of the new location, there will be no problem. Otherwise, a successful transplantation appears to depend on the degree of tolerance or adaptability of the transplanted animal species. At the same time it has to be remembered that introduction of a new species of animal into an area may markedly affect the communities of the existing area. In this context it seems to be of some importance to describe here a variety of changes in the benthic communities in District IV of Mutsu Bay observed for a period of 3 years after transplantation of scallop spat (Yamamoto, 1951b).

(2) Further division of District IV and favourable habitats for scallop spat

There are in Mutsu Bay two areas which are noted to show a high survival rate of scallop spat. In one of the two, located off the coast of Nobeji, detailed investigations were carried out to determine the ecological features of the area. No specifically unique inorganic environmental features were noted in this area except that the bottom of the area was composed mainly of gravel with a small amount of silt and the depth of the area is less than 20 m. However, this area was characterized by the frequent appearance of Lepidopleurus assimilis and Gammarus sp. and by the infrequent appearance of Echinocardium cordatum and Pectinaria hyperborea, in addition to the dominance of those benthic animals described earlier.

In another area, off the coast of Kawachi, a similar pattern was observed in the appearance of benthic animals. On the other hand, an area, off the coast of Hamaokuchi, known to show a very low survival rate of scallop spat, was characterized by the dominance of Echinocardium cordatum, followed by Pectinaria hyperborea and Theora lubrica. The bottom of this area consisted of soft silt, and the depth was less than 20 m.

From these findings further investigation was felt to be necessary. In District IV, 39 more new sites were surveyed to examine the detailed benthic fauna of this district by the same method as described previously (Fig. 12). The dominance of Ophiura sarsii, Mardane sp. and Dentalium makiyamai was a common feature of all the spots surveyed. On the other

hand, the frequency of appearance of the following benthic animals showed quite a wide variation: Lepidopleurus assimilis, Echinocardium cordatum (Fig. 13), Pectinaria hyperborea, Gammarus sp. and Patinopecten yessoensis. Of the 39 points surveyed, spots where the individual number of each one of these species of animals, expressed as a percentage of the total number of the benthos found at the same spots, was unusually high, were selected and classified according to the species of animal using the method of Kato et al. (1952). The survey spot where the 60% confidence limit (the vertical lines in Fig. 14) did not intersect with the horizontal line for a given species of animal was taken to be significantly different from the others. According to this classification method, District IV of Mutsu Bay is further divided into the following three subdistricts: I, where significantly large numbers of Lepidopleurus assimilis and Gammarus sp. are observed; III is rich in Echinocardium cordatum and Pectinaria hyperborea; and II is an intermediate zone between I and III. These three subdistricts are arranged in Mutsu Bay to form a mosaic pattern. Subdistrict I occupies an area of District IV where the current is constantly moving, and it is considered to be the most favourable site for survival of scallop spat. On the other hand subdistrict III appears to be an unsuitable area in this regard (Fig. 12).

Lepidopleurus assimilis is a benthos animal which crawls on gravel or shells, eats algae present on the surface of these objects and prefers to inhabit an area of constantly moving current. Gammarus sp. is a crustacean animal of similar nature. On the other hand, both Echinocardium cordatum and Pectinaria hyperborea inhabit mud and, accordingly, they are detritus feeders. There will be no doubt that these differences on the sea-bottom play a certain important role as a deciding factor in the survival of scallop spat. Certain species of lamellibranchs, such as Theora lubrica, are frequently found in a site where a current is stagnant and, therefore, it may be used as a biological marker for locating such an area (Yamamoto & Habe, 1959).

(3) Oxidation-reduction potentials of the bottom of scallop spat areas

The results of the surveys for benthic animals in Mutsu Bay strongly indicate that the nature of the sea-bed has an important bearing not only on the distribution of certain species of animals but also possibly on the survival rate of scallop spat. Measurements of oxidation-reduction potentials of the ocean bottom were pioneered by Nomura and his coworkers (Nomura & Kagawa, 1947; Nomura 1952; Nomura et al., 1955). Although the ecological significance of their studies has not been fully realized by many research workers, there will be hardly any doubt that not only the quantity but also the quality (oxidation-reduction potentials) of organic matter in the bottom affects the metabolism of all benthic animals.

The apparatus used for our studies is shown in Fig. 15, (1) a platinum electrode (Pe), inserted into the bottom of the sea. The electrode was prepared by sealing a platinum plate (Pt) into a glass tube held by a steel frame. A lead disc (L) was attached to the unit to avoid the

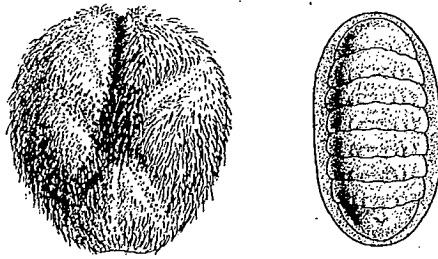


Fig. 13. Benthic animals, Echinocardium cordatum (left) and Lepidopleurus assimilis (right), known to be a biological marker in Mutsu Bay for predicting the survival rate of the scallop spat Patinopecten yessoensis.

The left figure is about life-sized, while the right is approximately 5 times as large as the actual size.

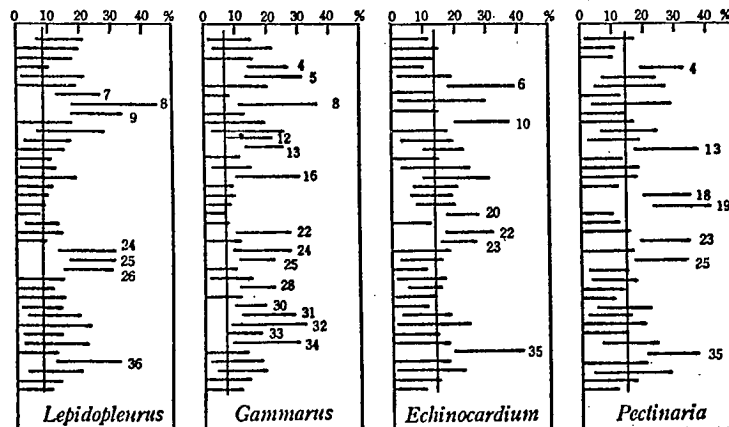


Fig. 14. Confidence limits of the percentage of individual number of Lepidopleurus assimilis, Gammarus sp., Echinocardium cordatum and Pectinaria hyperborea detected at various sites of District IV in Mutsu Bay.

The horizontal lines show 60% confidence limits of the percentage of individual number of each species to the total number of benthic animals at various spots. The vertical line indicates the average percentage of each animal species in all the sites surveyed. The numbers denote the site number which corresponds to that in the map of Mutsu Bay (Fig. 12).

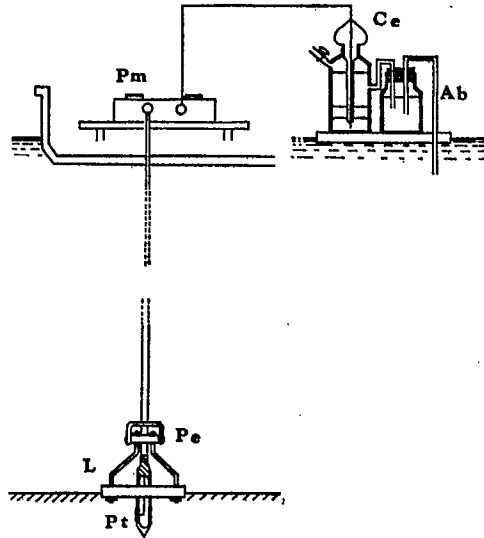


Fig. 15. Apparatus for measuring the oxidation reduction potentials of the sea-bed.

Ab - agar bridge, Ce - calomel electrode,
L - lead disc, Pe - platinum electrode,
Pm - potentiometer, Pt - platinum plate.

electrode tipping into a horizontal position, (2) a saturated calomel electrode (Ce) floating at the sea surface and an agar bridge (Ab) which connected the calomel electrode and sea water, and (3) a potentiometer (Pm) placed in a boat. Determinations of the oxidation-reduction potentials were made at several spots in Mutsu Bay (Table 8).

Considering the results of both Table 8 and Fig. 12, the sea-bottom showing rH values of 20.0-22.5 appears to be a favourable habitat for bottom-living larvae of Patinopecten yessoensis. Two sites, spot No. 20 (Hamaokuchi) and No. 38 (off the coast of Yokohama, District III), both of which are known to be unsuitable for the growth of spat show low rH values of 16.8-18.0.

It was our experience that the determinations at gravelly sites along the coastal areas required considerably long periods of time for measurement and tended to yield variable results. Therefore, the values obtained at such areas, for example spot No. 36 (Nobeji area) and No. 15 and 16 (Kawauchi area) have to be taken into account, and further investigation will be necessary to ascertain these points.

It is of extreme interest to note that an area of stable rH appears to offer a favourable habitat for scallop spat. Judging from the findings presented so far, it also can be said that scallop spat appears to require quite restricted environmental conditions for a proper habitat.

9. Abnormal development and its mechanism

Three factors which are possibly involved in the abnormal development have already been described, and each one of the three has been dealt with separately. Therefore, in this chapter ecological observations made at the site of abnormal development will be described mainly to understand this phenomenon more clearly.

(1) Features of the site of abnormal development

There are in Mutsu Bay two sites where abnormal development has been frequently observed; one is an area 35-50 m deep, located west of Natsutoma Peninsula between Ohshima and Futagonana, and another is off the coast of Kakuchigai toward Yokohama and is also 35-40 m deep. These two areas belong to District III rather than District IV which is usually considered to be the best habitat for scallops, Patinopecten yessoensis (Fig. 12). Abnormal development of scallops, observed in 1927, the year which showed the largest annual catch of scallops in the history of the scallop fishery of Mutsu Bay, occurred in these two areas, and those observed in both 1948 and 1956 occurred along the coast of Ohshima-Futagonana (Aomori Prefecture Marine Experimental Station Report, 1930).

Table 8. Oxidation-reduction potentials (rH) of the Mutsu Bay sea-bed.

Date	Spot No.	Depth of spot	pH at bottom of spot ¹	Eh(mV)	rH ²	District No. (see Fig. 12)
July 11/55	32	20 m	7.9	+95	19.0	IV
"	36	10	8.2	+291	26.0	IV
"	28	20	7.9	+132	20.3	IV
July 12/55	27	25	7.9	+138	20.5	IV
"	24	18	7.9	+136	20.4	IV
"	25	22	7.8	+177	21.6	IV-1
Apr. 13/55	24	18	7.9	+132	20.4	IV-1
"	25	22	7.8	+122	19.7	IV-1
"	37	20	7.8	+113	19.3	IV
"	35	35	7.8	+93	18.6	IV
"	38	45	7.8	+35	16.8	III
"	20	17	7.8	+72	18.0	IV
July 14/55	7	16	7.9	+84	18.6	IV
"	8	18.5	7.9	+198	22.4	IV-1
"	8'	23.5	7.8	+136	20.1	IV-1
"	8''	38	7.8	+160	21.0	IV-1
"	16	10	7.9	+ca435 ³	30.3	IV
"	15	10	7.9	+ca180 ³	21.9	IV

¹ Water oozing out from the sea-bed was measured by colorimetry using thymol blue and phenol red.

² The value was corrected for the pH of the spot.

³ Measurements were carried out before the apparatus was stabilized.

The sea-bottom of these areas is deeply covered with fine silt containing large amounts of broken shells from Balanus rostratus and other species of Balanus. During the summer season, formation of hydrogen sulfide has often been seen in the silt layer. The coast of Ohshima-Futagonana is known to have a swirling current resulting from the meeting of an anti-clockwise current in Aomori Bay (western area of Mutsu Bay) and an oceanic current running into Ohshima from the entrance of Mutsu Bay. Also, a clockwise coastal current originating in Nobeji Bay (eastern area of Mutsu Bay) joins with the flow of the oceanic current and runs into this area. These tidal conditions may in part account for the appearance of large numbers of plankton in this area, especially planktonic larvae of

benthic animals. The coast of Kakuchigai is also one of the swirling current centres of Nobeji Bay, and the nature of the bottom at this district, similar to the coast of Ohshima-Futagonana, consists of fine silt, containing pieces of broken shell. Also, this area is known to contain large numbers of planktonic larvae (Fig. 8).

These two areas are characterized by the presence of large numbers of not only planktonic scallop larvae brought in by the swirling current, but also plankton of other species and so-called 'Marine Snow' possibly derived from these plankton (this will be discussed later in detail). During the summer months, marine snow of about several metre thickness has often been seen in these areas. Other benthos frequently found in these areas are Obelia plana (Fig. 16), 30-40 cm long at full maturation, and Asabellides sibirica Wirén*, known to live in a tubular tunnel made by silt and mucus at the sea-bottom. Both are believed to provide substratum for adhering larvae of the scallop Patinopecten yessoensis, and are often caught with scallop spat on them in July.

When abnormal development of scallops was found in 1956 off the coast of Ohshima-Futagonana, approximately 15,000 tons of the spat were collected between 1957 and 1958 and then transplanted into various areas of Mutsu Bay. In August of 1957, the first survey was conducted to examine the number of benthic animals in this area, and again in July of 1959 a similar survey was carried out at the same spot as in 1957 (Table 9). In 1957 both the variety of animal species and the number of each species were quite meagre and that nearly all of the animals known to have permanently settled there were dead. Pinnixa ruthbuni found in the largest number in the 1957 survey belongs to Crustacea, lives in groups and is migratory. Although the 1959 survey shows an improved pattern of the distribution of benthic animals, no Obelia was observed. A large number (1960 in 1 m²) of dead shells of bottom-living scallop larvae were found in the area. Since none of these was found in the 1958 sampling, they must have come into the area after the summer of 1958. It is not known whether these large numbers of dead shells represented the death of spat in the area or if they were brought into the area from not so distant locations by water currents. However, judging from the rather fresh appearance of these shells, since dead shells are usually broken into pieces within a few years after death, it is very likely that large numbers of adhering scallop larvae came into the area in 1958, but nearly all of them died there. If this was the case, the mechanism of abnormal development can be explained by the fact that the abnormal development results in most cases from abnormally high survival of scallop spat (Yamamoto, 1960).

* Identification of this species was made by Mr. M. Imajima of National Science Museum.

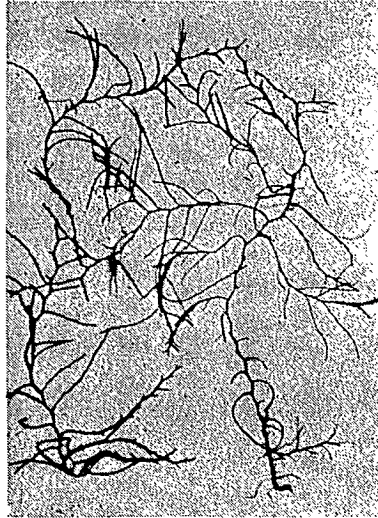


Fig. 16. Obelia plana distributed on the sea-bed, 35-50 m deep, off the coast of Ohshima-Futagonana. This plant is known to provide substratum for adhering larvae of Patinopecten yessoensis.

Table 9. Benthic animals at the site of abnormal development in 1956.

Species	Number/m ²
<u>August 16/57</u>	
<u>Pinnixa ruthbuni</u>	22
<u>Episiphon makiyamai</u>	7
<u>Pectinaria hyperborea</u>	3
<u>Thyasira tokunagai</u>	2
<u>Dead shells</u>	
<u>Hiatella orientalis</u>	
<u>Balanus rostratus</u>	
<u>Episiphon makiyamai</u>	
<u>Raeta pulchella</u>	

<u>July 2/59</u>	
<u>Prionospio pinniata</u>	24
<u>Telepsavus costarum ?</u>	9
<u>Episiphon makiyamai</u>	12
<u>Anisocorbula venusta</u>	8
<u>Thyasira tokunagai</u>	10
<u>Lucinoma annulata</u>	6
<u>Echinocardium cordatum</u>	4
<u>Pectinaria hyperborea</u>	2
<u>Ringicula niinoi</u>	2
<u>Pinnixa ruthbuni</u>	2
<u>Raeta pulchella</u>	2
<u>Cavernularia obesa</u>	1
<u>Dead shells</u>	
<u>Patinopecten yessoensis</u>	1,960
<u>Arca boucardi</u>	18
<u>Thyasira tokunagai</u>	16
<u>Ringicula niinoi</u>	8
<u>Balanus rostratus</u>	5

(2) Ecological studies of marine snow and abnormal development

Recent advances in electronic technology have brought new equipment into the field of the fishery industry including a high-frequency acoustic detector which is able to detect the presence of not only groups of fish but a single fish or even groups of plankton. Fortunately, the author was able to borrow one of these instruments with dual channels of 50 kc and 200 kc from the Japanese Industrial Research Institute and to carry out several observations by the use of this apparatus on the nature of the water layer at the bottom of the sea.

In early March the presence of a layer one to two metres thick, that reflects a sound-wave, is sometimes detected immediately above the silt at the bottom of Mutsu Bay. After the month of April, two or three layers of phytoplankton are formed at a sea-depth of 5 to 20 m, and layers of zooplankters start to appear at about the same location as phytoplankton. The quantity of zooplankton increased with advance of the season. The increase in the quantity of this plankton in spring is believed to be brought about by increases in the nutritious salts from the bottom, an increase in the water temperature, an increase in the intensity of sunlight and an increase in the inflow of land water.

The growth of the plankton starts to decline gradually from mid-June toward summer. However, at about the same time the sound-wave-reflection zone starts to reappear immediately above the base silt and increases in thickness. In July to August it becomes 3 to 4 m thick. This layer tends to become very thick in a hollow place or around a mud bar on the bottom. The texture of the layer appears to be rather coarse, and its capacity to reflect a sound wave is as weak as that of plankton.

This layer becomes no longer detectable by the instrument in September when the exchange of upper and lower sea water takes place. This exchange continues until December and the winter season then sets in. This sound wave-reflection zone (or: layer) has been called 'marine snow'.

When large volumes of sea water are collected from the sound wave-reflection zone just above the bottom silt, in most cases distinctive marine snow is no longer visible in the container. However, if the water is allowed to settle for a while, one can see the presence of large quantities of sediment. Even when water is filtered through a plankton net, the presence of these sediments is still recognizable. Microscopic examination of the sediment has shown only live diatoms; the major part of the sediment consists of unknown particles containing broken pieces of diatom shells and protoplasmic materials. Pieces of broken shell from zooplankters are rarely seen in the sediment. Therefore, it appears that the sound wave-reflection zone above the bottom silt consists of intermediary metabolites from plankton. In other words, it is composed of what is called marine snow, or suspended silt or sometimes detritus.

When the water temperature was 22-24°C in summer, sea water was collected from various depths and analyzed for the degree of saturation of soluble oxygen. Values of 70-90% were obtained on water collected from a spot 20 to 100 cm above the sea-bed, whereas water taken from the sound wave-reflection layer gave values of 60-80%. Crevice water from the bottom silt showed a value of only 40%. Although large experimental errors are usually unavoidable in this type of experiment, it appears that a steep gradient in the amount of soluble oxygen in sea water is formed immediately above the bottom silt when the temperature is high. The formation of this gradient is probably due in part to degradation of organic matter contained in the silt and in another part to degradation of marine snow.

In order to study these points in detail, a few model experiments were carried out in the laboratory. The silt obtained from the coast of Futagonana was placed to a depth of 10 cm at the bottom of a water tank and sea water was layered on top of the silt to a depth of 40 cm. When the water temperature rose above 20°C, the amount of soluble oxygen in a water layer of about several cm adjacent to the bottom silt was much less than that in the water of the upper layers. The thickness of this bottom oxygen-poor layer increased with time after standing. If the surface was stirred, this layer disappeared, but was again formed within one-half day after stirring.

When scallop spat, which had just started their benthic life and which had a shell length of 10 mm were placed into the tank that had formed the oxygen-poor layer at the bottom, they showed continuous characteristic swimming. As a result, the bottom silt was stirred up, and the sea water became cloudy. Within 3 to 4 hours nearly all of the spat were dead and those few that survived were adhering to the wall of the glass tank. This continuous swimming of the spat is seldom observed under natural conditions, and obviously is caused by both a lack of oxygen and the presence of suspended detritus.

It is quite conceivable that similar phenomena to these laboratory findings may occur under the sea. When adhering scallop larvae descend to the bottom of the sea to start their benthic life in summer, a greater part of them will probably die. Large numbers of scallop spat will be able to survive only in a year when special environmental conditions have existed. At least one of these special conditions would be that a shortage of soluble oxygen has been absent at the site, that formation of marine snow has not taken place at the site, or the spat have come down and settled in an area of no marine snow.

It seems noteworthy to add here that the major composition of the stomach contents of benthic animals are very similar to the contents of the marine snow sediment. Therefore, under circumstances where the marine snow is not accompanied by a shortage of oxygen, it provides food to benthic animals. In other words, the marine snow may occupy a very important place

in the production of marine animals. Thus, the statement made by Blegbad in 1915 that benthic animals selectively take detritus, may prove to be the true state of things.

(3) Observation on the fishing grounds with bathyscaphe

A bathysphere 'Kuroshio Go (The Black Current)', manufactured in 1951 under the direction of Professor N. Inoue of Hokkaido University has contributed invaluable help to the survey of the continental shelf around Japan. It was reconstructed in 1960 and converted into a bathyscaphe (submarine) of 11.3 m total length, 2.2 m width and 12 ton air weight. Its capacities are: maximum submerged depth, 200 m, maximum number of crew 7, and submerged speed, 2 knots. We were able to conduct three surveys at different times by use of either the old bathysphere or new bathyscaphe.

The conditions of the sea-bed off the coast of the Ohshima-Futagonana line, where abnormal development of the scallop Patinopecten yessoensis has been frequently observed, appeared to be gently rolling and covered with soft silt. When a part of the bathyscaphe touched the bed, this apparently stirred up the silt and sometimes nothing could be seen for a while. Numbers of holes of various sizes were scattered all over the area. Among the submarine creatures, light brown Cavernularia obesa, Balanus rostratus and Cynthia roretzi deeply impressed our curiosity. The presence of a few Obelia plana was also observed.

On the other hand, the sea-bed (22-25 m deep) located off the coast of Kawauchi was sandy silt or sandy silt containing broken shells. The bottom was dotted with groups of Scytosiphon lomentarius, Desmarestia viridis, Sphaerotricha divaricata, Acrothrix pacifica, Extocarpus sp., Ceramium boydenii, Polysiphonia japonica, Rhodomela sp.* and between them Terebrataria coreanica, Coptotyris adamsi, Arca boucardi, Modiolus difficilis, Asteriidae sp., Solaster paxillatus and Patinopecten yessoensis were seen. Also large quantities of scallop spat were seen to adhere to a variety of seaweeds. According to Dr. Nakamura (personal communication), the seaweed seldom grows on the sea-bed deeper than 20 m. However, we observed and collected a lot in the area.

When the bathyscaphe submerged or rose to the surface, a lot of suspended particles were observed beneath the sea surface. However, the quantity rapidly decreased, when the ship went down more than 10 m deep. Then near the bottom the quantity of marine snow started to increase suddenly. This vertical distribution pattern of suspended particles was identical with that examined with the acoustic instrument.

* Identification of this species was kindly done by Dr. Y. Nakamura of Seaweed Research Institute, Hokkaido University.

Mr. Nishizawa of Hokkaido University found (personal communication) that the quantity of suspended particles seen in Mutsu Bay was larger than that in any part of Hokkaido and also their size in Mutsu Bay was bigger than that in Hokkaido. He also noted that the particles in Mutsu Bay looked like long woolly fibres. Our submarine observation also revealed that each marine snow particle sometimes reached several centimetres in length.

Distribution of the suspended particles appeared to show a different pattern at the various sites surveyed: these were off the coasts of the Ohshima-Futagonana line, Wakinozawa, Kawauchi and Kominato. The first site had the most abundant particles, and the size was found to be also the largest. A dense population of particles was observed particularly in the area of Futagonana-Urashima, and the density appeared to decrease toward the Ohshima district. Both the quantity and the size of the particles were much smaller in the areas of Wakinozawa and Kawauchi than those in the Ohshima area. In one area of Wakinozawa district, close to the entrance of Mutsu Bay, hardly any layer formation of suspended particles was seen at the sea-bed.

Those findings again appear to confirm that the site of abnormal development corresponds to a special area where suspended particles stay, or in other words, an area which forms the centre of a swirling current.

10. Conclusions

There are many problems to be answered in the propagation of the scallop Patinopecten yessoensis in Mutsu Bay. Of these, the obviously important ones have been discussed in separate chapters. However, the author would like to summarize these at the end of this booklet.

There are four important points to be considered in this topic. The first one is to secure a large supply of the scallop spat. It would be difficult in Mutsu Bay to expect a large catch of spat every year, since the size of spawning depends totally on natural environmental conditions and, therefore, no artificial control is possible. However, from the practical viewpoint, if a sizable quantity of scallop spat is secured every two or three years and if their future growth can be protected with reasonable success by artificial means, then the scallop resources will be safely maintained. For this, prediction with a fairly high degree of precision for the size of spawning for that year will be required at least one month in advance. Also, information concerning conditions of the areas which have been known to show large quantities of adhering scallop larvae has to be provided. Further development of the current research will enable us to meet these two requirements.

The second point concerns the rearing of spat on a large scale. The difficulties of this problem have been discussed several times in

several chapters. Neither management of food for the spat nor control of environmental conditions for the growth of the spat has been successfully achieved on a large scale. Most of the studies carried out on this problem have aimed to rear the planktonic larvae until they grow to the adhering larvae. After this stage of development they are released into open sea or reared in tanks or pools under controlled conditions. The latter is possible in certain species of animals such as the sea-ear Notohaliotis discus. Once the scallop spat are released into open sea, any attempt to rear them under this environment will be next to impossible, since the scallop has a migratory nature under unfavourable conditions.

The third point will be to promote research on how to improve the survival rate of benthic scallop spat. As already discussed, certain promising experimental results are being undertaken. However, there are still many unknowns to be answered and conclusive evidence has to be established to achieve the goal. Once it is attained, how much will the scallop fishery in Mutsu Bay receive from the benefits of it!

The last point, which has not been fully discussed in this booklet, is the maintenance and protection of the resources by means of a voluntary refrain from fishing. This has been carried out with success in Mutsu Bay. Whenever abnormal development occurs, scallop spat caught are transplanted into various coastal areas and allowed to continue their growth at the new sites. Depending on the estimated quantity of the resources in Mutsu Bay, the quantity of the annual catch as well as the location of the fishing ground are voluntarily set by each coastal fishery co-op. According to our records, small scale abnormal development has been observed every two to three years in either District II or III of Mutsu Bay. Even on these occasions this practice has been rigidly carried out. There is no doubt that the practice of such self-control has contributed much toward the continuance of a relatively sizable minimal annual catch of the scallop in Mutsu Bay since the end of the Second World War.

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