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THE PROPAGATION OF SEA URCHINS

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The propagation of sea urchins

By Isao Matsui

FOREWORD

From ancient times, in both the East or West, a close relationship has existed between sea urchins and man. The discovery of a large number of sea urchin shells from kitchens in the ruins of Bombay or from ancient tombs in various places in Japan makes us realize the extent sea urchins were used to satisfy the nutritional requirements and tastes of our forefathers.

Since he took up residence in Shimonoseki-Shi after the War, the author has taken an interest in the marine products which were closely related to the industries of the area, and has devoted his time to a study of the resources and propagation of animals which were the object of dragnet fisheries in the western region: globefishes, sea urchins and others, and to the training of students, in addition to specialized studies.

The study of the methods of propagating sea urchins began in 1960 with assistance from the City of Shimonoseki and much was accomplished. The author regrets the fact that he was unable to thank everyone before the results were officially published. The author was fortunate in being responsible for establishing libraries in the Library of the Fisheries University with the collection of books from Drs. Hiroshi Oshima and Haito Ikeda, authorities on the Echinoderms in Japan, and for naming the libraries after them. The availability of these books was very convenient for carrying on the work.

In comparison to the highly developed techniques of land cultivation which have been developed partly because of the limitations of the resources and the productive capacity of the land, we have depended too long on the natural production of the seas, mainly because of their rich productive capacity. The day has finally arrived when it has become essential to cultivate our marine resources.

Although cultivation of the sea is important, the author hopes that the primitive methods of production will be modernized with the object of stabilizing the economy of fishing villages by controlling the sea urchin resources, which are found over wide areas, and enable impoverished fishing villages to emerge from their present economic plight.

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1. Structure. The sea urchins belong to the Echinoidea of the Echinodermata.

(1) External structure

Almost all species of the Echinoidea, which are used as food, belong to the Regularia. The species, which belong to this class, are oval in shape and possess many hard spines on their surface. The spines can be classified into the primary spine, the secondary spine and the miliary spine. The colour differs depending on the species. The spine moves by the muscles attached to the ball and socket arrangement at its base. Between spines there are rod-shaped pedicellaria which thicken at the end. Their function is to clasp and carry food to the mouth and to remove dirt which adheres to the surface. The exterior of the body is covered by a strong exoskeleton. The underside is relatively flat and is called the buccal side. The mouth is located in the centre of the underside. The upper side is called the aboral pole. The anus is located on this side. There are five teeth in the mouth. The area surrounding the mouth is called the peristome. Five pairs of ambulacral feet and five pairs of gills emerge from the peristome in a branch-like fashion. On the side, the region which surrounds the anus is the periproct. The periproct is surrounded by small plates of various sizes and shapes. This is called the apical system and has 10 special plates. Adjoining the periproct there are 5 genital plates containing reproductive openings which release eggs or sperm cells. The other single plate is larger in size and has a countless number of apertures in addition to the reproductive openings. This is called the madreporic plate. The other five plates, which are found alternating with genital plates, are called the terminal or occular plates which form the end of the ambulacral area. An aperture, which is smaller than the reproductive opening, is found on the occular plates. Long filamentous ambulacral feet with suckers at the ends extend from between the spines. Between the peristome and the periproct twenty rows of a group of two rows of plates are found. Five groups, from which the ambulacral feet emerge, and five groups, in which no ambulacral feet emerge, are found alternately. The former is called the ambulacral zone, the latter the interambulacral zone.

(2) Internal structure

A greater portion of the interior of the exoskeleton is occupied by the sex glands and the digestive tract. The internal side of each interambulacral zone is occupied by flat spindle-shaped sex glands (gonads) consisting of many small lobes. Their size differs markedly depending on the spawning season or environment. Since sea urchins are dimorphic sexually, females have yellow ovaries and males white testes. An oviduct (seminal duct) runs through the centre of the gonads, which joins the reproductive opening.

The digestive tract starts with the mouth on the lower surface and ends in the anus on the upper surface. The jaw has a complicated structure, a collection of five prominent cones, and is called Aristotle's lantern. In the middle of each jaw there is a tooth whose end protrudes in the lower surface. The esophagus is a tube which proceeds upward starting from the centre of Aristotle's lantern. At some distance it bends into a U-shape, proceeds downward towards the interior of the shell and joins the stomach. The stomach bends into a U-shape in the internal side of each ambulacral zone and surrounds the body. The intestine bends sharply from the stomach and proceeds in the opposite direction. It is a thick tube which surrounds the body running along the back side of the stomach in the internal side of each ambulacral zone. It is bent into a U-shape as in the case of the stomach. The intestine ends in the rectum which proceeds directly upward. The rectum ends in the anus. In addition to these the ambulacral system consists of a thin membranous organ which surrounds the esophagus, the ambulacral ring canal, which is colourless, transparent and thin, the five radial canals, the axial gland, the Polian vesicles and the stone canal.

2. Useful species and their distribution

(1) Useful species, their characteristics and distribution

The useful varieties are either eaten fresh or made into granular or paste products for food, the so-called "uni". The former differs locally in the varieties and in the degree of utilization; for the latter limited species, special local products, are used. However, because of the shortage of raw material, many imported varieties are utilized mixed with the domestic varieties.

As edible species the following two varieties in 14 species in 10 genera are known:

1.	*Strongylocentrotus pulcherrimus*	"bafun uni"
2.	*S. droebachiensis*	"obafun uni"
3.	*S. sachalicus*	"sanriku obafun uni"
4.	*S. franciscanus*	"harinaga obafun uni"
5.	*S. intermedius*	"ezo bafun uni"
6.	*S. nudus*	"murasaki unimodoki" (kita murasaki uni)
7.	*Anthocidaris crassispina*	"murasaki uni"
8.	*Pseudocentrotus depressus*	"aka uni" (hirata uni)
9.	*Temnopleurus toreumaticus*	"sansho uni"
10.	*Mespilia globulus*	"koshitaka uni"
11.	*Tripneustes gratilla*	"shirahige uni"
12.	*Pseudoboletia maculata*	"madara uni"
13.	*Toxopneustes pileolus*	"rappa uni"

14.	T. elegans	"rappa modoki"
15.	T. chloracanthus	"midori rappa uni"
16.	Colobocentrotus mertensii	"jingasa uni"

S. droebachiensis, S. intermedius and S. nudus are most commonly found in the Tohoku section (Translator's note: the northeast section of the mainland of Japan, Honshu) and is an important source of "uni" in the section. The first two are often mistakenly identified as S. pulcherrimus. The last species is often mistaken for Anthocidaris crassispina.

The characteristics and the distribution of these species are as follows:

Strongylocentrotus pulcherrimus (A. Agassiz)

The species is called "maganjo" or "magase" in Fukuoka-Ken (Translator's note: an area in Kyushu).

The shell is spherical with flat upper and lower surfaces. The peristome does not sink deeply. The shell measures approximately 3.5 cm in diameter and 2 cm in height. The diameter of the peristome is less than half of the diameter of the shell. Two vertical rows of large-size tubercles and six vertical rows of medium-size tubercles are found in the ambulacral zone. In the interambulacral zone, in addition to two vertical rows of large-size tubercles, five vertical tubercles, which are of medium and approximately equal size, are found. There are four vertical rows of ambulacral feet. The primary spines are thin and short, ordinarily 5 mm in length and generally dark green in colour. The spawning period is around March to April. This is the best species to use as a source of "uni". The distribution extends from the northern end of Honshu to the southern end of Kyushu. They are found under rocks in shallow waters. The species is specific to Japan.

S. droebachiensis (O.F. Müller)

The species is called "hokuyo bafun uni" and "midori uni". It is found throughout the world.

The species is large in size, the diameter of its shell ranging from 8-9 cm. The spines are thin and short. The colour varies from individual to individual. Some are greenish brown with a tinge of purple; others pale yellow and still others pale brown. The spines also differ in colour; green, at times red or purple. In the ambulacral zone the nonporiforous zone has two vertical rows of tubercles externally; the central section is wide and has a single row of irregular tubercles. There are seven pore pairs. The ambulacral is extremely wide and made of two vertical rows. The species is found in abundance in areas north of Iwate-Ken (Translator's note: an area in the northeast section of

Honshu), Hokkaido, the Kuriles and Korea. Abroad it is found in the Americas, the coastal areas of both the Pacific and the Atlantic Oceans, Greenland, Iceland, various parts of northern Europe and in the northern section of Siberia.

S. franciscanus (A. Agassiz)

As in the case of the previous species, this one is found in cold salt water. One of the largest species, it is found throughout the world. The shell measures 15 cm in diameter and 7-8 cm in height. The primary spines measure 3-6 cm in length, are strong and hemispherical. The buccal region is flat. The ambulacral feet form 8 to 9 vertical rows. Eight to nine and occasionally seven to 10 pairs form slanting arcs on the outer side of a single remarkably large tubercle found on each plate. The spines on the peripheral portion are extremely long. There are two vertical rows of markedly large tubercles in the ambulacral zone and the interambulacral zone. In other areas only very small tubercles are sporadically found. In large-size individuals the centre of the interambulacral zone is exposed. There is a prominent milled ring surrounding each large tubercle. The body is dull brown in colour. The spines are light brown. The species is found at a depth of 0 - 125 m in Hokkaido, the Aleutians, Alaska and the coastal areas along the Pacific Ocean in North America.

S. intermedius (A. Agassiz)

The species is called "gaze" in Muroran (Translator's note: a city in Hokkaido) and "bozu gaze" in Iwate-Ken.

The shell measures 9 cm in diameter and 2-3.5 cm in height. The primary spines are short, measuring 5-8 mm. They are merely 1/4 to 1/6 of the diameter of the shell. The colour is usually dark green. However, some are brown and others are brown or pale yellow. There are marked individual variations. In the apical system two of the occular plates enter deeply in the ring of the genital plate, and reach the periproct. In the nonporiferous zone of the ambulacral area there are two vertical rows of large tubercles and a single row of irregular medium size tubercles between them. The interambulacral zone is extremely wide. On the outer side of the two vertical rows of large tubercles there are six vertical rows of medium size and many small tubercles. The spawning period extends from July to October. The species is found at a depth of 0-35 m along the coastal areas extending from the Kuriles, Hokkaido to Fukushima-Ken in the northeast section of Honshu.

S. nudus (A. Agassiz)

The species is called "nona" in Muroran.

The shell measures 8-10 cm in diameter and 1.5-5.5 cm in height. Its lower surface is flat. The peristome is approximately 2/5 of the diameter of the shell. The primary spines do not exceed 3 cm. They are bright reddish-brown in colour. Those of the young of the species are green. The shell is purplish-brown in colour. Ordinarily six ambulacral feet are found forming one arc. The species resembles Anthocidaris crassispina and S. intermedius. The young of the species resemble Pseudocentrotus depressus. However, it can be distinguished by the spicule on the wall of the ambulacral foot and the pattern on the surface of the primary spine. That is to say, in the present species and in S. intermedius the spicule of the ambulacral foot is a bow-shaped rod which branches at two ends; in A. crassispina it is a needle-shaped structure with spines at the centre; and in P. depressus it is bow-shaped and branches at both ends but the two spines in the centre are missing. Further, coarse vertical lines are found on the surface of the primary spine. In the case of the present species and P. depressus horizontal rows of small tubercles are found at a fixed distance between the vertical lines and in the case of the present species fine vertical parallel lines are observed running between them. In A. crassispina such small tubercles are totally absent. The spawning period extends from September to November. It is found in shallow seas to a depth of approximately 200 m in seas north of Sagami (Translator's note: area near Tokyo), in Hokkaido and in coastal areas of Korea and Tsushima (Translator's note: an island off the coast of Nagasaki-Ken) in the Japan Sea.

Anthocidaris crassispina (A. Agassiz)

The species is called "katakawa" in Fukuoka-Ken and "kuzokaze" in Iwate-Ken.

The shell measures 7 cm in diameter and 3.5 cm in height. The shape is flat and spherical. The peristome is relatively small being less than 1/3 of the diameter of the shell. In the nonporiferous part of the interambulacral zone and the ambulacral zone, two vertical rows of regularly positioned large tubercles are found. In addition to these in the ambulacral zone vertical rows of medium size tubercles are observed in the centre and both ends. In the perforated area of a wide ambulacral zone, an array of obliquely arcing 5 to 8 ambulacral pores is observed. The spines are strong and large with sharp ends. The surface is smooth. The primary spines are somewhat the same length as the diameter of the shell. They are uniformly dark purplish black. The spawning season starts in May and continues to the early summer. The species is found among reefs in shallow seas in Hakodate, Honshu, Shikoku, Kyushu, the Bonins and the eastern shores of China. The reason why the species is called "katakawa" in the Echizen area (Translator's note: means hard shell) is that its shell is thick and hard. In the Amakusa area the species is used mainly as the source of "uni".

Pseudocentrotus depressus (A. Agassiz)

The shell measures 8 cm in diameter and 2-3.2 cm in height. The shell is extremely flat, hence the name "hirata uni" (Translator's note:

flat sea urchin). Both the surface of the body and the spines are uniformly dark red. The peristome measures 1/2 to 1/3 of the diameter of the shell. The ambulacral feet are pale red in colour and found in each ambulacral zone in 3 to 7 vertical rows. The primary spines are short, measuring less than 1/3 of the diameter of the shell. Their ends are dull. The species spawns at the end of the fall. It is found among pebbles in shallow seas from Hokkaido to Kyushu. It is found further inland and over wider areas than Anthocidaris crassispina. The species is also called "onigaze" in Echizen.

Temnopleurus toreumaticus (Leske)

The shell measures 4 cm in diameter and approximately 2.5 cm in height. The shell is circular with a flat lower surface. The dorsal surface forms a low cone. The shell is thick and strong and is yellowish brown. Two vertical rows of large tubercles are found in each zone; in the interambulacral zone on the side of the mouth they form 4 to 6 rows. The sutures between plates form prominent lateral grooves. Those in the ambulacral zone are particularly prominent. These are totally absent in the buccal zone. The primary spines measure approximately 1/3 of the diameter of the shell. They are flat and pale red and have 3 to 4 lines of purplish black lateral spots. The spawning period extends from the end of June to July. The species is found in shallow sandy bottoms in inland bays in the southern central section of Honshu and in the south of Korea. The one which resembles the present species is T. reevesi (Gray). It has a relatively thin and brittle shell which is pale gray. The characteristic of the species is long needle-shaped spines. The species is found in areas south of Hakodate and in the outer seas of Okinawa.

Mespilia globulus (Linné)

The shell measures approximately 4 cm. The height is a little less than the diameter. The shell is almost a sphere. In the centre of the interambulacral zone there is a wide area where no spines are located. In the ambulacral zone there is a narrow area in which no spines are found. The colour is dark green. The spines are thin and short. There are white or purple stripes against the background of red or green. The spawning period extends from July to August. The species is found in large quantities in pebbly beaches in shallow waters and coastal areas in the south of the Tokyo-Yokohama district. In some sections of Kyushu the species is used as food.

Tripneustes gratilla (Linné)

The shell measures over 14 cm in larger specimens of the species. The shell is roundish pentagonal in shape. The width of the ambulacral zone is extremely wide. Thus the perforated portion is also wide. The ambulacral feet are arranged in three vertical rows. In the nonporiferous area there are four vertical rows of primary spines. In the interambulacral zone more than eight vertical rows are observed. However, they are irregular and indistinct and difficult to distinguish from medium size tubercles. The primary spines are short with sharp ends. The shell is either uniformly white or reddish brown or locally reddish brown. The ambulacral feet and the ambulacral zones can be distinguished by their colour.

The spawning period extends from July to August. The species is found in shallow waters facing the ocean in the south of Kishu (Translator's note: an area in the southern section of Honshu), Amami Oshima (Translator's note: an island located off the southern tip of Kyushu), Formosa, India and tropical waters of the Pacific Ocean. In Okinawa the species is known as "gachicha" and is the most common source of "uni". In Amami Oshima the species is collected in large quantities and eaten raw.

Pseudoboletia maculata (Troschel)

The shell measures 5-7 cm in diameter, 2.5-3.5 cm in height, is a somewhat pentagonal, low and flat sphere. It is brittle and weak. The peristome measures approximately 1/3 the diameter of the shell. The area, which surrounds the peristome, is either flat or sunken. The shell and the primary spines are generally white and dotted with radial or large irregular dark brown spots. The spines, which are located in the area, are also of the same colour. The distribution extends from the southern section of Kyushu to the Indian Ocean. There are records of collection at depths of 20-70 m.

Toxopneustes pileolus (Lamarck)

This is a large species whose shell measures 10 cm in diameter and 5 cm in height. The shell is a somewhat pentagonal circle. The peristome is wide, measures approximately 1/3 of the diameter of the shell, and is deeply depressed. The central portions of the ambulacral zone and the interambulacral zone are exposed. In the nonporiferous zone near the equator there are 6 vertical rows of tubercles. However, on the upper surface they decrease to two vertical rows. In the interambulacral zone in the equatorial zone 8 vertical rows of tubercles are found. In the buccal zone both zones are covered densely with large-size tubercles. The whole surface is covered with short spines and pedicellariae which open in a trumpet-shade form. The spines have dull ends, vertical lines and red lateral zones. Their ends are white. The pedicellariae are uniformly white or purple in the centre and secrete toxin. The ambulacral feet are found in three vertical rows. The spawning period extends from April to July. The species is found in shallow seas in various places in the Pacific Ocean south of the Bay of Sagami.

T. elegans (Döderlein)

This species resembles _T. pileolus_. The species is rare and known only in the Bay of Kagoshima and in Amami Oshima. In comparison to _T. pileolus_ the shell is higher, spindle-shaped. The whole surface is yellow and lacks the dotted pattern. The vertical suture of plates becomes purplish black as it nears the apex. Near the end of a primary spine a prominent purple-black ring is found. The spines on the dorsal side are short with white upper portions and green lower portions. The spines in the buccal region are long, large and white. The species is consumed in private homes in Amami Oshima.

I. chloracanthus (Clark)

The species resembles I. pileolus but the tinge of red is totally absent. Both the shell and the spines are green with white dots or white stripes. The primary spines have one or more rings. The ends and bases are white. Occasionally the diameter of the shell exceeds 10 cm. The species is found in warm seas in the south; the northern limit is Nobo in Nagano-Ken (Translator's note: an area in the central section of Japan). The species is eaten raw in Amami Oshima.

Colobocentrotus mertensii (Brandt)

Including the spines around the circumference the longer axis measures 7 cm and the shorter axis measures 6 cm. The height is 2.5 cm. The body is somewhat oval in shape. The dorsal surface rises prominently; the ventral surface sinks a little. The spines on the dorsal side are rod-shaped and flat on the ends. They are short and grow densely. A single row in the equatorial region of the periphery consists of ones which are flat, rectangular in shape and long. A small number of short and small spines are found on the ventral side. The dorsal side is purplish black and the ventral side is pale red. The species is found clinging closely to reefs at water's edge, which are covered by rough seas, in the islands south of Kishu. It is used as food in Ogasawara (Translator's note: a group of islands located in the east of Okinawa).

(2) Species used for food abroad

Shells of sea urchins were found in a kitchen in Bombay (Keller, 1913). Since ancient times, sea urchins have been eaten either raw or cooked, in various places in the world such as the coastal areas of the Mediterranean Sea, the tropics, or Alaska. Since olden times the processing of sea urchins in Japan has been highly developed. Of late it has not been possible to meet demands and they are imported in large quantities from Mexico, Taiwan, Okinawa, Korea and China. The species which are used for food in foreign countries are as follows:

Strongylocentrotus dröbachiensis (O.F. Müller)

This species is found in holes in rocks in shallow seas in the northern section of the Pacific Ocean, Alaska, the Aleutians, Kamchatka, Norway, Sweden, Denmark, Scotland or Iceland. Depths of 0 to 1200 m have been recorded. The inhabitants of the Aleutians or Alaska use the species for food. It is shipped to markets in the city of New York from the seas around Rhode Island, Boston or Maine by Italian fishermen. It is used for food mainly by Italians and immigrants.

S. franciscanus (A. Agassiz) "harinaga O-bafun uni"

S. purpuratus (Stimpson)

There are 8-10 holes in each arc. The primary spines are short and small. The colour of the shell is purple. The latter has 9-10 holes. The primary spines are long. They are reddish brown and occasionally have a tinge of purple. These are found in such places as the coastal areas of the Pacific Ocean in Alaska and California.

The species is used for food by Italians and immigrants along the Pacific coast of America and native Indians and Greeks in British Columbia. It is recorded that the Chinese have exported the species to China in large quantities. It is relished as having a better flavour than caviar.

Echinus esculentus (Linné)

The shell measures 20 cm in diameter and is nearly spherical in shape. It is the largest species. The colour is dark red. At times it has a tinge of blue or purple. On it white thorny tubercles are readily observed. The spines are red with purple tips. The southern limits of its distribution are England, Iceland, France and Portugal. Thus the species is not found in the Mediterranean Sea. However, it is used for food by inhabitants of the coastal areas of Portugal. It is said that the species was used for food by the poor in England in the old days and that in recent times it is no longer used for food.

E. melo (Lamarck)

This is a large species. The shell measures approximately 15 cm in diameter and is tall. It is almost spherical. The shell is brown. The border between plates is distinguished by a white line. The spines are green. The species is found in the Mediterranean Sea, Portugal, West Africa, Cape Verdi, Azores, Canary Islands and western Ireland. The species is called the melon or the burred melon of the sea by Italian fishermen in the Mediterranean Sea.

Psammechinus microtuberculatus (Blainville)

The shell measures 3.5 cm in diameter. The colour is green, yellow or ash green. The species is small in size. The spines have dark brown ends, are dark brown in colour, thin and short. The species is found in the Mediterranean Sea, Naples and the Adriatic Sea. In Italy it is called the chestnut from the sea.

Paracentrotus lividus (Lamarck)

This is a large-sized species. The shell measures 7 cm in diameter, is dark purple, brown or brown with a tinge of green. It burrows into rocks in shallow water. It is an extremely common species which is caught in large quantities in southern France and Italy and is used for food. It is said that it resembles crayfish in flavour when cooked. Since it possesses mature eggs almost all year round in the Mediterranean Sea, it is regarded as good material for experiments in genetics. It is a species well-known to zoologists. In Italy it is called the burr of the sea or female porcupine. The species is found in the coastal areas of the Mediterranean Sea, the coastal areas along the Atlantic Ocean, the south of the English Channel, Azores and south to the Canary Islands.

Tripneustes esculentus (Leske)

This is a large-size species, its shell measuring 15 cm in diameter. The species is called the egg of the sea in the western section of India. It is found in Bermuda, Bahamas, Florida, Tortugas, western section of the Indies, Jamaica, Brazil, and other areas. In Jamaica, the species is eaten raw, baked in the shell, or in omelets. In Bermuda it is relished by the Portuguese.

Sphaerechinus granularis (Lamarck)

This is a large sized species with the shell measuring 16 cm. The colour is violet. The spines are violet with white tips. The species is found in the Mediterranean Sea, Naples, Nice, Spain, Portugal, Azores, Medielar(?), and the Canary Islands. In Italy it is called the burr of the sea.

Arbacia lixula (Linné)

The shell measures 5 cm in diameter. The species is extremely common along the coastal areas of the Mediterranean Sea to the west coast of Africa, Azores, Brazil and the Bay of Naples. Fishermen call the species a female porcupine. Fishermen believed that the species was female and that Paracentrotus was the male. They relish it.

Centrechinus (Diadema) saxatile (Linné)

The species resembles C. setosus (Jackson) of Japan. It is often mistaken for the latter. As in the case of C. setosus (Jackson) it has a beautiful blue pattern against the background of black of the shell. The spines consist of ones with black and white horizontal stripes and ones which are entirely white. The species is found in areas extending from the coastal areas of East Africa to India, Thailand and the Malay Peninsula to the Pacific Ocean. It is used for food in Malayan districts.

Loxechinus albus

The species is eaten raw or cooked with rice. It is found down to the southern sections of Chile (Bernasconi, 1947).

3. Living environment

(1) Geographical distribution

The geographical distribution of the Echinoidea is wide extending from the Antarctic and Arctic Oceans to the tropics. However, the species which are used for food in this country show a characteristic distribution.

Generally few species are found in cold water regions. Many species are found in warm water areas. These can be classified into the following 3 types.

(a) Species which can be found in both cold and warm water regions

Strongylocentrotus pulcherrimus - from the northern sections of Honshu to Kyushu.

Anthocidaris crassispina - from the southern section of Hokkaido to southern waters.

Pseudocentrotus depressus - as above.

(b) Species which are found in warm water regions

Temnopleurus toreumaticus - in the Pacific Ocean south of the Bay of Tokyo and Noto Peninsula (Translator's note: in the central section of Japan) in the Japan Sea.

Mespilia globulus - south of Boshu (Translator's note: another name for Chiba-Ken, an area near Tokyo).

Tripneustes gratilla - south of Kishu (Translator's note: another name for Wakayama-Ken, an area in the east of Shikoku).

Pseudoboletia maculata - south of the southern section of Kyushu to the Indian Ocean.

Toxopneustes pileolus - in the Pacific Ocean south of the Bay of Sagami (Translator's note: the bay in the east of the entrance to Tokyo Bay), in the Japan Sea, to the south of the Sea of Hibiki (the sea to the west of southwest end of Honshu) to the Indian Ocean.

Colobocentrotus mertensii - Kishu, south of Kagoshima.

(c) Species found in cold water regions

S. intermedius - north of Fukushima-Ken (Translator's note: an area to the northeast section of Tokyo) to the Kuriles.

S. sachalicus - as above.

S. franciscanus - as above.

S. droebachiensis - as above.

S. nudus - as above. Also found in Tsushima (Translator's note: an island between Korea and Kyushu).

(2) Vertical distribution

If the vertical ecological section in the sea is divided into the water-pouring-zone, the intertidal zone (the high tidal sub-zone, middle tidal sub-zone and low tidal sub-zone), the upper-shallow sea-zone, the middle-shallow-sea-zone and the sub-shallow sea-zone, the species, which are commercially utilized to a great extent, are almost all distributed around the intertidal zone. However, some southern species such as Pseudoboletia maculata and Toxopneustes pileolus are found in the low-tidal-sub-zone and in the upper portion of the upper-shallow-sea-zone and S. nudus is found from the intertidal zone to the middle-shallow-sea-zone. Along the coastal zone of Hidaka in Hokkaido it is found at a depth of 2-9 m. It is also found at a depth less than 2 m (Kawamua, 1964). The deepest depth is 100 m (Utmomi, 1960). Even among the species, which are found in the intertidal zone, such species as Strongylocentrotus pulcherrimus, S. intermedius, Mespilia globulus or Temnopleutus toreumaticus are found in zones extending from the high tidal sub-zone to the middle tidal sub-zones as centre, and the centre of distribution of such species as Anthocidaris crassispina range from the middle tidal sub-zone to the low tidal sub-zone.

Sea urchins are generally found in shallow seas. However, there are records in areas of low latitudes where they have been collected at considerable depth. S. droebachiensis (the North Sea type) has been collected at a depth of 220 m. In Alaska it has been collected from a depth of 1200 m. While S. franciscanus is found at a depth of 10-20 m in Hokkaido, it is found at the depth of 0-125 m in the Aleutians. S. nudus is found at depths of 0-200 m; there is a tendency for the depth to increase as the latitude becomes higher.

The quantity and the colour of the gonads are related to the depth. Those individuals of Strongylocentrotus pulcherrimus which inhabit a small-stone-zone where the depth is 4 m at most and where the effects of waves are slight, are larger in size. Their gonads have good colour and are larger in quantity. As the depth increases, the size becomes smaller. If the size of the animal is large, the development of their gonads is extremely poor. The colour of the gonads becomes brown or blackish brown. Their quantity is small or they are totally absent. Down to depths of approximately 4 m the size tends to increase with the increase in depth. At depths exceeding 4 m their growth seems to be inhibited by the distribution of seaweeds especially green algae which are used for food.

S. intermedius is found in large numbers at depths exceeding 50 cm. A depth of 35 m has been recorded. However, as the depth increases, the development of the reproductive glands becomes poorer (Kawamura, 1964).

(3) Salinity

Since members of the Echinodermata are marine animals, they generally prefer regions of relatively high salinity and are sensitive to changes in salinity. However, they are found in the interior of bays. There are species such as Mespilia globulus and Temnopleurus toreumaticus which can withstand relatively low salinity.

Strongylocentrotus pulcherrimus has a little resistance to low salinity and is not found in seas which are affected by water from rivers. In coastal areas with a strong interior bay character it tends to be distributed in deeper regions.

Experiments by the author and his co-workers show that the optimum salinity for Strongylocentrotus pulcherrimus is 27‰ or higher, that it does not die at 20 - 23‰, that the salinity of 15‰ or lower is not suitable for living, that the vitality is suddenly lost at less than 13‰, and that instant death takes places at 7‰. Kawana (1938) reported a salinity of 30-34‰ in the best fishing ground in Echizen. Comparisons among Strongylocentrotus pulcherrimus, Anthocidaris crassispina and Pseudocentrotus depressus, which are most commonly found in seas in the central section of Japan, show that Strongylocentrotus pulcherrimus is the most coastal in character and of low-salinity type, that Anthocidaris crassispina is the most open-sea and high-salinity type and is found among reefs down to the depth of approximately 10 m, and that Pseudocentrotus depressus is intermediate between the two.

(4) Terrain or bottom characteristics

Many of the species are found in reef zones. Species such as Strongylocentrotus pulcherrimus and Anthocidaris crassispina prefer to live lurking among reefs. Temnopleurus toreumaticus is found on sandy beaches and Mespilia globulus is found on sea shores.

The bottom character most suitable for Strongylocentrotus pulcherrimus is pebbles or sandy areas with no mud and small-stone zones. It prefers hard rocks with many crevices. Flat muddy beds are not suitable.

The optimum zones such as those mentioned above can be judged from geographical features (Kawana, 1936). Maritime regions with cliffs at the back have sharply sloping sea bottom with large rocks. Pebbles and small stones are few in such areas. Thus sea urchins are not found in large numbers. On the other hand, many areas with gently sloping backgrounds have shoals extending over long distances with the border between sand and reefs at some distance off. Such an area forms a good fishing ground with many pebbles and small stones.

S. nudus is found among reefs and boulder-zones but not in sand-zones (Kawamura, 1964).

S. intermedius is found widely in reefs and boulder-zones. However, it is reported that in Lake Saroma (Translator's note: located in the southeast portion of Hokkaido facing the Sea of Okhotsk) it is found in reefs, sandy-pebble zones and in sandy-mud zones. The sea urchins, which are found in the reef zones, are smaller in size in comparison to those found in the sandy-mud zones (Kawamura, 1960).

The relation between the environment and the living conditions of S. intermedius in Rebunto (Translator's note: an island off the northern extremity of Hokkaido) is shown in Table 1 (Kawamura, 1964).

Finally those factors which affect the adherence of plants on which sea urchins feed, such as the size, quality and smoothness of rocks, are important.

(5) Relation between growth and distribution

Kawamura (1964) established the relationship between growth and the distribution in S. intermedius in Rebunto.

Yearling sea urchins are found in the reef and boulder zones at depths less than 50 cm. They are not found in the boulder zones where the diameter of rocks are approximately 1 m. They occur largely among the roots of seaweeds or among a group of calcareous seaweeds. Where seaweeds are sparse, sea urchins are found adhering to the underside of boulders.

Second-year sea urchins measure approximately 1-3 cm in diameter. Most of them are found in waters less than 50 cm deep. Only a small number are found in depths lower than 1 m. Generally their size tends to become smaller as the water becomes shallower. In many cases they are found under stones or in crevices in rocks, in groups of five or six individuals or up to scores of individuals. However, they can be found in a large number on floating kelp or on boulders with seaweed adhering to their bodies.

The shell of three-year-old sea urchins measures approximately 3 cm in diameter. They are found in large numbers somewhat further off from the shore than two-year-old sea urchins at a depth of 50 cm. Hardly any of them are found at depths of 1-1.5 m.

The shell of four-year and older sea urchins measures over 4 cm in diameter. They are not found in any number in places less than 50 cm deep. They are found in large numbers at a depth of approximately 1 m. Their size tends to increase with an increase in depth. Near kelp zones they collect densely on the tips of the fronds of kelp. Where there is little kelp, they are found sporadically in many cases on floating weeds or with small stones adhering to their bodies.

(6) Relationship with adhering organisms

In the ecosystem of living things in shallow fishing areas, it is extremely important to clarify the relationship between individual sea urchins with that of other living organisms and especially the relationship between the Echinoidea and the living organisms which serve as food at the different trophic levels. However, there have been few studies in this field. Investigations on large-size benthic animals for a unit area (4 m^2) in areas along the coastal zone in Fukui-Ken (Translator's note: an area in the central section of Japan; faces the Japan Sea) show that the portion occupied by benthic animals such as *Strongylocentrotus pulcherrimus* show marked differences depending on the region (Fig. 5) (Taki and Higashida, 1964; Yoshida, 1964).

(7) Production by fishing villages

It appears that conditions favourable for the production of sea urchins are found in many areas across the country and with the exception of some special cases the resource is equally distributed among the fishing villages which are blessed with reef zones. However, depending on the amount of fishing and the methods used, these villages land quantities of sea urchins which are not related to the available sea urchin resources. This is due to the fact that people in small villages, whose main industry is catching sea urchins, enter other fishing grounds rich in these resources. Furthermore, the differences in the amount produced by fishing further away along the coast from these villages and the amount produced by women and children close to their own villages, results in differences in production of different species.

Of the fifty-one fishing cooperatives along the coast of the Japan Sea in Yamaguchi-Ken (Translator's note: located in the southern end of Honshu) forty of them or 80% of the total fish for sea urchins. It is a rare cooperative which is not so engaged. *Strongylocentrotus pulcherrimus* makes up 63%, *Pseudocentrotus depressus* 23% and *Anthocidaris crassispina* 14% of the catch of these cooperatives. The breakdown by cooperatives shows marked differences between neighbouring cooperatives or between cooperatives located in the same bay. For instance in the neighbouring fishing grounds in the city of Shimonoseki, despite the fact that they are under the identical First Class Fishing Rights, Isaki depends entirely on *Anthocidaris crassispina*, Minami-Kazedomari shows *Pseudocentrotus depressus* 10% and *Anthocidaris crassispina* 90%, and in Rokuren-To *Strongylocentrotus pulcherrimus* makes up 90% and *Pseudocentrotus depressus* 10%. Similarly, among neighbouring and closely located Kawadana, Kuroi, Murotsu, Yoshibo, Yoshimi and other places similar observations can be made (Nakamura and Inoue, 1965).

4. Nutrition

(1) Structure of the digestive tract

The esophagus is a tube, which starts in the centre of Aristotle's lantern, and which proceeds upwards. After a short distance it bends in a U-shaped form, proceeds downward inside the shell and joins the stomach. The stomach circles the body on the inner side of the ambulacral zone bending into a U-shaped form. The intestine proceeds in the direction opposite to that of the stomach. It circles the body on the inner side of the ambulacral zone and on the dorsal side of the stomach. In a manner similar to that of the stomach it bends into a U-shaped form. As it is a larger tube than the stomach, they can be easily distinguished. The terminal portion of the intestine proceeds upwards and joins the rectum, opens into the anal plate and ends in the anus. The digestive organs hang on the inner wall of the shell by means of many fibres (Fig. 2).

In the mouth and esophageal regions of *Strongylocentrotus pulcherrimus* there are cells which have basophile granules and secrete mucous polysaccharides, and cells which secrete zymogenic granules are located in the stomach. It appears that these cell groups take part in the absorption of nutrients in the Echinoidea. If grains of carbon, less than 5 μ in diameter, are added experimentally, they are captured by many non-granular amoebocytes which are present in the stomach and carried into the circulatory system. These secretory cells or amoebocytes are totally absent from the intestine and the rectum. Thus, they are regarded as organs which perform excretory functions after the food is digested and absorbed prior to and in the stomach (Fuji, 1962).

(2) Food habits

It has been established by Scott (1901), Awerinzew (1911), Belgrad (1915), Jensen (1915), Mielck (1922), Wesse (1925), Van der Heyde (1922), Hung (1956), Hung and Giese (1958) and others that a greater portion of the contents of the digestive tract in the Echinoidea consists of various species of seaweeds. Edward and Giese (1952) and Lasker and Giese (1954) reported that seaweeds were the main food in *S. purpuratus* and *S. franciscanus*. Similar observations were made by Heyde (1922) and Scott (1955) in *Echinus esculentus*, by Kawana (1938), Oshima et al. (1957) and Nakamura and Yoshinaga (1962) in *Strongylocentrotus pulcherrimus* and *Anthocidaris crassispina*, by Kawamura (1964) in *S. nudus* and by Fuji (1960) and Kawamura (1962) in *S. intermedius*.

On the other hand Heyde (1922) reported that *Toxopneustes* sp. and *Sphaerechinus* sp. fed on Crustaceans. Parker (1932) observed that *Arbacia punetulata* fed on Fundulus and reported that this species preyed on fishes which had poor swimming abilities although this could not be considered to be an aggressive move. Oshima et al. (1957) experimentally established that a small quantity of fish meat, which had been offered to

Strongylocentrotus pulcherrimus and Anthocidaris crassispina, was eaten by them. Even under natural conditions animals are often observed in the contents of the digestive tract.

A large portion of the stomach contents of S. nudus is seaweeds; consisting of 4 species of green algae, 8 species of brown algae, 7 species of red algae, Phyllospadix scouleri Hook, 2 species of land plants, more than 5 species of animals and detritus containing sand -- in total, 30 kinds of materials (Kawamura, 1964). Though sea urchins are omnivores to various degrees, various findings suggest that the main food is seaweed and that, when it is not found in a sufficient quantity, they feed on detritus.

In short, the Echinoidea, which belong to the genus Regularia, tend to be omnivores, but feed mainly on seaweeds.

(1) Changes in food habits accompanying growth

In the initial stages of development, from hatching until metamorphosis, Echinoidea larvae feed and grow on floating or clinging types of diatoms -- Nitzschia closterium, Navicula sp., Skeletonema costatum, Chlamydomonas, Chaetoceros simplex, or C. calcitrans.

After metamorphosis the larvae feed on calcareous algae. In the case of Strongylocentrotus pulcherrimus usually clinging diatoms are used as food until the shell grows to approximately 8 mm in diameter. Those animals larger than 8 mm feed only on seaweeds indicating a change in food habit (Nakamura and Inoue, 1965).

Results of an investigation, which was carried out on board a ship in Rebun-To in Hokkaido, on Strongylocentrotus pulcherrimus showed that yearling sea urchin larvae, from the time of metamorphosis until they are about 1 cm in shell diameter, feed mainly on detritus or pieces of organisms, which are rich in calcium, such as calcareous seaweeds, "nomi-hamaguri" or clinging-type diatoms but ingest almost no ordinary type seaweeds (Table 5). However, the stomach contents of two-year-old sea urchins, with shell diameters over 1 cm, consist mainly of green, brown and red algae with animal-type substances occasionally mixed with them.

(2) Selectivity

The colour of the gonad and its size differs depending on the type of seaweeds used as food. However, is it possible that sea urchins discriminate between types of food?

The food preference of Strongylocentrotus pulcherrimus can be expressed in the following order: Undaria pinnatifida, Cystophyllum fusi-forme, Eckloris bicyclis, Sargassum bacciferum, Chrysysmenia, Laurentia, Gelidium amansii and laver. If these are given at the same time, when 70% of Undaria pinnatifida is consumed, 60% of Cystophyllum fusi-forme, 40% of Eckloris bicyclis and 0% of Gelidum amansii and laver is consumed. When the Undaria pinnatifida is completely consumed, approximately half of the Eckloris bicyclis remains, and at about the same time sea urchins begin to eat Gelidium amansii and laver (Nakamura and Yoshinaga, 1954).

When Laminaria japonica Aresch, laver, Condrus ocellatus Holmes and Rhodymenia palmata (L.) Grev. are fed to S. intermedius mixed or singly, Laminaria japonica Aresch is taken in the largest quantity followed by Condrus ocellatus Holmes, Rhodymenia palmata (L.) Grev. and laver. The amount taken by a species when given singly is approximately the same as the amount taken when they are fed mixed. In their foraging action the movement is not to collect on seaweeds of a specific type. The tendency is to take any species which they may come upon by chance. The differences in the amounts of food taken are specific depending on the type of seaweeds and are not due to selectivity (Fuji, 1963).

In short sea urchins show no special selectivity. It appears, however, they show a preference for places where seaweeds, which can be taken for food, are found in sufficient varieties and quantities. This has been confirmed in S. nudus (Kawamura, 1964).

(3) Relation with water temperature

Within the range of suitable temperatures it is natural that metabolism becomes more active as the temperature rises. The amount of food taken by S. intermedius shows a seasonal change. This is related to the development of the gonads; but it is not possible to ignore its relation to water temperature. The seasonal variation in the amount of food taken differs depending on the size of sea urchin. The variation becomes smaller as the size decreases. It is more prominent in sea urchins of larger sizes. It begins to fall starting in June, becomes minimal during September-October, begins to rise starting in December and becomes maximum in April.

In March, when the amount of food taken is highest, and in November, when it is lowest, the food intake per individual specimen per day was optimum in the temperature range of approximately 5-15°C (Fuji, 1962).

The results of investigations on the seasonal variations in the rate of food intake by water temperature (0°C, 10°C, 20°C and room temperature) also show a similar tendency; July to September is the lowest and March to June is the highest (Kawamura and Hayashi, 1965).

In the case of Lytechimus variegatus, when the average water temperature is 21.4-29.8°C, the amount of food intake markedly increases with a rise in water temperature (Moore, et al., 1963).

In the case of Strongylocentrotus pulcherrimus there is a decrease in the amount of food intake when the water temperature is less than 12°C; 12-16°C is the optimal water temperature (Matsui, et al., 1960).

With reference to the relationship between the rate of food intake and the water temperature, the optimum rate is shown during summer at water temperatures of approximately 30°C. The limit is 34°C. In the former, the rate is markedly lower in winter in comparison to summer; a suitable temperature is approximately 22°C. In the latter the optimum is approximately 20°C; in summer it is 30°C. The rate does not differ greatly from that of summer. This clearly shows that the optimum temperature for food intake shows seasonal adaptation (McPherson, 1965).

(4) Light condition

The Echinoidea are generally nocturnal and are actively engaged in foraging during the night. Strongylocentrotus pulcherrimus is most active around 4 a.m. (Matsui, et al., 1960).

The activities of S. intermedius under natural light show various patterns depending on the strength of the light. Its activity is not related to time factors such as night and day but is influenced greatly by the strength of light. The limit is approximately 5000 lux. When light exceeds this amount the foraging activity is inhibited. Light not only influences foraging but also the amount of food ingested (Fuji, 1962).

(3) Amount of food intake

Table 8 shows the food intake of Strongylocentrotus and Anthocidaris crassispina when feeding on different types of food (Oshima, et al., 1957).

An examination of the table shows that brown algae such as Sargussum thunbergii Kuntze, Sargussum sereatifolium C. Ag. and Ecklomia cava Kjellm are taken in larger quantities followed by red algae such as Gelidium amansii and then by green algae such as lavers. Quantitatively the last two amount to only 1/4 to 1/5 of the brown algae. This fact was established with respect to the same species by Nakamura and Yoshinaga (1962) and with respect to S. intermedius by Fuji (1962).

The reason for the smaller amounts of green algae being taken for food is that in comparison to brown algae their leaves are thinner and hence the efficiency of intake is poorer (Oshima, et al., 1957).

In Strongylocentrotus pulcherrimus the food intake is 3.18% of its body weight per day (Nakamura, et al., 1962), 0.35-10.41% (Oshima, et al., 1957) and 3.7-5.3% (Matsui, et al., 1960); in Anthocidaris crassispina 0.43-5.53% (Oshima, et al., 1957), in S. intermedius 0.96-5.81% (Fuji, 1963) and 0.3-9.1% (Moore, et al., 1963), in Lytechinus variegatus 3.0% and in Tripneustes 3.8% (Moore, et al., 1963).

In the case of Anthocidaris crassispina (body weight 29-37 g) food amounting to nearly 10% of its body weight is found in its digestive tract. When Ecklomia cava Kjellm is fed the average intake per individual per day is 1 g. In the case of Strongylocentrotus pulcherrimus (11-12 g) the content of the digestive tract is approximately 5.5% of its body weight and the food intake is still 1 g per individual per day. Thus it takes a relatively large amount of food in proportion to its body weight and the food in the stomach lasts for a long period of time (Oshima, et al.).

When seaweeds of various species are fed to S. intermedius, there are differences of 0.5-3.0 g per individual per day depending on the species of seaweed.

By raising groups of sea urchins and changing the amount of food administered and thus regulating the food intake, it is possible to obtain an equation expressing the relationship between the amount assimilated (y) and the amount gained by the body (x). When the gain in the body weight is zero, i.e., the amount needed to sustain the body can be calculated as the value of x when $y = 0$.

The amount required to sustain the body was 13.4 mg per day in dry weight per individual in the case of Ulva and was minimal. It was 17.2 mg in the case of Alaria and was maximal. Laminaria showed a value intermediate between the two. Ulva at its minimal quantity was sufficient to sustain the body weight (Fuji, 1962).

Further there is a seasonal difference in the food intake. When Laminaria japonica Aresch is used as food, a single individual takes approximately 3 g per day over winter to spring. The amount gradually decreases starting at about May and becomes approximately 0.5 g over August to September.

However, this seasonal difference varies depending on the size of sea urchins. In the case of those with shell diameters less than 2 cm (two-year-old sea urchins) there are no marked seasonal variations and they maintain a level of approximately 1 g per day throughout the year. The efficiency of assimilation of seaweeds taken (food intake - amount excreted/food intake × 100) is approximately 70% in the summer; it falls in the winter to approximately 55%. The amount of Laminaria japonica Aresch, which is assimilated by those with a shell diameter of 55 mm, is approximately 270 mg in dry weight per day per individual during February-June and approximately 50 mg during September and October (Fig. 8) (Fuji, 1963). Kawamura and Hayashi (1965) experimentally reared 2- and 3-year-old sea urchins. Their findings were as follows: the amount of annual food intake was 35.7 g per individual in 2-year-old sea urchins and 114.1 g per individual in 3-year-old sea urchins; the food intake gradually increased from October to April and decreased from May to August; the rate of food intake was approximately 3% from October to January showing almost no change, rose to 6.8-9.1% from February to May, fell sharply from June, and became less than 1% in July and August.

The rate of food intake becomes larger as the size decreases (Fuji, 1963; Kawamura and Hayashi, 1965).

Approximately 35% of Thalassia consists of leaves and this corresponds to 5000 g in wet weight and 350 g in dry weight for every 1 m^2. It multiplies sufficiently in the winter. However, in the summer the yield is 40% of that in winter being 140 g in dry weight per 1 m^2.

Lytechinus takes this seaweed as its main food. Experiments, which have been conducted on actual grounds and in a laboratory, indicate the consumption to be 1.36-4.33 g per individual per day (Moore, et al., 1963).

The food intake differs depending on the volume of the shell. If 250 cc is taken as a standard for the volume of the shell for an individual of this size, the average annual intake is 7.15 g in wet weight per individual per day.

The intake by Tripneustes is very much smaller being 3 g in wet weight and 0.6 g in dry weight per day.

There is an annual increase of 80% in the volume of Tripneustes with a shell diameter of 8 cm. The growth is 6.27 g in total weight with calcium removed, 4.37 g in the gonad, and 1.90 g in tissues exclusive of the gonad. Since sea urchins of this size consume 166 g in dry weight of Thalassia during the year, the efficiency is 3.8% (Moore, et al., 1963).

Strongylocentrotus intermedius (shell diameter 5 cm) consumes 3 g in wet weight of Laminaria japonica per day; this corresponds to 6% of the weight of the shell. In the case of Ulva pertusa the figures are 0.5 g and 1%, respectively.

If the assimilation efficiency is obtained from the expression (food intake in dry weight/dry weight of food) × 100, the maximum is 83% for Scytosiphon lomentaria and the minimum is 32% for Phyllospadix iwatensis. Laminaria japonica or Chondrus ocellatus gives a value of 57%. Observations on the variations during the year when Laminaria japonica was used as food show the consumption to be 270 mg in dry weight per day per individual during February-June and 50 mg during September-October. The efficiency is 70% in the summer. It falls to 55% in the winter (Fuji, 1962). Results, which were obtained by Moore, et al. (1963) are shown in Table 11.

(4) Digestive enzymes and bacteria

Since sea urchins generally feed on seaweeds, enzymes which decompose seaweeds must be present in the digestive system. The protoplasm of the cells of seaweeds contain proteins and the red algae store floridean starch.

Protease, an enzyme which decomposes protein, and amylase, an ensyme which decomposes starch, are clearly present in the digestive tract of the sea urchin. However, these enzymes cannot completely digest seaweeds; neither can they digest agar. However, an extract from the digestive tract digests galactan iridophycin which is present in red algae.

Bacteria, which decompose agar, are present in large quantity in the digestive tract. The number of bacteria is 2×10^{11} per mℓ. These bacteria form thin films which surround pieces of seaweed in the intestine. These bacteria can digest the red alga Iridophycus flaccidum completely in a week. Further, they decompose agar. The bacteria, which decompose agar, can be isolated from the digestive tract of the sea urchin and made into a pure culture.

The isolated bacteria, which have been grown on agar cannot reduce sugar in the culture medium.

5. Propagation

Only the gonads of sea urchins are used commercially. Thus sea urchin fisheries and propagation are closely related to such environmental factors as the seasonal variations in the development of the gonads and the conditions for their development.

(1) Biological minimal shell diameter

The minimal shell diameter, at which reproduction is possible in the Echinoidea, is an important matter in the propagation and protection of sea urchins. Table 12 summarizes past studies.

Fuji studied the relationship between the developmental stages of the gonads and the shell diameter by examining tissue sections of the gonads of Strongylocentrotus intermedius and S. nudus. He reported that in the case of S. intermedius, sexual differentiation was not possible in specimens with a shell diameter of less than 15 mm; in the case of S. nudus the diameter was 30 mm, but in specimens with shell diameters larger than these, sexual differentiation was possible. He further reported that the shell diameters, at which the specimens become mature initially, were 30-35 mm in the case of S. intermedius and 40-45 mm in the case of S. nudus.

In the case of Tripneustes ventricosus, the gonads in the specimens with a shell diameter of 29 mm are not developed. One half of the 30-34 mm group had gonads which were not visible to the naked eye; in the other half they were immature. In the 35-39 mm group 10% (all males) were mature, 35% immature; and 55% were not developed. When the shell diameter becomes 40-44 mm, females mature and 61% of those examined were mature. When shell diameter exceeds 54 mm they remain in the state of sexual maturity throughout the year (McPherson, 1965).

(2) Spawning period

During the spawning period the gonads of Echinoidea become mature and it is impossible to process them or use them fresh as food. Thus the time and duration of spawning are important both from the standpoint of propagating sea urchins and also of the industry.

Among the species which are widely distributed there are wide variations in the spawning period depending on the area. However, among the species which are not widely distributed the spawning period is more fixed.

The spawning period can be roughly divided into 3 types -- spring, summer and winter. The representative species of spring spawning is Strongylocentrotus, the summer type Anthocidaris crassispina, and the winter type Pseudocentrotus depressus. However, the spawning period is dependent on water temperature. Thus it is early in low latitudes and is delayed in high latitudes. The spawning period is relatively short ordinarily lasting approximately two months at the most. However, among the northern species it is generally longer being ordinarily 4 months. In Aritama, S. intermedius spawns in the spring and in the summer (Kinoshita, 1955).

(3) Morphological difference between males and females

Since the discovery of the genital papilla by Hamann (1887) which permit one to differentiate between males and females, many studies have been carried out. In Arbacia punctata differences in sex are seen in the size of the shell, shape of the genital plate, the genital papilla, and in the colour of the tube foot. Males of A. lixula are tall and round and have a larger peristome and lantern (Cerami, 1924); however, Cascia (1930) observed no difference. Fishermen in Lesina easily differentiate between the males and the females of Paracentrotus lividus by the fact that males are smaller in size, black in colour and spherical in shape while females are flat and reddish purple in colour (O. Schmidt, 1878). The difference in colour was not observed by Camerano (1890) and differences in shape and size were not observed by Cascia (1930).

It was reported that males of Temnopleurus toreumaticus were slightly taller (Ikeda, 1931); however, this was denied by Mortensen (1943). In Cidaris membranipora females are flat while in Hemiaster (Abatsu) cavernosus males are flat. In Goniocidaris canaliculata the genital plates differ (Studer, 1880). In Echinocardium mediterraneum the female genital papilla is thick and short (Hamann, 1887); in Echinocyamus the male genital papilla is extremely long; and in Psammechinus miliaris red pigments are observed in the genital papilla of males while they are lacking in females (Marx, 1929). In males of such species as Echinus esculentus, Paracentrotus lividus, Psammechinus microtuberculatus, P. miliaris and Sphaerechinus granularis there are 5 reproductive openings, with short genital papilla whose edges are white, while they are not present in females which are somewhat depressed. Further, in the male the shell is smaller in size and is egg-shaped (Swann, 1954).

The reproductive openings of females of Lytechinus anamesus and L. pictus are large (Tyler, 1944; Metz, 1953). The ambulacral feet in the buccal region in females of Strongylocentrotus pulcherrimus are yellow and in males are light purple (Motomura, 1941). The reproductive opening in males of Temnopleurus toreumaticus is small (Ikeda, 1931).

The secondary sexual characteristics of 6 species can be divided into Mespilia globulus type and Tripneustes gratilla type. In the former the genital papilla of males is short and forms a protruding spindle-shaped tubercle while in females it is flat and caves in below the surface of the body. Toxopneustes pileolus belongs to this type. In the latter species the genital papilla of males forms an extremely long tube while in females it is short and forms into a thick protruding tubercle-like shape. Species such as Tripneustes gratilla, "nagauni", "tawashiuni" and Diadema setosum Gray belong to this type (Tahara, et al., 1958).

There are methods which differentiate between the sexes and which do not depend upon morphological differences between males and females. A thin needle can be inserted into the reproductive opening and the gonad can be collected directly. Sea water saturated with KCL can be injected and a part of gonad discharged naturally and examined under a microscope. When an alternating current of 10 volts is applied ova or spermatozoa are discharged. Ordinarily a 60 cycle alternating current of 110 volts is reduced to 10 volts by means of a transformer. This method was successfully used by Iwata (1950) in Mytilus and Heliocidaris crassispina.

(4) Sex ratio

The results of investigations by many workers on sex ratio of many species of sea urchins indicate that males tend to be slightly less than females although a ratio 1 : 1 seems to be a general rule among living animals. This appears to be due to differences in resistance to the environment between males and females.

Hermaphroditism is extremely rare in the Echinodermata. However, it has been reported in Arbacia punctulata, A. lixula, Dendraster excentricus, Echinocardium cordatum, Echinus esculentus, Paracentrotus lividus, Psammechinus microtuberculatus, Sphaerechinus granularis and Strongylocentrotus droebachiensis by Gadd (1907), Fuchs (1914), Herlant (1918, Gray (1921), Needham and Moore (1929), Heilbrunn (1929), Shapiro (1935), Neefs (1937, 1952, 1953), Reverberi (1940, 1947), Harvey (1939, 1946, 1956), Boolootian and Moore (1956) and Moore (1935, 1959). However, such occurrences are rare. Tripneustes and Lytechinus show relatively high rates of hermaphrodism (27%); it is reported that hermaphrodism is commoner when sea urchins are small and when the gonads begin to form. It is also reported that hermaphrodism occurs early in the season when the temperature is low. In many cases hermaphroditic animals become males; there are individuals which are hermaphroditic at maturity; however, the development is not complete (Moore).

In Japan the phenomenon was not observed in 1500 specimens of S. intermedius and S. nudus (Fuji, 1960).

(5) Number of eggs spawned

MacBride estimated the number of eggs laid by Echinus esculentus to be 20,000,000.

Harvey (1965) reported that the volume of eggs of <u>Arbacia punctulata</u> was 1,260,300 μ^3 (assuming the diameter of an egg was 74 μ and the jelly layer 60 μ, and there was no space between eggs). The number of eggs laid was 800,000 including the jelly layer for every 1 cc assuming that 26% constituted the space corresponding to 212,200 μ^3; that when the jelly layer was removed. the number of spawned eggs was 3,500,000; and that it was 4,700,000 if neither the jelly layer nor the space were taken into account. The number is approximately 8,000,000 if it is assumed that the number of spawned eggs is equal to the number of eggs collected by the method of KCL injection or by the electric method. Krahl (1950) reported that the number of eggs was 46,500 per 10 mm^2 and 4,300,000 grains for every g. It has been reported that <u>Asterias rubens</u>(?) spawned 2,500,000 eggs in two hours.

(6) <u>Artificial insemination</u>

There are 5 reproductive openings surrounding the anus (Fig. 1) and ova or spermatozoa are discharged from these openings. The gonads radiate out in 5 directions into the ambulacral zones from which no ambulacral feet emerge. The testis is white and the ovary is yellow. The two can be easily distinguished by colour.

(a) Cracking method -- the shell is cracked by inserting the sharp ends of a pair of forceps into the soft section around the mouth. The gonad is taken out by means of a pipette or forceps and placed in sea water. If the animal is mature, the eggs or sperm will spread in the water. If body fluids are mixed with the eggs, ciliates or bacteria, which are found in the fluids will multiply and kill the eggs or the larvae. Thus care must be exercised. The eggs should be allowed to stand quietly and should be washed several times after they settle.

(b) Method in which KCL solution is injected into the body -- the aforementioned method is simple and quick. However, body fluids or ciliates are easily introduced and fertilization and larval development are inhibited. The method which does not damage the gonad is as follows: the soft section between Aristotle's lantern and the shell is cut with a pair of scissors. All the oral organs are removed. The interior is washed thoroughly with sea water to remove the body fluids. Next a bottle with a mouth wide enough to hold the anal portion of the animal is filled with enough sea water to immerse the anus in it. If the specimen is mature, eggs or sperm will be discharged from the reproductive openings. The eggs and sperm are collected separately.

If the gonad does not discharge readily, 1 - 2 cc of 0.5 mol KCL solution (since the atomic weight of KCL is 64.5 g. 32 g can be dissolved in 1 ℓ) is injected with a pipette. This stimulation will cause the gonads to discharge eggs or sperm.

The eggs or sperm can be held for half a day even in summer and for a day if kept at a low temperature.

After fertilization, the eggs sink in sea water and it is necessary to change the water several times. The eggs are washed well which prevents the sea water from spoiling and removes the unused sperm.

(7) Occurrence

(a) Maturation -- the reduction division is complete before the eggs are discharged. The oocyte in the ovary releases a polar body with a single division. It contains large cells, which become eggs, with the same number of chromosomes; however, because of the small amount of cytoplasm they fail to become eggs. The large cells undergo a further division and release polar bodies. At this point the number of chromosomes is reduced by half and eggs are formed. The two other polar bodies degenerate. Immature eggs, which do not undergo reduction division, are the same size as the somatic cells, and a large nucleus is clearly observed along with the nucleolus in it. When the reduction division takes place, the nucleus becomes smaller. The egg measures approximately 90-100 μ and is surrounded by a thick gelatinous layer. The egg produces a substance called echinochrom which plays an important role in fertilization. At the time of fertilization this substance stimulates and attracts the sperm. It also exhibits an agglutinating phenomenon. It is also called the agglutinin or the fertilizin. Among its noteworthy features are the following: it requires a bivalent positive ion especially Ca^{++}. It is released by eggs and is not formed by other tissues and cells. It is secreted by mature eggs but not by immature eggs.

(b) Fertilization -- at the time of fertilization, the sperm approaches the egg by shaking the tail portion vigorously. As soon as the head of one sperm enters the egg, a membrane forms in that area and the fertilization membrane is formed. In a short time a transparent zone of a separate thin membrane forms on the surface of the egg. The sperm cell, which enters the egg, turns 180° with its midpiece advancing towards the centre and the aster appears. The nucleus gradually becomes larger, approaches and unites with the egg-nucleus and fertilization is complete.

(c) Cleavage -- shortly after fertilization the nucleus disintegrates and the chromosomes begin to form (the prophase); two asters appear, the spindle is formed and the chromosomes arrange themselves in a line along the equator (the metaphase); soon the chromosomes are drawn towards the two poles (the anaphase). The first division divides the egg into two equal halves including the egg axis. The second division also divides in a similar fashion yielding 4 cells. The space in the centre of the blastomere is the beginning of the blastocoel. The third division divides the cells equally at right angles to the egg axis separating the 4 cells into 8 cells with upper and lower portions. The fourth division divides the cell equally vertically at the animal pole, resulting in 8 cells of equal size. At the vegetal pole, the division results in unequal cells giving 4 large upper cells and 4 extremely small lower cells. The upper 8 cells are the mesomeres and later become the rudiment of the ectoderm.

The four cells in the middle are the macromeres, which is the part with pigment, and later become the rudiment of the endoderm. The four lower small cells are the micromeres and later become the rudiment of the mesoderm. In the fifth division the mesomeres in the upper position further divide into 16 cells with upper and lower sections. The macromeres divide vertically into 8 cells and arrange themselves into a single layer. The micromeres divide into upper and lower portions into 2 layers of 32 cells. In the sixth division the two upper and lower sections of the micromeres further divide horizontally into 4 upper and lower sections. The macromeres similarily divide horizontally into 2 zones. The micromeres undergo no division. This is the 56 cell stage and is called the morula stage. During the seventh division the cells undergo further division, the blastocoel becomes larger and the cells form a single layer on the surface. In the case of <u>Anthocidaris crassispina</u> the blastocoel is not distinct. However, in the case of such species as <u>Mespilia globulus</u> and others it is distinct. After 8-10 division the egg hatches. At about the ninth division cilia form on the cell, the hatching enzyme is secreted, the fertilization membrane dissolves and the cell becomes an embryo with cilia and starts to swim. The embryo enters into the floating stage in which it lives freely by means of ciliary movement. The period is referred to as the blastula stage. After this stage the embryo becomes somewhat longer, the cells become thicker and a portion with long immobile cilia develops. A forward and a rotary movement is carried out with this portion in the front. The micromeres, which eventually become mesoderm, gradually separate from the wall of the blastula into the blastocoel and run along the wall. They form the primary mesenchyme and become the rudiments of spicules. The transparent layer, which was in contact on the outer surface remains at the vegetal pole after the mesenchyme develops in the interior.

(d) Gastrula -- Following the blastula stage the formation of the gastrula starts. This consists of the formation of the depression of the archenteron and formation of spicules from the primary mesenchyme. The archenteron depression starts with the cells derived from those cells which eventually form the endoderm. The cells become somewhat longer. Gradually the depression starts from the surface of the wall. This endodermal plate contains the mesodermal secondary mesenchyme. The mesenchyme extends amoeba-like pseudopodia and grows towards the animal pole through the centre of the blastomere, reaches the wall of the ectoderm and unites the animal pole with the pseudopodia. At the same time the archenteron develops and reaches the upper wall. The blastopore which opens to the exterior of the side of the animal pole is formed. Also amoeba-like mesenchyme collects in two places in a triangle-shaped form and three-pronged spicules appear in the middle towards respective apices.

(e) Prism type or pyramid type (Prism larva) -- Continuing growth, the embryo develops into the Prism type. At this point it takes a form in which the axis of the gastrula inclines towards one side. At this point the skeleton develops. The oral depression forms and the mouth of the larva develops. Differentiation in the tissues of the digestive tract, which connects with the archenteron, takes place. The esophagus, which connects to the mouth, becomes thinner; the central sections broaden and become the stomach; the terminal section becomes thinner and develops into the intestine. The blastopore of the gastrula becomes the anus.

(f) Pluteus type (Pluteus larva) -- The skeleton develops markedly and straddling the mouth on the oral side a pair of "post-oral" arms and a pair of "front-side" arms are formed. At this stage of larval development the side of the animal with the mouth and the anus is the ventral side. The animal floats gently with this side up. It undergoes metamorphosis and develops into the larva of sea urchin.

The observations described above have been made in the laboratory. Under natural conditions fertilized eggs, which have been inseminated externally, sink to the bottom. In the case of Strongylocentrotus pulcherrimus they develop to the morula stage in approximately 10 hours. When they reach the blastula stage, cilia develop and they start to float near the surface of the water. They go through the gastrula stage and the pyramid type. They grow into the Pluteus type in approximately 3 - 4 days, undergo complicated metamorphosis and become sea urchin larvae. The period of floating is believed to be approximately 3 - 4 months. The larvae of the Pluteus type collect in large numbers near the surface of the water and float. The larvae, which have undergone metamorphosis and entered benthic life, adhere to Colpomenia sinosa (Roth) Derd. et Sol., lavers and other seaweeds and live on clinging type diatoms.

(8) Maturation period

With reference to the development and maturation period of the gonads there are studies by Miller (1931), Tennett, et al., (1931), Tennett and Ito (1941), Fuji (1960), Kawamura (1960), Matsui, et al., (1960) and others. The stages of development are defined in various ways by different workers; however, they can be generally divided into 4 to 5 periods.

(i) Zero period (neutral period)

The shell diameter measures 15-20 mm in Strongylocentrotus intermedius, 30 mm in S. nudus and 1.0-1.5 mm in S. pulcherrimus. The gonads are neutral. The external shape is thin and long. The body is semi-transparent. It is extremely difficult to distinguish the sexes.

(ii) The first period (period of recovery after spawning or virgin development period)

The gonads enlarge. It is possible to distinguish the sexes under a microscope. The gonads at the virginal development and the post-spawning recovery stages resemble each other. However, they can be distinguished since the follicular cell layer of the latter has large spaces and is reddish brown in colour while in the former it is small in size and white in colour.

Female: In the interior of the follicular cell wall many oogonia and a small number of oocytes appear. The oogonia are somewhat spindle-shaped; its cytoplasm is thin and surrounds the protruding nucleus made of the same substance. An immature oocyte is an irregular sphere and has a single nucleus of a relatively large size. The cytoplasm is smooth and can easily be distinguished from the follicles. The oocyte measures approximately 1.5-5 μ in diameter and the nucleolus is located in the reticulum.

Male: A large number of spermatogonia and spermatocytes appear along the follicular wall. The latter is small and can be stained with hematoxylin. Thus they can be distinguished. The follicular wall of males resembles that of females. There are many wrinkles in it and it is shrunken.

(iii) The second period (growth period)

The gonads are reddish brown but the difference in the colour of the sexes is not apparent.

Female: On the exterior of small leaves, small oogonia are observed; there are fewer of them than in the previous period. Immature oocytes of various shapes adhere on the inner side of small leaves. They measure 40-60 μ in diameter. A round germinal vesicle is located near the centre of the oocyte. It measures 20-30 μ.

Male: The testes exhibit active spermatogenesis. Spermatogonia and spermatocytes develop rapidly along the wall of the follicular cells. Towards the end the follicular cells become thickly fringed with a large number of gametes; however, no sperm cells are yet observed.

(iv) The third period (pre-maturation period)

Both in the male and female the gonads become markedly larger. At this stage it is possible to distinguish the sexes by colour. The ovary is yellow, brown or reddish brown. The testis is generally white with a tinge of yellow or cream.

Female: Active egg formation takes place. The egg cells become larger, assume an egg-shape, and push out prominently towards the centre of the follicular cell layer. They measure approximately 80-140 μ × 40-80 μ in size. The large sized germinal vesicle moves towards the pole of the egg cell and is smooth and round. The ovarian eggs gradually separate from the follicular wall. They are spherical or oval and measure 80-100 μ. The germinal vesicle measures 40 μ. The follicular cells contain egg cells 10-70 μ in size. The mature eggs are carried to the centre of the follicle; a greater section of the remaining portion is occupied by egg cells which attained the largest size.

Male: As in the previous period, active spermatogenesis takes place. There are marked increases in spermatocytes and spermatids. A small number of sperm cells begin to be formed at the centre of the follicle.

(v) The fourth period (maturation)

The gonads reach a maximum both in volume and size. The two sexes are readily distinguished by colour.

Female: Egg-shaped egg cells 80-100 μ in diameter fill the interior of the follicle. Immature egg cells extremely small in size are observed around the edge of the wall. The size of a mature egg does not differ from that of the previous period. The germinal vesicle can be stained with hematoxylin.

Male: It is full of sperm cells. Spermatogenesis does not go on too actively.

(vi) The fifth period (release period)

The gonads become thin and small after release. They become whitish brown in colour in both sexes. It becomes difficult to distinguish the sexes.

Female: The centre of the fillicular cell layer of the ovary is empty after discharge with a small number of mature eggs remaining in the ovary. The wall of the follocular cell layer shrinks and the middle layer, which consists of muscles and connective tissues, is clearly observed. The remaining eggs are absorbed by the phagocytes. The ovary assumes the conditions of the first period.

Male: There is a marked decrease in the number of sperm cells. A void develops in the follicular cell layer. The sperm cells which remain are observed near the wall.

Matsui, et al., (1960) defined the following periods on the basis of their study of *Strongylocentrotus pulcherrimus*: the first period, the period of disintegration and absorption, the second period, that of growth of the reproductive cells, the third period, that of multiplication, the fourth period, that of maturation, and the fifth period, that of spawning. The time of appearance of the various periods differs depending on the species and environment.

In the case of *S. intermedius* approximately 50% reach the first period in Rebun-To from November to February, from June to August approximately 50% have mature gonads, and from September to October they reach the spawning period.

It appears that local variations in various periods are due to the fact that the development of the gonads depends on variations in water temperature. The time of appearance of various periods tends to be delayed somewhat in places of low latitudes in comparison to those of high latitudes. Even in the same locale the appearance seems to be delayed in areas where the water temperature is low.

Further, it appears as though males mature slightly sooner than females.

(2) Relationship between light and maturity

Light and temperature are two factors which control maturity. Boolootian (1963) raised *Strongylocentrotus purpuratus* using circulated sea water maintained at 15° ± 0.5°C and exposed males in the spermatogenesis stage to light for periods of 14 and 6 hours per day, and made comparisons of the effect on maturity on the two. The results show that the 6-hour exposure stimulated the maturing processes. However, he felt there was a necessity for conducting further experiments with various combinations of exposure and temperature.

(3) Relationship with the phase of the moon

An examination of the relationship between variations in volume of the gonads and the phase of the moon shows that the volume changes regularly with the phase of the moon -- the volume is large during the period of a new moon and decreases as the phase changes to a full moon. This probably is the effect of the nocturnal and the negative phototropic character of the Echinoidea. This also coincides with the phenomena of spring and neap tides. Thus, it is possible that the difference in tides can be one of the stimuli (Moore, et al., 1963).

(9) Gonad coefficient

In order to indicate the relative size of the gonad, the gonad coefficient is widely used. The gonad coefficient is generally shown as the weight of the gonad (volume) × 10 or 100/Total weight (volume). Instead of the weight, the shell diameter is sometimes used. The volume is used widely abroad.

(1) Seasonal variations

Seasonal variations accompany the stages of maturation of the gonads; the gonad coefficient also exhibits seasonal variations. The value is important industrially.

Comparative studies were made on *Strongylocentrotus pulcherrimus* in the Yoshimi area and in the Mutsuren area. The results show there are differences between the two areas; that the minimal values were 7.9 and

10.7 observed in February, and that the maximal value was 24.1 observed in November.

In Fukui-Ken a maximum of 26 has been recorded (Kawana, 1938); the minimum was4 observed in March by those in industry. This is due to the fact that new tissues are formed immediately after spawning and there is a sudden increase in the weight of the gonads.

There are marked local variations in the development of gonads. Needless to say these differences are due to differences in the environment. The differences are observed in the monthly variations in gonad coefficients as well as in the degree of variation of various months. In Fukui-Ken the coefficient attains the highest value, 14.2 in April, decreases gradually and reaches the lowest value, 3.2 in January. In November before the spawning period, the variation is largest. It increases steadily to about February when spawning is completed and increases suddenly in March.

In the case of <u>Strongylocentrotus pulcherrimus</u> the coefficient is a minimum of 8 during October to November, 15 during January to February, shows a slow increase to June, and increases rapidly after June, reaching a maximum value ranging from 20-30 during July and August.

The period in which the gonad coefficient shows maximal and minimal values differs depending on the area. There is no marked geographical difference in the period of maximum value; however, the duration of the minimal value can be classified into two types. The classification depends on the duration of the minimal value. There are cases where the value rises immediately after the minimal value while in other cases the minimal value is maintained over a fairly long period. The existence of these two types is an indication of the effect of environmental conditions on the development of the gonads in sea urchins.

(2) <u>Relationship between shell diameter and weight (volume) of gonads</u>

The relationship between the shell diameter and the gonads can be shown by a gentle downward curve. After the gonads reach a certain stage of maturity, the relationship becomes linear.

In the case of <u>S. nudus</u> it occurs at 5-5.5 cm shell diameter (Kawamura, 1964).

In the case of <u>S. intermedius</u> the gonads of specimens with shell diameter less than 1 cm cannot be observed with the naked eye. A good portion of the gonads in those animals with a shell diameter of less than 1-2 cm are not developed; the gonad coefficients show values up to 0.1. The coefficients exceed 0.5 in those animals with shell diameter greater than 2.5 cm. Individual differences tend to become large in those animals with a shell diameter exceeding 3.0 cm (Fig. 20) (Kawamura, 1965).

Moore, et al., (1963) tried to establish the relationship between the shell diameter and the quantity of the gonad by multiplying the volume of the gonad (cc) by 10 and dividing this by the volume of the shell (Fig. 21 and Fig. 22).

In Lytechinus, large variations in the volume of the gonads are observed when a shell diameter of approximately 40 mm is reached.

An examination of the relationship between shell diameter and quantity in the gonad, (the volume of the gonads × 10/the volume of the shell), shows that the maximum value appears at shell diameter of 50-55 mm. In comparison to that of females, the proportion taken by the volume of the gondads in males does not become large until there is an increase in the shell diameter, and although it decreases after this sooner than that in females, the tendency is similar, and the difference between the two is slight (Moore, et al., 1963).

In the case of Tripneustes the transformation point is at a shell diameter of 60-62 mm (Moore, et al., 1963).

(3) Relationship with depth of water

In Strongylocentrotus pulcherrimus those animals found at depths exceeding 4 m have small gonads (Kawana, 1937). In Fukui-Ken those animals found in shallow waters, at depths of 1-2 m, had larger gonads with better colour, and this was closely related to the quantity of seaweeds, especially to that of green algae which was the main food. Collection is easier in shallow water than in deeper waters, and the opportunities for stone cover is better (Taki and Higashida, 1964). Further, the size of the sea urchin varies depending on the depth of water.

An examination of the gonad coefficients of S. intermedius with shell diampter of approximately 3 cm, by areas and by depths of water shows clearly that the gonad coefficients of sea urchins, which are found at depths less than 3 m, are without exception larger than those of individuals found at a depth of 4.5 m (Kawamura, 1964).

The gonad coefficients of specimens of Echinus esculentus, found in shallow waters rich in seaweeds, are large and the degree of shrinkage in these gonads, which is caused by discharge, is small. On the other hand gonads of specimens, found in deep waters where food is scarce, are small and shrinkage after discharge is large (Moore, et al., 1963).

(4) Relationship with the contents of the digestive tract

If a digestive-tract-content coefficient is defined as the ratio of the weight of the contents in the digestive tract to the weight of the sea urchin, in S. intermedius with a shell diameter 1-2 cm, the variation in the coefficients in the range 1.0-2.5 is large. The coefficients are higher in comparison to those of specimens with shell diameters exceeding 3 cm; but the group with a shell diameter 3 cm has a higher coefficient in comparison to those with shell diameters exceeding 4 cm; and the value tends to decrease in groups with the shell diameter exceeding 4 cm.

The digestive tract coefficient is higher than the gonad coefficient up to the point where the latter reaches approximately 1.3. When the latter exceeds 1.3, the former decreases in value. During May to August when the gonads develop, the digestive tract coefficient decreases with development in the gonad. During February to April, it shows a maximum value of 2.0; towards the end of August it becomes less than 1 and rises somewhat at the end of September. Thus, it is evident that there is a negative correlation between the two.

This fact shows there is a close relationship between foraging and the development of the gonads.

As has been mentioned, even though the gonads are identical qualitatively, quantitatively there are large differences depending on the habitat and environment.

This has been shown in the cases of Echinus esculentus (Moore, 1935), Strongylocentrotus purpuratus and S. franciscanus (Bennett and Giese, 1955). This is a fact tommon to all species of the Echinoidea.

A comparison of the weights of the gonads among groups of S. purpuratus from different latitudes shows that gonadal development in groups from low latitudes can be recognized early and there is no sudden development. On the other hand, in the groups from high latitudes the weight increases suddenly starting at the period somewhat before the spawning period. The phenomenon is due to food, water temperature and sunlight. It is believed that food, water temperature and sunlight exert a great deal of influence on the quantitative development of the gonads, the speed of development of the reproductive cells and the length of the reproductive period, and also the stimulation of the spawning action (Boolootian, 1959).

(10) Colour

The colour of the gonads differs depending on the species and environment. It appears as though the cause is mainly food.

Results of investigations at Shimonseki, on the relation between colour of the gonads and food in Strongylocentrotus pulcherrimus, show that the colour favoured by those in industry, tends to be found in sea urchins feeding on large quantities of green algae. On the other hand, individuals, whose gonads tend to be yellow, feed on large quantities of red, brown and calcareous algae (Matsui, et al., 1960).

Generally the volume of the gonads of specimens feeding on green algae, is large; the colour is also good. In many cases the colour of the shell generally is also green. Those which feed on brown algae have a small gonad volume whose colour is tinged with brown. Irrespective of the type of algae the sea urchin feeds on, the colour of the gonads becomes orange because of chlorophyll, carotene, xanthophyll and fucoxanthin, which are contained in green and brown algae. Chlorophyll is contained in large quantities in green algae, and fucoxanthin in brown algae. The colour which results from brown algae, becomes tinged with brown because of the presence of black-brown pigments and fucosan. Further, since the product comes into contact with air and since the moisture is removed from it, the colour becomes a deeper black-brown (Kawana, 1938).

In addition to the regular colour of the gonad, cells with grains of reddish pigment are present and specimens with spots in the gonads are found. This has been reported in Strongylocentrotus droebachiensis and S. franciscanus (Kindred, 1924), S. pulcherrimus, Anthocidaris crassispina and the Echinoidea of the Regularia (Kawaguchi and Yamasu, 1954), S. intermedius and S. nudus (Kawamura, 1964). In that section of the gonad with dots, a large number of cells with reddish black grains of pigment are present, and in the interior (it is not known if it is the interior or the surface of the sexual glands) C-shaped spicules approximately 60 μ in length are formed.

These black pigmented cells appear when part of the shell has been damaged or when calcareous algae have been consumed in large quantities. Further, the spicules are always present. It appears that the phenomenon is related to the formation of tissues with a calcium compound as the main component of the shell and the spicule. On the other hand, it appears as though the spots tend to decrease or disappear with the development of the gonads. Thus, it appears that the phenomenon is related to the quality and quantity of food and to the development of the gonads. In one experiment involving transplanted S. intermedius, 60% were found with dots, and spicules were found in most of the remaining specimens. The colour of the gonads was inferior (Kawamura, 1964).

6. Growth

In order to measure growth in the Echinoidea its age must be calculated. There are two methods to determine age. One is to analyze the composition of shell diameters in natural groups of sea urchins and the other is to raise them experimentally. In addition to these methods there is one which is based on the theory that the ring pattern caused by pigment deposits on the genital plate is related to age (Kume, 1929; Moore, 1935). Ordinarily, age determination based on the composition of shell diameters is widely used. The rearing method can be used for observations over a period of approximately a year. It is not suitable for investigations extending over a long period of time.

(1) Relationship between shell diameter and weight

In the case of Strongylocentrotus pulcherrimus its weight is 4 g when the shell diameter is 2 cm, 10 g at 3 cm and 25 g at 4 cm; thus, the increase follows a geometric progression. The curve slopes gently downward and the relation between the two can be shown by the expression W (Weight of shell) = 1.7 $D^{2.55}$ (shell diameter).

A similar relationship exists in Anthocidaris crassispina. The relation between the two is expressed by $W = 0.001\ D^{2.86}$.

In S. intermedius the expression is $W = 0.45\ D^{2.80}$.

In Tripneustes ventricosus the following expressions between the diameter and the height of the shell hold for two areas near Miami:

$H = 6.17 + 0.51\ D$ .... Shores of Boca Raton

$H = 8.34 + 0.55\ D$ .... Shores of Virginia Key

Morphological differences in sea urchins are related to environment. Thompson (1917) felt that two forces influenced the morphology of the sea urchin, one acted in the direction of gravity to pull the ambulacral feet downward, the other exerted its influence radially outward, and that these forces tended to flatten the sphere. However, Moore (1935) pointed out that in the case of Echinus esculentus, the individuals which were found in seas with violent waves developed flat and thick shells in comparison to those which had been found in relatively calm shores. He concluded that the flat shape of sea urchins in the Boca Raton area was the result of sea urchins growing on reefs which had been subjected to violent waves (McPherson, 1965).

(2) Relationship with age

If one attempts to obtain the composition of shell diameters in Strongylocentrotus pulcherrimus by Petersen's method of analysis of size frequencies, one obtains the equation $l_t = 47.45\ (1 - 0.71^t)$. Thus, growth will be 10 mm in the summer of the current year, 21 mm in the following year, 28 mm in the third year, 34 mm in the fourth year, 37.9 mm in 4.5 years, 40.61 in 5.5 years and 42.53 mm in 6.5 years. There is good agreement between the theoretical values and the observed values (Fuji, 1963).

The growth rates obtained by sampling shell diameters of Strongylocentrotus pulcherrimus, in Yamaguchi-Ken, show 8-9 mm in 0.5 years, 21-22 mm in 1.5 years, 32-33 mm in 2.5 years and 41-42 mm in 3.5 years (Matsui, et al., 1965). In Fukui-Ken they were 5 mm in 0.5 years, 12-13 mm in 1.5 years, 24-25 mm in 2.5 years, 35-36 mm in 3.5 years and 44-45 mm in 4.5 years. In Nagasaki-Ken they were 5-6 mm in 0.5 years, 15 mm in 1.5 years, 25-26 mm in 2.5 years, 35-36 mm in 3.5 years and 40-41 mm in 4.5 years. Thus, there are marked geographical differences. However, the southern regions do not always show good growth.

The results of investigations carried out in 1960 at Yoshimi and Mutsure-Jima in the City of Shimono-seki, show that growth differs considerably depending on environment even in areas relatively close to one another. Since the spawning period extends from October to the middle of March in Yamaguchi-Ken, there is a marked difference between the groups spawned at the beginning and at the end of the spawning period. Specimens of sea urchins collected on June 9, 1960 at Yoshimi measured 4.4-4.9 mm in shell diameter and 0.08-0.1 g in weight (3 specimens). Specimens collected on June 27 measured 2.8-5.9 mm in shell diameter and 0.1-0.11 g in weight (6 specimens). However, Nakamura, Inoue, et al. (1965) collected young sea urchins in March 1964 and reared them in the laboratory for a full year until March 1965. They obtained 3 specimens which measured 17.5 mm, 23.7 mm and 25.5 mm. The sea urchins raised indoors showed better growth than those collected from nature.

Past studies are listed in Table 23.

The growth rate in S. intermedius was measured by grouping shell diameters, which had a normal distribution, by means of Harding's method using probability paper (Fuji, 1960).

The results of the separation of normally distributed shell diameters by this method show 5 different groups with average shell diameters of 15.7, 33.1, 42.6, 49.2 and 54.9 mm (Table 24).

The equation of Bertalanffy can be applied to the growth curve which is derived on the basis of food and physiological mechanism. An attempt to derive a curve similar to Deming's by the least squares method on the basis of observed values of shell diameters and ages obtained from the frequency distribution, results in the following expression with a probability exceeding 50%:

$$D = 69.0383\ (1 - e^{-0.31524})$$

The shell diameters are estimated to be approximately 19, 32, 43, 49 and 55 at ages 1, 2, 3, 4 and 5, respectively (Fuji, 1962).

Results of investigations, which have been carried out at Oshoro in the north by a similar method show the average diameters to be 7.5 mm at 1 full year, 25 mm at 2 full years and approximately 35 mm at 2.8 years (Kawamura and Hayashi, 1965), showing considerable differences between the two areas.

Further, two groups with average shell diameters 6.3 mm and 23.8 mm were kept in a concrete water tank and filtered sea water was circulated through this tank. The sea urchins were fed with Laminaria religiosa Miyabe and raised at water temperatures of 7-26°C and specific gravity at 1.024-1.025. A comparison of these groups to natural groups (Oshoro) has shown that growth in the former was slower than the latter (Fig. 27) (Kawamura and Hayashi, 1965).

In summary, in S. intermedius, growth rates are higher in the 1 and 2 year old groups -- the tendency being especially marked in the 1 year-old group, in the 2 year old group the rate gradually becomes slower beginning in the summer. However, in both groups, growth continues throughout the year. In 3 year and older groups, growth is limited to the winter season for a period of 4 months starting at about November and growth ceases completely in the summer.

An examination of the annual variations in the ratio shell height/shell diameter in Strongylocentrotus pulcherrimus shows that the height of the shell is large during the spawning season extending from November to March, and the shell diameter shows large values during April to October. This indicates that growth in height and diameter of the shell varies seasonally (Matsui, et al., 1960).

The results of the investigation made on Strongylocentrotus droebachiensis are shown in Table 26 (Swan, 1961).

Further, with respect to specific differences, S. franciscanus has a faster growth rate than that of S. droebachiensis. S. purpuratus has a slower growth rate than S. echinoides (Swan, 1961).

Results of examinations by age groups of the relation between the shell diameter and the shell volume of Lytechimus variegatus are shown in Fig. 29. Measurements of the shell diameter growth made in the Bermuda and Miami area, show that shells with a diameter of 10 mm at the end of January grew rapidly during the summer to 50-55 mm in January of the 2nd year; the same shells measured 70 mm in the 3rd year showing a considerably slower rate of growth. The maximum size was 78 mm (Moore, et al., 1963).

An examination of the growth rate of T. ventricosus using increases in shell diameter, shows that the diameter grew 6 mm every month from August to November, continued growing during the winter through March, and finally grew to over 60 mm. It reaches 75-80 mm in November of the same year (McPherson, 1965).

(3) Relationship with body tissues

If the body of S. intermedius is divided on the basis of "life-functions" into four parts consisting of (1) the shell (in addition to the shell-plate, spines, ambulacral feet, the membrane inside the shell and the peristomal membrane); (2) the lantern (the pharynx); (3) the digestive tract (the digestive tract, the water-vascular system and the stone canal); and (4) the gonads; and if the proportion of the increase of each of these sections to the total increase is obtained in the body of the sea urchin, which has been raised from February to July on Laminaria japonica Aresch. as food, it is evident that the proportions can be segregated into two groups on the basis of the size of the shell diameter. One group is the larval group with a shell diameter less than 28 mm in which approximately 60% or more of the food is used for increase in the shell; the other group is the mature group with the shell diameter exceeding 38 mm and here 60-90% is used for increase in the gonads. A somewhat similar tendency is observed in the increase in protein (Table 27). However, even in the mature group, where the food is used mostly for hyperplasia in the gonads, from a seasonal point of view, the period from November to February corresponds to the recovery period after spawning, and even though there is an increase in the amount of food intake, a good portion of the nutrients, which are digested and absorbed, are used for shell growth. Thus, the shell growth is maximum in this period. The amount of food taken is a maximum during the period from March to May. The nutrients are directed towards the development of the gonads which vary greatly in quality and quantity, and the growth in the shell decreases. During the period extending from June to August the amount of food taken decreases, the nutrients are used mostly for hyperplasia in the gonads and shell growth is very small or ceases entirely. During the period September to October, spawning takes place and as the result of the discharge of eggs the hyperplasia in the body becomes negative. The amount of food taken also becomes small (Fuji, 1963).

In _Tripneustes_, with a shell diameter of 80 mm, the gonads weigh 4.37 g and the tissues exclusive of the gonads (excludes spines) 1.90 g. An examination of the relationship between the shell diameter and these two factors shows that at a shell diameter of 40 mm, as the gonads develop, the ratio of the two becomes reversed. At a shell diameter 70 mm the hyperplasia for the most part ceases (Moore, et al., 1965).

(4) _Relationship with water temperature_

Water temperature is a factor in the growth of aquatic creatures. Kawamura and Hayashi (1965) raised _S. intermedius_ in water tanks measuring 80 × 50 × 40 cm with water circulating at various temperatures and made comparison of their growth rates.

The results show that even though _S. intermedius_ is found in the northern part of Japan around Hokkaido and belongs to the type which prefers colder seas, its growth takes place most favourably in the water temperature range 5-7°C, followed by 10-12°C. Growth is poorest in the range 18-20°C. After May it was raised under temperatures somewhat approximating natural conditions. The results were similar to those noted in the tanks.

In mature specimens of _S. intermedius_, growth ceases during the summer season. This is common to sea urchins which inhabit the colder region and is the result of the effect of water temperature. Within the water temperature range 0 to 10°C no direct effect of water temperature is observed; however, an adverse effect is observed at temperatures exceeding 20°C (Kawamura and Hayashi, 1965).

Echinus esculentus and Lytechinus variegatus are extremely sluggish when the water temperature is high in comparison to the activity noted when the water temperature is low and as was the case in the previous species growth ceases in the summer (Moore, 1935; Moore, et al., 1963).

An examination of annual variations in Tripneustes ventricosus in the water temperature range of 20-32°C, shows that active growth takes place from the end of November to the end of February reaching a maximum at 22°C; from March to July although as the water temperature rises close to 32°C, growth becomes slower, and growth ceases when the water temperature reaches the maximum (McPherson, 1965).

(5) Relationship with type of food

Two types of seaweeds, Ascophyllum and Laminaria, were fed to Strongylocentrotus droebachiensis for one year from July 12, 1956 to July 1957, and comparisons were made of the resulting growth.

Results have shown that growth was better, approximately 70% or more, in specimens which were fed with Laminaria in comparison to those fed with Ascophyllum (Swan, 1961).

(6) Life span

No previous work definitely established the life span of the sea urchin. The maximum shell diameter of Strongylocentrotus pulcherrimus was reported by Fuji (1963) as 52 mm and diameters exceeding 45 mm were rare. Mortersen (1943) reported it was 55 mm. On the basis of growth rates the life span appears to be over 5 to 6 years; probably 7 or 8 years.

There is a record of Psammechinus miliaris having been kept for 6 years (Bull, 1938).

7. Rearing larvae

Although present conditions do not require the artificial production of urchin seed for increased production or for propagation of the Echinoidea in the coastal areas, nevertheless active attempts are being made to rear the larvae for the cultivation of Echinoidea.

(1) Methods of rearing

Brooks (1882) and Garman and Colton (1883) reared plutei of Arbacia punctulata with no food and the larvae metamorphosed. However, this does not mean that food is unnecessary for growth and metamorphosis. It is believed that the growth was due to the use of sea water rich in diatoms.

C. Grave (1902) reared larvae of Mellita testudinata by feeding them Nitzschia closterium.

Shearer, de Morgan, Fuchs (1914) and others cultivated large quantities of Nitzschia closterium and Lichmophora by Miquel's solution (Allen and Nelson, 1910), and used it as food. They succeeded in raising the larvae of 4 or 5 species of sea urchins. They were able to bring the sea urchins to maturity. Further, Fuchs (1914) by a similar method was able to obtain an F_2 generation by mating them.

The young after metamorphosis benefit from the addition of the calcic protozoa Trichospherium. It is reported that it is found in abundance adhering to the red algae Corallina (Shearer, Morgan and Fuchs, 1914).

Miquel solution:

A solution: KNO_3 - 20.2 g Distilled water - 100 cc

B solution: $Na_2HPO_4 12H_2O$ - 4 g $CaCl_2 6H_2O$ - 4 g

$FeCl_3$(solution) - 2 cc HCl - 2 cc

Distilled water - 80 cc

2 cc of A solution and 1 cc of B solution are added to 1ℓ of sea water which is heated to 70°C and sterilized. In order to remove the precipitates which form when B solution is poured into the sea water, the supernatant is transferred without disturbance.

Ketchum and Redfield (1938) reported that the best results for culturing Nitzschia were obtained when 0.002% Na_2HPO_4 $12H_2O$ and 0.01% KNO_3 was added to sea water at 20°C. In Japan, the Miquel-Matsui variation method is widely used.

M.W. Johnson (1937) raised the larvae of Strongylocentrotus franciscanus with diatoms consisting mainly of Navicula.

Onoda (1932) artificially propagated Mespilia globulus and fed the larvae with several species of diatoms which were found adhering to Zostera marina L. He kept the larvae for 35 days and was able to bring them to the metamorphosis stage.

Yamabe (1962) fed Chaetoceros simplex, Skeletonema costatum and Chlamydomonas to Pseudocentrotus depressus and reared them for approximately 40 days during which time metamorphosis was completed -- the main body of the pluteus disintegrated along with the withered arm and the imago form appeared. He carried out several rearing experiments.

The results show: that 5 days after hatching the size is 475 μ and that food is not required up to that period; that the ideal rearing density is 10 individuals per 1 cc and that some effects are noticeable when this is raised to 10^2 individuals. The favourable temperature range is 19-23°C. It appears as though 21°C is most favourable.

When the specific gravity (σ_{15}) is lower than 20, growth slows down suddenly. When it is less than 18, growth ceases entirely.

Results seem to be better at higher salinities.

Fifty larvae (8 days after fertilization) in which the postero-dorsal-arm was starting to develop were placed in a 500 cc beaker. The water was kept at approximately 20°C and was replaced with fresh sea water once in 3-7 days. Chaetoceros was used as food at the rate of approximately 10^4 cells per 1 cc. The experiment was continued for 40 days until the metamorphosis was complete; the yield was 42%.

Uchida (1963) raised the pluteus larvae of Strongylocentrotus pulcherrimus and Pseudocentrotus depressus by maintaining a dynamic balance between food and larvae and by circulating the water by means of air. The yield was high. Further, he succeeded in bringing about metamorphosis in 20 odd days. Uchida and Uno (1964) conducted similar experiments by adding Chaetoceros simplex to pluteus larvae of Strongylocentrotus pulcherrimus and established the fact there was a close relationship between the growth of larvae, the rate of malformation and the density of the food. A density of 30,000 cells of the food organisms per mℓ at the beginning of the rearing period produced extremely good growth in the larvae. When the density reached 70,000 cells/cc, growth was not normal and malformation resulted. They felt that a constant density was necessary for a high rate of metamorphosis.

Nakamura and Inoue (1965) used a 2ℓ flask with a flat bottom as a container and Chaetoceros calcitrans as a food which was administered in such a way that the concentration was 10^4 cells/cc. The water temperatures were maintained at 15-20°C in the case of Strongylocentrotus pulcherrimus and at 26-27°C for Anthocidaris crassispina. They were raised by pumping air into the flasks. It was found that up to the time, when the shell diameter was approximately 8 mm, they only ate adhering diatoms. After this period they subsisted solely on seaweeds. Thus a change in the food habit was observed at a shell diameter of 8 mm. In Anthocidaris crassispina its characteristic colour began to appear at about 6 mm.

Seaweeds were given when the shell diameter reached 3 mm since the yield after feeding on seaweeds was extremely good, over 90%. Thus, although the density of floating diatoms affects the yield, the rate of malformation and growth when used as food, appears as though a change from adhering diatoms to seaweeds at the earliest possible period is desirable.

Geotaxis -- Many research workers abroad (Bagioni, 1905; Parker, 1922 and others) have concluded that geotaxis is not present in the larvae of many species. However, Yasumasu (1963) suggested that free swimming embryos of Pseudocentrotus depressus and Strongylocentrotus pulcherrimus sank to the sea bottom due to geotaxis in various developmental stages. Neya (1965) raised larvae of Strongylocentrotus pulcherrimus in large tanks and observed that they did not collect at the bottom, but suspended themselves in a belt-like fashion in a certain position in the tank. The position of the larvae changed with the passage of time during the day, and this movement was not due to geotaxis, but to the movement of light; they collected at the light. The larvae showed vertical movement but their movement on the surface of water had no consistent direction. They show a particularly active upward movement in the dark, and when light is shone, they move downward. When these movements come to equilibrium, they collect at the point of optimum intensity.

(2) Effect of chemicals

Okubo, et al., (1961) investigated the effect of various chemicals on embryos of Strongylocentrotus pulcherrimus and Anthocidaris crassispina in their initial stage of development (Table 34).

An examination of the table shows that the concentrations which caused no adverse effects on the development of Echinoidea are somewhat similar to the safe concentrations for saltwater fishes in the coastal areas.

(3) Improvement of species

With the success in experimentally rearing larvae, experiments are actively being conducted to improve the species by crossing.

Among those species whose spawning periods are close, natural crossings take place, and the following crosses have been reported:

Echinus esculentus × E. acutus	(Mortensen, 1928)
E. esculentus × E. elegans	(Mortensen, 1928)
E. esculentus × Psammechinus miliaris	(Mortensen, 1928)
Strongylocentrotus droebachiensis × S. pallidus	(Vasseur, 1952)
S. purpuratus × S. droebachiensis	(Swan, 1953)
S. purpuratus × S. franciscanus	(Swan, 1953)

Morgan (1893) artificially crossed Arbacia punctulata males with Asterias forbesii females and made observations up to the gastrula stage. Since then genetical experiments have been attempted by many research workers on many species.

Results of these experiments indicate that morphologically the maternal characteristics are inherited and that the type which is intermediate between the two species is rare. It has been reported that *Arbacia punctulata* male × *Lytechinus variegatus* female (Tennent, 1912), and others resulted in intermediate types.

Temnopleurus toreumaticus ♀ × *Mespilia globulus* ♂
Mespilia globulus ♀ × *Temnopleurus toreumaticus* ♂
Temnopleurus toreumaticus ♀ × *Anthocidaris crassispina* ♂
Anthocidaris crassispina ♀ × *Mespilia globulus* ♂
Mespilia globulus ♀ × *Anthocidaris crassispina* ♂
Mespilia globulus ♀ × *Diadema setosum* Gray ♂
Temnopleurus toreumaticus ♀ × *Astriclypeus manni* Verrill ♂

In the above experiments normal larvae were produced from *Temnopleurus toreumaticus* ♀ × *Mespilia globulus* ♂ and *Mespilia globulus* ♀ × *Temnopleurus toreumaticus* ♂, but the other combinations produced malformed larvae. Generally a paternal or a maternal inheritance is exhibited. The speed of occurrence of the paternal side has no effect on that of the hybrid larvae. Stronger pigmentation is dominant in the young (Onoda, 1934).

Uchida (1963) observed that when *Pseudocentrotus depressus* × *Strongylocentrotus pulcherrimus* were crossed the rate of fertilization was low. The larvae developed normally till the beginning of the pluteus period, but malformed larvae appeared in large numbers when the pedicellaria formed. Morphologically the maternal characteristics were exhibited. Uno (1965) succeeded in crossing *Pseudocentrotus depressus* ♀ × *Anthocidaris crassispina* ♂, *Pseudocentrotus depressus* ♀ × *Strongylocentrotus pulcherrimus* ♂, *Strongylocentrotus pulcherrimus* ♀ × *Pseudocentrotus depressus* ♂ and *Strongylocentrotus pulcherrimus* ♀ × *Anthocidaris crassispina* ♂ and observed that the rate of fertilization in every hybrid was approximately 50% which is lower than the fertilization rate of a single species. The number of days required to complete metamorphosis was 23 days in the case of *Pseudocentrotus depressus* and *Anthocidaris crassispina* and this was the shortest time. The others required approximately 30 days. In each case the rate of metamorphosis was 5-12%. Morphological characteristics of the hybrid larvae were investigated by observing the spicules. It was found that a relatively large number of plutei, which had inherited the character of females, were present.

Nakamura and Inoue conducted experiments to cross and rear *Strongylocentrotus pulcherrimus* ♂ × *Pseudocentrotus depressus* ♀ and *Strongylocentrotus pulcherrimus* ♀ × *Pseudocentrotus depressus* ♂. Fertilization resulted in both cases. In the latter cross ambulacral feet and spines developed. The larvae were destroyed on the 35th day after they settled to the bottom. They reported the young showed characters closer to *Strongylocentrotus pulcherrimus*.

For industrial purposes it would be desirable to produce an improved strain by crossing Strongylocentrotus pulcherrimus, which has superior qualities, with a species such as Pseudocentrotus depressus or S. intermedius which have a large size.

Production of sea urchin seedlings of existing species is not too important. Stress should be placed on producing hybrids which are superior to existing species with respect to the size of the gonads, which results from animals of a larger size, or which exhibit a faster growth rate. One problem will be the difficulty of cross breeding because of marked differences in the spawning periods. However, as has been established in many investigations, the maternal characteristics are dominant, and the problem can be solved readily by preserving the sperm cells for a long period of time.

(4) Methods for preserving sperm cells over a long period

The preservation of sperm cells was developed in connection with artificial insemination in cattle. In the past a temperature range of 2-5°C, which is slightly higher than the freezing point, has been regarded as most suitable for preserving sperm over a long period of time. However, since the development of the deep-freezing method in 1949 it became possible to store sperm and maintain a high rate of fertilization and the method now is widely used. However, there has not been any necessity for its use in marine animals and no investigations have been made. It is hoped that the method will be successfully applied to cross breeding sea urchins.

The principle of the deep-freezing method is as follows: as a primary diluting solution, the seminal fluid is mixed with 1 part yolk and 3.92 parts citric acid soda at 30°C. (The author does not specify what type of yolk is used. He does not mention whether the proportions are by volume or by weight. N.B.) The temperature is then lowered to 4°C in 1-1/2 or 2 hours. The mixture is further diluted by addition of 14% glycerine and citric acid soda and left standing for 6-18 hours to bring about the so-called glycerine equilibrium. Then the mixture is cooled suddenly to -79°C by means of dry ice. By this procedure the water in the seminal fluid does not crystallize but goes into a glass-like form. Depending on the species of cattle, the concentration of the diluting solution, the type and the quantities of additives, the concentration of glycerine, the glycerine equilibrium time differs. Before this method can be applied to marine animals it will be necessary to investigate these factors. There is hardly any reduction in the rate of fertilization when sperm is preserved for two years (Table 35).

In view of the progress which has been made in the field of artificial insemination, an improvement in the rate of fertilization can be expected.

Harvey (1956) reported that sea urchin sperm preserved for 4-5 days at a water temperature of approximately 8°C gave 100% fertilization.

8. Ecology

(1) Movement and life habits

The movement of sea urchins is slow. Movement is accomplished through the spines on the buccal side. When the animal moves along a sloped surface of a rock, it uses the ambulacral feet.

Many workers have recorded the speed of movement of various species.

The speed in a short period of time is extremely fast. Generally the reef areas, in which sea urchins live, rise and fall markedly. As has been shown by Holmes (1912) the sea urchin is able to move in any direction by means of its spines and ambulacral feet. It does not move in a straight line but takes a circular path with the result that the straight line distance covered is relatively short. In experiments which were conducted by the author and his co-workers (1960), the distance covered was merely 4 m in 3 months.

Many species attach pebbles, shells and seaweeds by the ambulacral feet to the body. It is believed that this habit protects them against harmful enemies or against strong light.

In ancient times sailors believed that when sea urchins hugged the stones a storm was approaching and they would not sail out of a harbour (Camerarius, 1654).

A similar belief is held in fishing villages across Japan. When sea urchins remain deep in the fissures in reefs or at the base of rocks or when they hug small stones, this phenomenon foretells an approaching storm and one must be cautious.

The sea urchin is apheliotropic and nocturnal. *Strongylocentrotus pulcherrimus* forages actively during the night. It is most active at about 4 a.m.

(2) Enemies

Although the sea urchin is protected by spines, it is preyed upon not only by men, but also by fish, gastropods, birds and marine mammals as well as land animals.

Fish: *Gadus aeglofinus* eats *Echinocyamus* and *Echinus* (Smith, 1891) or *Arbacia* or *Strongylocentrotus* (A. Agassiz, 1872-74; Nordgaard, 1899). *Gadus aeglofinus* and other large fish eat large quantities of *Echinarachnius parma* and *Mellita pentapora*. *Anarhichas lupus* swallows *S. droebachiensis* whole, disregarding spines (Coe, 1912). The same species was observed eating Echinus esculentus in a tank (Östergren, 1938). Trigla gurnardus, a species of cunner, eats Psammechinus miliaris; Platessa vulgaris, a species of flatfish, eats P. miliaris and Echinocyamus pusillus; Rhombus laevus and R. maximus, species of flounders, and Solea vulgaris eat Echinocyamus pusillus (Sauvage, 1892). Cestracion (Centracion japonicus Dumeril) eats sea urchins (Petersen, 1918). In the western section of the Indian Ocean the queen trigger Balistes vetula, toadfish Opsanus beta, grunts Haemalon sp. and others also eat sea urchins (Mortensen, 1943). On the other hand in the seas near Denmark it is regarded as worthless as bait for fish (Petersen, 1918).

In Japan Hoplegnathus fasciatus pokes and cracks the shell of Anthocidaris crassispina or Pseudocentrotus depressus with a great deal of effort with its pointed lips, bores holes and eats the contents (Nakamura, 1932). In Hokkaido the sea urchin is the best bait for Hexagrammus otakii; it is used by rolling it very gently; in addition the shells of the sea urchin are crushed and used as groundfish bait (Matsuzaki, 1942).

Gastropoda: Carnivorous gastropoda, which belong to the Cassididae, Cassis madagascarensis eats Plagiobrissus grandis and C. tuberosa eats Tripneustes esculentus, Phalium ganulatum and Mellita quinquiesperforata (Moore, 1956).

Crustacea: A lobster twists its body, holds a sea urchin under its arms; first removes the spines with its mandible, makes a hole in the shell and eats the contents (Nakamura, 1932).

Mammals: A sea otter will sink to the bottom of the sea, search and collect sea urchins, float on its back on the surface, crack the shell and eat the contents (Matsumae, 1781). It may nibble at the shell, open a hole, and within a short time either suck or lick out the internal organs. Sea otters in the central section of the Kuriles were observed holding two sea urchins, one in each hand, breaking the shells by striking one against the other (Matsuura, 1943). Similar observations were made by Barabash-Nikiforov (1933).

Results of investigations of the stomach contents of sea otters during 1934-1940 in the Kuriles indicated that the largest portion, 23.9%-40.9% was made of Strongylocentrotus sachalinicus, followed by octopi, 23.6%, sea mussels and other shellfish, fish eggs and young fish in the order mentioned (Miyatake, 1940, 1943). In the Komandorskiyes, sea urchins were the main food of sea otters. They occupied 59% of the total diet, followed by molluscs, crabs, fish and seaweeds (Barabash-Nikiforov, 1935).

Dugongs feed mainly on Zostera such as Cymodocea or Posidomia; however, they also take sea urchins, sea cucumbers and crabs (Taylor, 1908).

Alopex lagopus catches and eats sea urchins and other Echinodermata (Mori, 1943). Further, it is reported that sea urchins make up most of the winter food (Mortensen, 1943).

Birds: When they are exposed on reefs at low tide, sea urchins are caught and eaten by birds. Crows carry them up in the air and drop them on a rock. Herring gulls carry Echinus esculentus or Lytechinus in the air as high as 10 feet and if the ground is wet sand, drop them 4 to 5 times until the shell breaks, and eat the gonads. In Greenland downy gulls eat sea urchins. However, these gulls cannot catch sea urchins found at a depth exceeding several cm. Several species of small wading birds, especially plovers and others clean up the entrails of sea urchins left by gulls (Mortensen, 1943).

Diadema antillarum, which is found in the western section of India, preys upon the Echinodermata (sea urchins or starfishes) and especially upon one species Tripneustes esculentus. It never preys upon the other 3 species. Whether this is preferential or whether it is due to difficulties because of body structure is not known. However, it chooses the species which possess weak and soft spines. In addition to Diadema, Astropyga pulvinata eats Echinodermata when starved.

Diadema is able to consume a single individual of Tripneustes completely in approximately 24 hours (Quinn, 1965).

(3) Parasites

A large number of species and a large quantity of parasites are found in the Echinodermata. It is not known if they cause disease or death in the sea urchin.

Approximately 12 species of the ciliata (Colpidium echini Russo, Cryptochilum echini Maups, Anophrys echini Di. Mauro) are parasitic in the digestive tract of the Echinoidea of Japan. The following constitute the 5 main species (Fukui and Kamimura, 1933): Entorhipidium echini, Entodiscus borealis, E. indomitus, Cryptochilum echini and Anophrys elongata. They come into containers along with the gonads at the time of artificial insemination, multiply, capture and eat the young at various stages of development. On the wall of the digestive tract of Spatangoids, Sporazoa are observed.

Two species of nematodes, Oncholaimus echini and Ichthyonema grayi, are parasitic in the coelome and in the digestive tract of Echinus esculentus. Trematodes are commonly observed in the gonads and include Syndesmis echinorum and Mespilia globulus.

Gastropods such as Stylifer, Pelseneeria and Mucronalia bore holes in the shells of sea urchins. Several species of Crustaceans are also found in sea urchins. Pionodesmodes phormosomoe causes swelling in the shell and Echinocheres globosus causes abrasions of the spines. Small crabs are parasitic in the rectum of sea urchins found in South America and cause irregularities in the apical system. Zebrida adamsii lives on several species of sea urchins found in the tropics, attacks and causes damage to the spines and to the ambulacral feet. As examples of animals leading a parasitic or symbiotic existence, one can mention a bivalve, Montacuta, which lives among the spines of Spatangus or Echinocardium, and Philomedes brenda, which occurs around the anus of Strongylocentrotus droebachiensis.

(4) Respiration and excretion

The amount of oxygen consumed in an hour by Strongylocentrotus pulcherrimus with a shell diameter 2.5-3.0 cm was 0.50-0.81 cc at 31.6°C. The average was 0.72 cc.

The respiration rate (O_2 cc/hr) of two species, Tripneustes esculentus and Lytechinus variegatus, increases with temperature up to approximately 35°C; but for the same temperature the respiration rate is larger in winter than in summer (Fig. 39). In Lytechinus it is 0.5-0.95 cc at 15°C and 2.2-2.8 cc at 30°C. In the case of Tripneustes the consumption is 0.8-1.5 cc at 15°C and 3.3 cc at 30°C.

Thus, for animals of the same size, the oxygen consumption is larger in Tripneustes. Further, within the same species, smaller individuals have greater respiration rates than larger individuals.

With respect to various tissues the consumption is 1.47-1.54 cc/g of dry weight for the digestive tract and body tissue. This is 5 times the consumption in the gonads, 0.24-0.30 cc.

It is difficult to determine the amount of excretion on the basis of the quantitative determination of carbon. The ratio on the basis of phosphorus determination is 106 : 1. The amount of excretion is proportional to the capacity of the shell when calculated using as a percentage the amount of food taken. Seasonal variations are not too marked in the case of Tripneustes. However, in the case of Lytechinus there is a slight increase in summer. The rates of excretion are 4.5% in summer and 16.2% in winter in Lytechinus and 2.1% in summer and 2.3% in winter in Tripneustes. Those of the former are much larger.

9. Production

(a) Size of catch and amount processed

The consumption and demand for Echinoidea is increasing annually. Increased demand is followed by an increase in the size of the catch (weight of gonads) and in the amount processed, by approximately 20%. Of the total production in Japan (14,000-19,000 tons, 1961-1963), 45-58%

is produced in Hokkaido. A recent trend shows sudden increases in production in Nagasaki-Ken and Kumamoto-Ken. Generally production in the northern areas is larger than that in the southern areas. Yamaguchi-Ken processes 48-64% of the total production.

In 1962 the total catch was 16,474 tons. The monthly variations show a maximum of approximately 4,400 tons in July and a minimum of less than 500 tons during October to March. The yield was large during May to August and accounted for approximately 70% of the total catch (Fig. 41).

An examination of the catch by species in the Japan Sea in Yamaguchi-Ken shows Strongylocentrotus pulcherrimus makes up the largest portion of the total, 63%, followed by Pseudocentrotus depressus 23% and Anthocidaris crassispina 14%. An examination of the monthly variation in catch shows that 85% of the total is caught in 5 months during April to August (Fig. 42).

Table 39 shows the annual production of 7 main processing companies in the city of Shimonoseki which processes over half of the total production in this country. An examination of the table shows increasing annual production.

The sea urchins come from Hokkaido, 188-230 tons annually, from the districts of Sanriku and Kyushu, 75 tons each, and from the district of Shikoku, 9 tons; the ken (prefecture) itself supplies 80-90 tons. In addition 150-260 tons are imported from Korea (Table 40).

As the consumption of sea urchins increases, the production in the coastal areas will reach a limit, and efforts to import them not only from Korea but also from such countries as China, Southeast Asia, New Zealand, Australia and Central and South America can be expected. However, an analysis of the Japanese statistics shows that the areas of production of sea urchins are localized and the size of the natural resource and the amount of catch do not always coincide. Rather, since the fishing habits of fishing villages are based on customs and traditions of long standing, there are probably areas in which the industry is not prosecuted seriously. This can be inferred from the fact that even in fishing villages along coastal areas in the Japan Sea in Yamaguchi-Ken, the collection of this rich resource in the nearby seas is open to fishermen from other villages. Thus, it is possible that an increase in production can accrue by positive promotion and by the introduction of mechanization based on the results of propagation experiments.

(2) Extent of the resource

Examples of fishing to the maximum limit are often observed, such as when beaches are opened for short periods at the opening of the fishing season. After the fishing season, a considerable amount of new stock of commercial-size sea urchins are found in a fishing ground which has recently been stripped.

The location and method through which the population is replenished are extremely interesting problems which have not been clarified. Some suggestions have been made.

Shallow seas along the coastal areas are most suitable habitats for Strongylocentrotus. In nature the most powerful group occupies the best location. Thus, the weak and the small (Kawana suggests the young and the weak; however, groups of smaller sizes are found in shallower areas and are not always found in deeper regions) are found in deeper regions and these groups move in from the open sea to replenish the population at the end of the fishing season. It has been suggested that migration might take place horizontally from the neighbouring seas (Kawana, 1938).

The young measure 0.8-4.5 mm in shell diameter and are those which hatched during the winter and the spring of the current year. During the summer they are found adhering to the roots of calcareous algae, Amphiloa dilatata Lamx, Phyllospadix scouleri Hook and other seaweeds (Kawana). Those, which measure less than 2-10 mm in shell diameter, are observed living under small stones (Minamizawa, 1959). The writer and other workers often observed groups of small sea urchins living among small pebbles, on reefs and in the roots of seaweeds. These are either overlooked or are not caught during the fishing season, grow and appear in the fishing ground to replenish the depleted population. The migration of weak, small and old from the deeper areas is conceivable on the basis of the phenomena of separate habitats and of the sphere of influence.

In Fukui-Ken the difference between the high and the low tides is small and the catch is made mainly by female divers. On the basis of the stage of development of the gonad, the limiting size of the catch appears to be 2 cm. Results of investigations, based on shell diameters, of individuals remaining in the fishing grounds after the fishing season, show there is no decrease in individuals less than 15 mm. The replenishment during and after the fishing season is made mostly by individuals less than 15 mm in shell diameter; the replenishment by groups of 15-20 mm is extremely small. Individuals over 20 mm do not contribute to the replenishment of the population. They become the objects of the catch. The larger the size the larger the proportion in the catch (Fig. 43; Table 41). They will be over 2.5 years old.

Since the age composition of the population, which includes survivors and replenishing groups, at the beginning of the next fishing season is not known, it was estimated on the basis of the shell diameter composition at the beginning of 1956-1958 fishing season which was investigated by the Fukui Fisheries Experimental Station. Survival rates (p_t) were also determined. These are shown below:

$$p_{1.5} = 0.50 - 0.37 \text{ (Average 0.40)}$$

$$p_{2.5} = 0.32 - 0.23 \text{ (Average 0.25)}$$

$$p_{3.5} = 0.15 - 0.05 \text{ (Average 0.08)}$$

The fishing season in Fukui-Ken is controlled by the Fisheries Control Regulations and last merely 31 days from July 21 to August 20. During this period a large catch is made with maximum effort. Table 43 shows the survival rates by year classes at the beginning and at the end of the 1958 fishing season.

A comparison of the survival rates for 1958 and those for 1956-1958 shows that in the case of the 1.5 and 3.5 year classes the rates are higher in the former but approximately equal in the case of 2.5 year class. This is due to the fact that efforts are expended mainly on the 2.5 year class. It is not known if the higher rates for 1.5 and 3.5 year classes are due to fishing intensity, or to the natural mortality during the winter. In any case, there is a marked natural decrease in the initial period and when the animals become large enough to enter the fishery, the artificial decrease becomes unduly large.

The quantity of seaweed used for food by sea urchins is one of the factors which determines the level of gregarious density of the sea urchin resource.

The average value of the gregarious density for mature specimens of Lytechinus is $2/m^2$ with a maximum of 15; in the case of a group of young animals of shell diameter approximately 23 mm the average is 43 and the maximum is 250. A mature individual will eat an average of 0.7 kg Thalassia annually; the maximum intake is 5.5 kg. The intake by small-sized sea urchins is 2.25 times that of large sized groups; thus, the average value is $1.6/m^2$ per year with the maximum of 9.1 kg. Thalassia is found in the Bay of Biscay at a density of 1484 plants per 1 m^2. A single leaf grows on the average 5 cm per week, or 114 mg wet weight. This is equivalent to an annual growth of approximately 8.8 kg wet weight.

Thus, in this region the sea urchin resource is in equilibrium with the food resource; and based on this it is believed that a gregarious density of this magnitude is suitable (Moore, et al., 1963 and 1965).

At a density of 10 individuals per 1 m^2 Paracentrotus lividus does not interfere with the growth of large sized seaweeds. It has been observed experimentally that, when a single individual specimen had been placed in a basket with a bottom area of 0.28 m^2, there was a decrease of 33-50% in seaweeds; and that 3 individuals completely removed large sized seaweeds (Kitching and Ebling, 1961).

In Oshoro Bay in Hokkaido, as measured by its efflux, over 5 kg per 1 m^2 of Laminaria religiosa Miyabe are produced during February to May. Assuming that 4 kg/1 m^2 of this resource is taken for food by sea urchins in a month, it is possible to obtain the number, size and weight of individuals per 1 m^2 which can inhabit this area. The value so obtained agrees well with the gregarious density found there (Kawamura, 1965).

(3) Catch rate

The catch of sea urchins (weight of finished product) per man per day varies depending on the amount of the resource, environment and ability. In the village of Saki in Fukui-Ken the fishing season opens on July 30 and closes on August 13. In 1953 the total catch by 105 workers during 12 working days was 402.9 kg. On the opening day 103.4 kg was collected by 99 workers. This meant that 25.6% of the total was caught on the first day. On the next day the catch decreased to one half of that of the opening day. The maximum catch per man per day was 1.15 kg, the minimum 0.37 and the average 0.91 kg.

(4) Relation between production and water temperature

Peaks of sea urchin production and outbreaks of herring in Fukui-Ken approximately coincide in number; furthermore, the peaks of sea urchin production precede those of herring production by two years (one year in cases). That is to say, the fluctuations in sea urchin production between 1907 to 1912 and those since 1940 are similar to the production of herring with a two year lag period and those of 1913 and 1939 coincide with a one year lag period. This is an extremely interesting phenomenon. However, even in the latter situation the outbreak of 1921 occurred two years after and the outbreak of 1939 does not coincide at all.

The close relationship between the two is correlated with water temperature during the spring herring season in Hokkaido, to the water temperature in the fall at Himezaki in Sado, and to the air temperature in the fall in the city of Fukui. This is due to the fact that production of both Strongylocentrotus pulcherrimus and herring are controlled by the changes in the warm Tsushima current (Kawana, 1956).

10. Propagation

Even an extremely abundant resource such as the Echinoidea will diminish if it is intensely exploited. With the increasing demand and consumption of Echinoidea it is now necessary to propagate the resource. At a marine experimental station 200 specimens were collected every year from one area for a period of 3 years and because of depletion of the resource the work could not be continued and transplantation was required (U, Dr. Keitaro Uchida?, Nagasaki Fisheries Experimental Station, 1956).*

*Reference uncertain in Japanese original.

As a supplier of Echizen Uni (Echizen sea urchin) Fukui-Ken has a long history of production and propagation. An attempt at propagation was made in 1910 by putting stones into the water. Later during 1912-1926 putting stones in the water was carried out three times. Underwater goggles were invented in about 1902. Prior to that date the fishing ground extended to the depth of 3 m; however, after the introduction of goggles it became possible to dive to the depth of 7 m and there was a marked increase in the catch. Starting in about 1935 the catch exceeded the limit and it is said that the resource began to decrease (Kawana, 1938).

Investigations and studies on the propagation of *Strongylocentrotus pulcherrimus* were only started in 1935 at the Fisheries Experimental Station in Fukui-Ken. Attempts to increase the catch by establishing artificial reefs by putting rocks into the sea, dense-transplant stocking experiments and transplant-propagation experiments were carried out during 1936 and 1937. The results have been summarized by Kawana (1938).

After the War, since propagation by establishing artificial reefs began to be undertaken with government subsidies in 1953, fundamental research on the propagation of sea urchins especially *Strongylocentrotus pulcherrimus* and *S. intermedius* have been carried out.

In the past propagation of sea urchins has been carried out actively mainly by establishing artificial reefs and transplanting animals. Restrictions on the fishing season by mutual agreement among associations have also been in effect in several areas.

In order to maintain the sea urchin resources permanently and to stabilize production it will be necessary to plan and put into effect a positive method of propagation. At the same time it will be necessary to establish fishery regulations and enlist the voluntary restraint by fishermen to plan for the propagation and the protection of the resource. To accomplish these objectives the following points must be considered:

a. Extension and renewal of fishing grounds or of habitats

   (i) Artificial reefs
   (ii) Cover stone
   (iii) Beach building

b. Transplant propagation

c. Breeding control

d. Elimination of enemies

e. Establishment of areas closed to fishing

f. Restriction of the fishing season

g. Restriction on size

h. Restrictions by fisheries regulations

(1) Extension and renewal of the fishing grounds or suitable habitats

To increase production by propagating Echinoidea in restricted areas such method as the extension of an area in which the sea urchin lives, i.e., construction of new fishing grounds by building artificial reefs or extension of suitable habitats or renewal of these habitats by adding cover stones can be undertaken.

As the algae on which sea urchins live adhere to rocks, extension of the adhering areas must be undertaken. Furthermore, since sea urchins are nocturnal, areas in which they can avoid light during the day must be constructed.

The rock surfaces on which sea urchins live are not even and they lie one upon another. Hence it is difficult to express the number of sea urchins per unit area in terms of a flat surface. However, from the point of view of rearing food organisms, it may be considered tentatively as a numerical value related to a plane.

In the case of Strongylocentrotus pulcherrimus the values differ markedly depending on the environment; the minimum ranges between 11-125, the maximum 47-244, and the average 26-145 (Table 44).

Results of investigations, which have been carried out at Rebun-To indicate that the number of sea urchins varies depending on depth. Down to the depths of 1.5 m the minimum is 15, the maximum 662; to depths of 3.0-4.5 m the minimum is 1 and the maximum 224. The respective averages are 166-214 and 24-47.

It has been reported that the number of specimens of Paracentrotus lividus in Curlaw Bay in Castle Island was 1957 in 290 m^2. This corresponds to approximately 10 specimens per 1 m^2 (Kitching and Ebling, 1961).

In the case of Lytechinus variegatus, in areas which were inhabited by large sized groups only (average shell diameter 65 mm), the average density was $1.0/m^2$ with a maximum of 15; the average density in the case of small sized groups (average shell diameter 23 mm) was $42.8/m^2$ with the maximum of 250 (Moore, et al., 1963).

As is evident from the above discussion the gregarious density of sea urchins differs markedly depending on the environment. Such factors as the shape and the formation of the reef, the composition and the quantity of plant groups, which serve as food, or the equilibrium between related organisms in the ecological system are all important.

Paracentrotus lividus has been raised in a basket with a bottom area of 0.28 m^2. It was observed that a single sea urchin inhibited 33-50% of the propagation of the seaweeds and that 3 individuals completely eliminated large sized seaweeds (Kitching and Ebling, 1961).

Calculations were made on the number of sea urchins which could live in 1 m^2, assuming that the food intake of S. intermedius with a shell diameter of 5 cm was approximately 3 g per day, and that it consumed 4 kg of kelp per 1 m^2 per month. The results gave densities of 160 with the shell diameter of 2.5 cm, 100 with 3 cm, 70 with 4 cm, 50 with 5 cm, 25 with 6 cm and approximately 20 with 7 cm. These values approximate the maximum values observed in nature (Fuji, 1962).

However, on many occasions one finds that a large number of sea urchins with poor growth collect and live in areas with scarce seaweed resources while in neighbouring areas with rich seaweed resources there are small densities with good growth. In view of their mobility it appears that migration to neighbouring areas is quite possible. This suggests that the seaweed resource alone is not always sufficient to estimate the number of sea urchins which can be produced in an area.

Sea urchins avoid light by creeping into crevices and crawling on the underside of rocks. Thus, it is possible to increase the gregarious density by increasing the number of crevices. An assembly of rocks rich in crevices lying one upon another will provide a more favourable living environment than a reef with many undulations. The purpose of the cover stone is to create crevices by turning over naturally buried rocks. By turning over rocks several times during a fishing season it is possible to create a more suitable habitat. Repeated annual rolling of rocks makes it impossible for brown algae to settle; however, it is suggested that this does not interfere with the propagation of green algae (Kawana, 1938).

(2) Effects of building artificial reefs

The practice of building reefs by dumping rocks into the sea was initiated in Fukui-Ken in 1910 and has been carried out in various areas since. Several assessments have been made of the results. It was reported that, even in cases where the results had not been too favourable, the cost of the project can be recovered in 3 years (Kawana, 1938).

It was further reported on the basis of investigations which were carried out in various coastal areas, that the number of sea urchins was larger in areas where artificial reefs were built and harvesting was practiced, than in areas where harvesting alone was carried out, or in areas where neither artificial reefs were built nor harvesting was carried out. Consequently it was suggested that building artificial reefs was effective (Taki, 1961).

During the period extending from 1928 to 1932 building reefs was actively encouraged by means of a national subsidy. An examination of the relationship between sea urchin production (the average weight of the gonads of a single specimen of Strongylocentrotus pulcherrimus is 1.68 g) of various fisheries cooperative associations and the quantities of reefs built shows that the production clearly increased in some areas but not in others. However, the production showed a marked decrease in areas where the practice was not carried out; thus, the benefits of the practice are evident. In some cases despite the fact that the rocks were put in the sea, the effects are not evident. The areas, which are suitable for sea urchins are ones which have great quantities of rocks on which they live. Thus, in areas which are already rich in rocks, the effects of building reefs will not be too marked while in areas where rocks are not found in sufficient numbers, the effects will be readily seen (Oshima, 1962).

Oshima (1962) made an attempt to establish a theoretical relationship between the quantity of rocks used and the production of *Strongylocentrotus pulcherrimus*.

Assume that the number of rocks, which can be used as a habitat by sea urchins in a given area, be X. Let x_0 be the number of rocks already present. If x_1 rocks are added during the first year, those rocks which can completely meet the objective will be:

$$x_1(X - x_0)/X$$

In the second year if x_2 rocks are added, those which completely meet the objective will be:

$$x_2 \cdot \left\{X - x_0 - x_1 \cdot (X - x_0)/X\right\}/X = /x_2 \cdot (X - x_0)/X \cdot (X - x_1)/X$$

Of the x_3 rocks cast during the third year, the number which are effective, will be expressed as:

$$x_3 \cdot \left\{X - x_0 - x_1 \cdot (X - x_0)/X - x_2 \cdot (X - x_0)/X \cdot (X - x_1)/X\right\}/X =$$

$$x_3 \cdot (X - x_0)/X \cdot (X - x_1)/X \cdot (X - x_2)/X$$

Therefore, the effective rocks of the x_n rocks added to the environment in the n-th year will be:

$$x_n \prod_{i=0}^{n-1} (1 - x_i/X)$$

Thus, the increase in production of sea urchins over the previous year after adding rocks will be proportional to:

during the 2nd year $\quad x_1(1 - x_o)/X$

during the 3rd year, and $\quad x_2(1 - x_o/X)(1 - x/X)$

during the (n+1)-th year $\quad x_n \prod_{i=0}^{n-1} (1-x_i/X)$

If the same quantity of rocks is added annually, $x = x_2 = \cdots\cdots x_n = x$.

The increase in production in the n-th year over (n - 1)-th year will be proportional to:

$$x(1-x_0/X)(1-x/X)^{n-2} = x \cdot (1-x_0/X)/(1-x/X)^2 \cdot (1-x/X)^n$$

If y represents the production in the n-th year of adding rock:

$$dy/dn = kx \cdot (1 - x_0/X)/(1 - x/X)^2 \cdot (1 - x/X)^n$$

The integration of the above expression will result in the following expression:

$$y + c = kx \frac{1 - x_0/X}{(1 - x/X)^2} \cdot \frac{(1 - x/X)^n}{\ln(1 - x/X)}$$

If y_0 represents the production in the 1st year after adding rocks:

$$y_0 + c = kx \frac{1 - x_0/X}{1 - x/X} \cdot \frac{1}{\ln(1 - x/X)}$$

Consequently, the following expression holds:

$$y = y_0 + kx \frac{1 - x_0/X}{1 - x/X} \cdot \frac{1}{\ln(1 - x/X)} \cdot [(1 - x/X)^{n-1} - 1]$$

Since x/X is generally small, by ignoring $(x/X)^2$ and higher terms, the expression becomes:

$$y = y_0 + kx(1 - x_0/X) \frac{-(n - 1)x/X}{- x/X} = y_0 + kx(1 - x_0/X)(n - 1)$$

An examination of the equation shows that the annual increase is proportional to $(1 - x_0/X)$; thus, the production can be considered as being proportional to x, the quantity of rocks added and further to $(1 - x_0/X)$. Needless to say $(1 - x_0/X)$ differs from area to area. In areas which naturally abound in rocks, this term is markedly small and the effects due to adding rock are small. In areas with few natural rocks this term is large and the effects of adding rocks are considerable. Following this logic it was assumed that the production y after x years can be expressed by the equation $y = a + bx$, and a and b were calculated by the method of the least squares using data available in Fukui-Ken and by taking 1952 as the base year (Table 49). An examination of the table suggests there were sufficient rocks already in Kaji and Minami Sugau in 1952 and that in Sugahama the existing supply was also sufficient, and hence further addition of rock did not result in any noticeable increase. A further examination suggests that in the cases of Saki, Yasushima and Himuki the supplies of rock have not yet reached their limits and marked increases are still occurring (Fig. 48). Adding rock was not carried out in Hayase; however, the effects of the practice can be gauged by the size of $(1 - x_0/X)$.

Somewhat flat cut natural rock is the most suitable rock to add. Basalt, quartz, trachyte or granite are good. The rocks should be hard; the hardness should exceed 10 if possible. The water absorption and abrasion rates should be small. Ideally various sizes should be mixed. The size should range from large ones, which can barely be turned over, to small ones weighing 25-30 kg. It is reported that those weighing 38-45 kg are most efficient from the point of view of transportation (Kawana, 1938).

To extend the habitat and gain the maximum effect, the site should have a solid bottom with few rocks, and should be located so that the waves will not bury the rocks. The depth should be less than 2-3 m.

Settling of seaweeds is optimal at depths of approximately 2.5 m.

The optimum number of rocks to be added must be determined in accordance with the topography of the area. However, the results of experiments by the author and other workers seem to indicate it should be over 5 and less than 10. If the rocks are limited to this range, it will be possible to place them on the bottom without piling them up.

The time to add rocks is not related to the spawning period of the sea urchin. The time should be chosen to coincide with the optimal period for the settling of seaweeds. Thus, it should probably be around September.

The effects of adding rock are realized in the year when 2- to 3-year-old sea urchins, which will migrate from the surrounding areas, have grown to a size large enough to be harvested. It will require 3-4 years before the full benefits are realized. Kawana (1938) reported that 400 pieces of cut stone, ranging in size from 37.5 to 56.3 kg would be required in order to increase the production by 3.75 kg in an average area. The conclusion was based on the assumption that 20% of the rock will be ineffective -- it might be buried in the bottom or lost through other causes -- on the average 5 individuals would settle on each rock, and each sea urchin would yield 2.25 g of finished product. The theory is open to criticism because of the lack of objective data (Minamizawa and Ogawa, 1954).

(3) Transplanting

The development and the quality of the gonads in the Echinoidea differs greatly depending on the environment. Thus, transplanting sea urchins with poorly developed gonads to areas where the development and quality are likely to be more favourable, and hence increase production is an important technique in the propagation of sea urchins.

Kawana (1938) reported an approximate five-fold increase in production of gonads in a year along with an improvement in the quality in one transplant experiment. Since then transplanting has been carried out in many areas in Fukui-Ken and the practice has been adopted in many other areas in Japan. Recently with the expansion in the sea urchin industry, in Hokkaido, transplanting of S. nudus and S. intermedius has been carried out voluntarily by associations and villages mainly along the coastal areas of the Japan Sea with favourable results in many instances.

Sea urchins, which were living in the outer sea off Agawa in Yamaguchi-Ken, were transferred to an inlet with a sand and gravel bottom. The transplant yielded favourable results both in quantity and quality especially in the case of Anthocidaris crassispina (Nakamura and Yoshinaga, 1962).

Sea urchins of Kukiai (a nursery) in Rebun-To, where the growth of S. intermedius is poor, were transferred to Horotomari, where fishing is prohibited, and comparisons were made of the gonadic coefficient, degree of fatness, total weight/(shell diameter)^2 × shell height = DH × 10, digestive tract content coefficient (weight of digestive tract/DH) × 10, shell weight coefficient (shell weight/DH) × 10, shell height and ratio between diameters. The results showed that the development of the gonads of the transplanted sea urchins was 2.8-4.4 times (average 3.6 times) better than that of sea urchins in the nursery, and that the ratio was somewhat inferior being 0.86 times that of the sea urchins which had been in the prohibited area.

It was observed that sea urchins in the nursery area had a high shell height, the colour was light brown and the spines were white and broke off readily; sea urchins in the prohibited area had a low shell height, the colour of the shell was green, and the spines were of the same colour, thick and hard; the transplanted sea urchins showed characteristics intermediate between the two. It was further observed that because of these characteristics the different animals were readily distinguishable (Kawamura and Hayashi, 1964).

Results of similar experiments showed that the transplanted sea urchins consistently showed better results than those in the nursery. Furthermore, they developed to over 80% of that of sea urchins native to the area (Kawamura, 1965).

Transplant experiments with S. nudus show similar marked effects (Kawamura, 1966).

(1) Conditions for the location of a transplant area

The first condition is that the supply of seaweeds, which serve as food, be plentiful throughout the year. Even though the area is suitable for the propagation of seaweeds, if they are lost at any time the area is not suitable. On the other hand even if the area is poor for seaweeds to settle out in or for their propagation, the area will be suitable if it is located so that seaweeds, which have been washed free in other areas are carried to it by wind, waves or tidal current. Seaweeds serve not only as food but also as a habitat for the young. On the other hand when they wither, they can cause death to a large number of sea urchins. Thus, a certain amount of wave action is necessary.

The second condition is the water depth. Generally small-sized or young sea urchins are found in shallow areas and as the depth increases, they tend to become older or larger in size. In shallow areas large-sized sea urchins have little resistance against the violent physical and chemical environmental changes and easily perish; thus, they tend to migrate to deeper regions. Hence the transplanted seedlings should be placed below the low water mark. In the case of Strongylocentrotus pulcherrimus the gonads develop poorly in deeper regions. The depth must be less than 4 m. Within this range, development improves as the depth becomes shallower. From the standpoint of the relationship between the gonadic coefficient and the shell diameter in S. intermedius, it appears the development in the gonads tends to become inferior as the depth in which they live becomes greater. However, the difference becomes less significant as the size increases. It has been suggested that the upper limit of the zone in which kelps thrive, should be the upper limit of the area for transplanting S. intermedius (Kawamura, 1965).

Since Strongylocentrotus pulcherrimus has a low resistance to low salinity, areas which are affected by floods will be unsuitable. The areas which show signs of denudation, should be carefully avoided. There are records of mass mortalities of S. intermedius in areas near the mouths of rivers which are affected by fresh water but where seaweeds develop well (Kawamura, 1963).

(2) Time for transplanting

Generally the transplant is carried out after the completion of the sea urchin fishing season. This means that the time for Strongylocentrotus is between October and December, and for S. intermedius between September and October. At Otaru in Hokkaido a transplant was tried in the middle of April after the spawning season and it was found that the development of the gonad was over five times as much as the gonad development in sea urchins which had not been transplanted. Thus, if a transplant is made in September-October, growth in the shell diameter can be expected to take place during the winter. However, from a standpoint of only gonad development, the transplant can be carried out as late as April. Thus, a proposal has been made for a transplant in the fall to be harvested in April and May with a further transplant to be harvested in August. This will make it possible to carry out two transplants and two harvests during one year (Kawamura, 1965).

(3) Migration

Even though a transplant is effective, if migration is appreciable, the benefits will be small.

Sea urchins sense the approach of violent waves due to typhoons and other causes, and hide in gaps in the reef, cracks in a rock or adhere to a rock. Instances of sea urchins being washed free by waves over long distances are few. However, as a defensive move the young tend to migrate from shallow to deeper regions as they become older. On the other hand, when a population is suddenly depleted in a shallow area, a migration of animals from the deeper area takes place to replenish the shallow water population. Further, a migration between areas of the same depth is believed possible. It appears that these migrations take place mainly after the spawning season when intense foraging activities are undertaken.

The instantaneous speed of the sea urchin is fast. However, the distance covered in its migration in the environment is not great. Further, in areas rich in seaweed resources no appreciable annual migration takes place. Therefore, if the transplant is carried out in an area rich in seaweeds, it will not be necessary to take into account migrations over a wide area.

(4) Administration of breeding

On the basis of age composition the primary year class of the catch seems to be 3 year sea urchins. Biologically the minimum age is two years; from the standpoint of the gonadic coefficient 4-year-old sea urchins appear to be the most desirable for harvest. From the standpoint of sea urchin cultivation it will be better if the object of the catch is limited to those animals which are over 3 years in age.

Theoretically it will be possible to maintain a constant and planned annual production of sea urchins by working with fisheries associations which hold the fishing rights. This will be done by dividing the potential fishing area into three subdivisions and harvesting annually one of the three in rotation. In order to efficiently manage the fishing areas, the amount of seaweed which is required to maintain the estimated sea urchin resource, must be calculated and supplied. Under natural conditions, groups of sea urchins, which collect on seaweeds can be observed. When they are placed in baskets and raised under high densities, if the circulation of water and the supply of seaweeds are sufficient, the effects of this high population density may not be significant. Furthermore, natural mortality will be extremely small. If this type of culture can be carried out at low cost, it will be possible to culture sea urchins in baskets which are suspended from rafts.

(5) Elimination of enemies

An extremely large number of eggs are laid by sea urchins and a correspondingly large number are lost during the initial developmental period through environmental factors and predators. If the natural mortality in this initial period is lowered by a fortuitous favourable turn in environmental factors and a marked decrease in predators, the sea urchin population will become more abundant. It will be possible to raise young sea urchins by artificial insemination and to produce seedlings in large quantities. However, the sea urchin resource has excellent reproductive and propagative power. At the present time the adoption of such methods of artificial propagation are not required.

6. Fisheries control

(1) Establishment of protected areas

Restricted areas have been established in Hokkaido mainly to protect the *S. intermedius* and *S. nudus* resources. The objectives are to maintain reserve supplies of sea urchins by protecting the young and the spawning groups.

The coastal area has been divided into 16 sub-areas and in each area a restricted area 150 × 30-40 m has been established. An investigation at Funatomari in Rebun-To shows that the number of individuals found in a restricted area is not always greater than found in fishing areas, but the shell diameter tends to be larger. In view of the fact that the quality and quantity of the gonads deteriorates with age and also that natural mortality will become more marked with increasing age, a policy which prohibits fishing in one area over a long period of time appears to require further considerations. It will be more advantageous to prohibit fishing for a 3-4 year cycle and to allow fishing in rotation. Furthermore, to protect the young stock it will be more effective to prohibit fishing in the shallow water areas which are in the neighbourhood of the low water mark where the younger groups are found in large numbers. However, it may be difficult to administer this policy.

(2) Fishing season

In order to protect a species, fishing is prohibited during the spawning season. The practice is widely carried out. However, in the case of the sea urchin, on account of the phenomenon generally referred to as "tokeru" (dissolve), the gonads cannot be processed during the spawning season. Thus, during the spawning season usually no fishing takes place. In Yamaguchi-Ken in the coastal area along the Japan Sea, the spawning season of S. pulcherrimus extends approximately from October to March, that of A. crassispina from May to August, and that of P. depressus from November to March. The fishing season excludes these periods (Fig. 52). The spawning season varies depending on the year and environment. Thus, it has been a practice for many years to establish the detailed dates for harvest based on actual conditions.

In many cases dates for the catch are determined independent of the prefectural fisheries regulations, voluntarily after annual consultation among young men's and women's sections and other groups which are formed within various fisheries associations. The consultation takes place ordinarily among several associations which are historically, economically and geographically related. The principles of the restrictions on the fishing season in areas facing the Japan Sea in Yamaguchi-Ken are noted below:

Akawa area: The time of the catch and the prices are discussed in May. The opening day is set for the 1st day of the first spring tide. Assuming that one tide consists of 6 days, fishing is allowed during a series of 4 tides, i.e., it is possible to fish for a total of 24 days in two months during the year. Diving is not allowed during the first tide. The use of a boat is also restricted during the same period.

Kawajiri: From the spring tide at the end of April to the spring tide at the end of August for 7 days during each tide for a total of 63 days. Diving is allowed for 28 days from July to the end of August.

Waku: From the spring tide at the beginning of May to the spring tide at the end of July, a total of 36 days.

Yatama: Same period as above; 6 days during each tide for a total of 30 days.

Kogushi: May 1 to August 31 for S. pulcherrimus and April 20 to September 20 for P. depressus.

Mutsure: 4 days during the spring tide at the end of April, 4 days during the spring tide at the middle of May, and 8 days during the two tides in July, a total of 16 days.

In the case of A. crassispina the fishing season is in the winter, the number of men engaged in harvest is small. Thus, there are no special restrictions.

Restrictions similar to these are in force in areas which depend on sea urchin fisheries. Table 54 shows the fishing restrictions of several prefectural fisheries control regulations.

In Fukui-Ken it has been a custom for some time to catch S. pulcherrimus from the end of July to September, and in May, 1917, by a prefectural law sea urchin fishing was prohibited during the period extending from August 11 to July 20 of the following year. The period was amended to August 21 to July 20 of the following year in May 1932. The law is still in effect. However, the fishing season has been shortened further voluntarily by various fishing cooperative associations. The restriction is observed very strictly. In Fukushima-Ken fishing is prohibited during March 1 to May 31.

In Hokkaido each association carries on the practical application of the fisheries control regulations from its own standpoint (Table 55). The fisheries cooperative association at Funatomari in Rebun-To allows fishing from June 25 to August 20 for S. intermedius and from August 1 to August 31 for S. nudus. Fishing is permitted from 6 a.m. to 10 a.m.

(3) Restriction on shell diameter

Restrictions are placed on the shell diameter of the sea urchin through the fisheries control regulations. Table 56 shows the prefectures and the restrictions. While detailed regulations apply to prohibiting fishing, no such consideration is given to the question of shell diameter.

Theoretically the biologically minimal shell diameter is taken as a standard. However, there is a close relationship between the shell diameter and the gonadic coefficient. In S. pulcherrimus the average weight of the gonads of 2 year sea urchins ranging in shell diameter from 2-2.5 cm is 0.5 g and that of 3 year sea urchins with shell diameter ranging from 3-3.5 cm is 1.55 g. Thus, the extension of the harvest by a period of a full year results in the increase in yield of approximately 3.1. In the case of P. depressus it is 2.8, 2 in S. nudus and 2 in S. intermedius.

Thus, it would be advantageous to prohibit the catch of individuals with shell diameter less than 3 cm in the case of S. pulcherrimus, 4.5 cm in the case of P. depressus, 5 cm in the case of A. crassispina, 4 cm in the case of S. intermedius and 6.5 cm in the case of S. nudus.

(4) Restrictions by fisheries regulations

The sea urchin fishery is carried out under Dai Isshu Kyodo Gyogyo-Ken (The First Class Co-operative Fishing Right) and is one of the poorest and most primitive fisheries in the fishing villages. The simplest type of gear is used and the introduction of machinery tends to be discouraged. Since the introduction of the glass bottom box in

1910, the catch has increased. However, fishing by a simple diving apparatus, to say nothing of aqua lung, is prohibited over the whole country. Ordinary diving is the only method permitted.

In some areas in Kanagawa-Ken even the use of wet suits is prohibited.

The fishing methods are not uniform throughout the country. They can be classified into 3 categories: "rikutori" (land catch) or "dotsuki" (waist attachment), diving and "isomi" (off shore).

"Rikutori" or "dotsuki": irrespective of the state of the tide the worker walks into the water until it comes up to his knee, hip or chest. He peers into water with a glass bottom box or underwater goggles and catches sea urchins by turning over stones with his foot or using a hook with a handle. The work is carried out mainly by women and children. The catch consists mainly of S. pulcherrimus. In some areas S. nudus is caught during the winter. In Yamaguchi-Ken this is the only method allowed on the opening day. Small-sized sea urchins are found in shallow waters and hence to protect them the fisheries associations in Hokkaido prohibited the "dotsuki" method recently.

Diving: when sea urchins in shallow areas are exhausted by "rikutori", diving is carried out. In some areas the catch is made by diving from the beginning. The operation is carried out both by men and women. The use of sophisticated equipment is prohibited. The operation is carried out mainly by divers in the nude. In Yamaguchi-Ken diving is prohibited during the opening week during the first spring tide. Ships 1 to 3 tons in size may be used or workers may wade from the land to the sea. The recent use of wet suits made for use with aqualungs affords protection against cold. This has made it possible to increase the fishing efficiency.

"Isomi": this is also called "catch by boat". Ordinarily one man goes out in a small fishing boat. He scrapes off sea urchins from rocks with a hook attached to the end of a long pole and scoops them up in a dip net as he manipulates the boat with a Japanese scull. The fishing gear is made to suit topography, depth and current and is skilfully used. A. crassispina and P. depressus are the main species in the catch.

7. Rearing and cultivation

(1) Rearing

S. pulcherrimus is caught when the water temperature is low and the weather is uncertain. Furthermore, fishing is restricted by tidal conditions. These conditions, which are beyond human control, interfere with steady production in a fishing village. In order to satisfy the constantly growing demand for sea urchins as a fresh food a way must be found to circumvent such difficulties. Rearing is the most effective method.

As has been established in rearing experiments it is possible to keep sea urchins over a long period of time with a yield of 100%, if a supply of well oxygenated sea water is maintained and if a suitable amount of seaweed is added. If the catch can be landed, even during bad weather, in an area with strong currents but not affected by fresh water, the area can be closed off with wire netting and the sea urchins can be held by feeding them with lavers, which have high efficiency as food, in a sufficient quantity to last for a few days. The daily requirement can be assumed to be approximately 3% of the total weight. They can also be held by catching them during a spring tide when the fishing conditions are favourable and placing them in baskets made of wire netting or of synthetic material (the shape of the baskets, whether oval or rectangular, is immaterial). The sea urchins collect on seaweeds which serve as food and live in the baskets. This kind of gregarious life hardly affects their natural mortality nor their growth. If they are kept for less than 10 days at a water temperature of approximately 25°C, the gregarious density does not have to be taken into consideration. The major problem will be a sufficient flow of sea water. Care must be taken to ensure that meshes will not be blocked by sea urchins, seaweeds or pieces of seaweeds. The mesh size should be determined on the basis of the smallest shell diameter that can be marketed. It will be desirable to have the mesh size slightly larger than the minimal commercial size. This will set the mesh size for S. pulcherrimus at 2.5-3.0 cm, for A. crassispina at 4.5-5.0 cm and for P. depressus at 4.0-4.5 cm.

It is important that dead sea urchins be removed quickly.

Favourable results can be obtained by piling up rocks in a suitable site or by building a beach in a small area and releasing sea urchins in these areas. They can be fed by putting seaweed in a net and fixing it securely so that it will not be washed away by waves. However, it will be difficult to locate a suitable site.

(2) Culture

S. pulcherrimus, which is sold for the highest price and has a high economic value, can be raised by the suspension method. Since the sea can be utilized vertically, production per unit area is large. The method is readily administered and can meet the demand at any time. Furthermore, it makes it possible to raise dense concentrations of sea urchins of superior quality.

A suitable location for this raft-type culture must have strong flow of sea water but not so strong that it will damage the raft. An area should be chosen where the water temperature is over 10°C at depths less than 4 m, where the quantity of chlorine does not fall below 15‰, where the effect of river water is felt, and which is not affected adversely by organic substances from neighbouring nurseries. The area should also be easily accessible.

The raft can be built in the usual way. Its size should be large enough to withstand damage but not so large as to cause interference with the flow of sea water inside the raft. Sea urchins will be placed in a basket. The mesh size should follow the standards indicated in a previous section. The basket should be set at a depth of approximately 4 m in an area 1-7 m in depth. The depth of the basket should be raised or lowered by 2-3 m about the central position so that the basket will be at a shallow depth when the water transparency is less and at a deeper depth when the water transparency is great. Sea urchins are apheliotropic; they are active and forage during the night. In short, an area with a short period of sunshine is more suitable.

Seedling specimens with shell diameters ranging 1.0-1.5 cm are used. Within manageable limits larger baskets will be easier to manage. Feeding should be done approximately once every ten days. Needless to say the interval should be varied depending on withering and discolouring of the seaweeds and on the season. The quantity of food to be administered daily will depend on the type of food used. In the case of lavers it can be obtained by taking 3% of the total weight as a daily ration.

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Table I [page 16]. Distribution and environment of S. intermedius.

Region	Depth of water	Bottom character	Seaweeds	Living conditions
Nishi Kamidomari	20cm	Reef	lavers, Rhodomela ladrix (Turn.) C. Ag., Phyllospadix scouleri Hook and others	Yearling sea urchins adhere to roots of seaweeds; two-year-olds and older sea urchins are found in crevices on reefs.
	1.0 m	Reef	kelp	Collects under kelp.
	1.5 m	Boulders (over 50 cm in diameter)	below the kelp zone; kelp is found sporadically.	Sea urchins are found under the leaves of kelp. Where no kelp is found, sea urchins are seen with laver or Phyllospadix scouleri hook on their body.
	3.0 m	As above	almost identical with the conditions at 1.5 m; lavers	As above.
	4.5 m	As above	as above; lavers, Castaria turneri Grev., Desmarestia viridis (Muell.) Lamour.	As above.
Edoya	50cm	Boulder (approx. 20 cm in diameter)	Phyllospadix scouleri Hook, Sargassum enerve Ag., lavers, Rhodomela ladrix (Turn.) C. Ag., and others.	Sea urchins are found between seaweeds and between rocks.
	1.5 m	As above	Phyllospadix scouleri Hook, and calcareous algae.	Seaweeds adhere to sea urchins.
	3.0 m	As above	abounds in Desmarestia viridis (Muell.) Lamour and other seaweeds.	As above.
	4.5 m	As above	Calcareous algae (non-jointed).	As above.
Benzai-domari	30cm	Reef	Phyllospadix scouleri Hook, Rhodomela ladrix (Turn.) C. Ag., Sargassum enerve Ag., lavers, Fucus evanescens Ag. and jointed calcareous algae.	Yearling sea urchins are found among dead leaves of Phyllospadix scouleri Hook and near the roots of lavers and Rhodomela ladrix (Turn.) C. Ag. Offshore they are found among jointed calcareous algae. Two year sea urchins and older ones are seen with seaweeds adhering to their body.
	1.0 m	Boulder (over 50 cm in diameter)	kelp, Castaria turneri Grev., Phyllospadix scouleri Hook and Undaria pinnalifida (Harv.) Suring.	Found in the roots of seaweeds and between rocks.
	1.5 m	As above.	kelp, Castaria turneri Grev., Phyllospadix scouleri Hook, laver and jointed calcareous algae.	As above.
	3.0 m	Reef (some mud)	floating kelp and laver	Very few sea urchins. Dead shells are found.
Minami Kamidomari	0-70 cm	Small boulders on reef	Almost none. Few Phyllospadix scouleri Hook are found.	Yearling sea urchins: around the lower part of stone. Two year sea urchins and older: under stone.
	1.0 m	Boulder (approx. 20 cm in diameter)	Sargassum enerve Ag., Phyllospadix scouleri Hook and others.	Between and under rocks.
	1.5 m	As above	As above.	As above.
	3.0 m	As above (somewhat larger)	Phyllospadix scouleri Hook, Desmarestia viridis (Muell.) Lamour and others.	Sea urchins are observed with seaweeds adhering to their bodies.
	4.5 m	Reef and boulder	Castaria turneri Grev., Sargassum enerve Ag., Phyllospadix scouleri Hook, Desmarestia viridis (Muell.) Lamour and kelp.	Sea urchins are found among seaweeds.
Higashi Kamidomari	30 cm	Reef and Boulder (approx. 30 cm)	Phyllospadix scouleri Hook and floating Desmarestia viridis (Muell.) Lamour. Small numbers of Phyllospadix scouleri Hook is growing.	Yearling sea urchins are found among the roots of Phyllospadix scouleri Hook. Two year sea urchins and older are found under and between stones.
	1.5 m	Boulder (approx. 30 cm)	Desmarestia viridis (Muell.) Lamour and others.	Sea urchins are observed between rocks with seaweeds adhering to their bodies.
	3.0 m	As above	As above.	As above.
	4.5 m	As above	Castaria turneri Grev., Desmarestia viridis (Muell.) Lamour and kelp.	As above.

Table 2 [page 18]. Sea urchin catch by association in the outer seas of Yamaguchi-Ken*

Name of association	Catch (Unit - kg)								Proportion of species (%)		
	1952	1953	1954	1955	1956	1957	1958	1959	Strongylocentrotus pulcherrimus	Pseudocentrotus depressus	Anthocidaris crassispina
Ezaki	110	110	110	100	100	90	80	80	0	20	80
Udago	2,440	2,440	2,440	2,440	3,570	3,570	4,500	5,620	85	5	10
Oiminato	3,770	3,700	3,700	3,700	3,700	3,700	3,700	3,940	90	5	5
Oiura	5,070	5,630	4,380	6,440	6,270	5,300	7,050	5,440	80	15	5
Koshigahama	20	20	40	50	50	50	60	60	70	20	10
Tamae	190	170	170	160	150	140	130	130	5	90	5
Mitsumiura	80	80	70	80	80	110	80	80	60	15	25
Oshima	680	520	750	880	660	1,010	2,400	1,280	75	20	5
Utsu	1,540	1,490	1,380	1,430	1,200	1,170	1,780	1,030	75	20	5
Honmura	750	560	560	470	480	670	1,120	650	75	20	5
Nohase	2,250	2,250	2,250	2,250	2,250	2,250	4,680	4,830	20	50	30
Tori	3,930	3,750	3,750	3,450	3,190	3,000	3,190	3,000	75	15	10
Senzaki	5,620	5,620	5,620	5,620	7,500	7,500	7,500	6,680	30	20	50
Fukagawaminato	10	10	10	10	10	10	10	10	20	50	30
Kinamito	4,800	2,290	1,850	1,800	2,000	3,190	3,630	4,430	20	25	55
Tsuki	10	10	10	10	20	40	40	40	50	30	20
Tateish	2,610	2,610	2,610	2,610	2,610	2,610	2,610	2,610	70	20	10
Kawajiri	1,090	1,090	1,160	1,630	830	980	1,240	1,010	75	20	5
Oura	17,300	15,020	16,120	14,460	13,570	12,830	14,180	12,360	20	50	30
Kurino	260	380	270	230	300	360	450	260	80	15	5
Agawa	340	380	320	650	620	770	1,080	690	60	35	5
Shimato	1,870	1,870	1,870	1,870	1,970	1,760	2,560	2,250	65	20	15
Hichu	100	90	370	300	330	240	320	280	70	20	10
Kakushima	2,630	2,590	3,080	3,900	3,970	4,500	4,650	4,470	60	40	0
Tokugyu	380	380	380	380	410	410	1,090	1,770	20	50	30
Waku	1,270	1,170	1,370	1,190	1,650	1,750	1,860	1,710	60	40	0
Yatama	750	960	560	740	1,680	1,400	1,440	1,230	70	15	15
Futami	1,100	1,060	1,030	1,280	1,300	1,240	1,930	1,080	70	20	10
Yudama	380	380	380	380	410	800	1,330	1,010	55	40	5
Kokushi	2,230	2,230	2,230	2,230	2,230	2,610	3,020	3,000	60	40	0
Kawatana	560	560	560	560	560	750	940	860	60	30	10
Kuroi	80	80	80	80	80	80	80	80	65	20	15
Murotsu	140	80	290	220	430	700	1,130	590	75	5	20
Yoshibo	1,880	1,880	1,950	4,500	4,320	1,730	1,690	2,250	80	10	10
Yoshimi	750	750	750	750	750	990	1,150	1,050	25	25	50
Futai-Shima	130	180	230	210	400	650	1,000	860	90	5	5
Yasuoka	70	70	70	70	70	70	80	80	30	25	45
Isaki	90	90	90	90	90	90	90	90	0	0	100
Rokuren	380	380	380	380	380	560	1,050	1,050	90	10	0
Minami Kazedomari	20	20	20	20	20	20	20	20	0	10	90
Total	67,610	62,950	63,260	67,620	70,210	69,700	84,940	77,960	63	23	14

*Weight of gonad.

Table 3 [page 21]. Occurrence by species and the quantity of the contents of digestive tracts. (Number of specimens investigated - 112).

Species	Number of occurrences	Quantity in digestive tracts		
		Over 50%	10 - 50%	Less than 10%
Ulva pertusa Kjellm	83	29	54	0
Zostera marina L. variety	3	1	2	0
Enteromorpha intestinalis f. cylindracea J. Ag. variety	2	0	2	0
Cladophoraceae	1	0	1	0
Ectocarpales	1	0	0	1
Sphacelariales	1	0	0	1
Desmarestiales	8	1	6	1
Punctariales	55	18	37	0
Colpomenia	21	10	10	1
Kelp	35	20	15	0
Sargassum	4	1	3	0
Species unknown (brown algae)	5	1	3	1
Calcareous algae	9	0	7	2
Polysiphonia	6	0	0	6
Lawrentia	5	0	3	2
"isomurasaki" (shore purple)	1	0	0	1
Rhodomela	3	0	3	0
"nokogiri hiba" (saw dried-leaf)	22	0	15	7
Species unknown (red algae)	4	0	2	2
Phyllospadix scouleri Hook	15	0	6	9
Species of wheat	1	0	0	1
Leaves of land plants	1	0	0	1
Benthic Coelenterata	3	0	1	2
Balanus	1	0	1	0
Crustacea	10	0	0	10
Polyzoa	1	0	0	1
Bone of animal species unknown	1	0	0	1
Detritus with sand	66	6	42	18

Table 4 [page 22]. Food habits of the Echinoidea.

Species	Stomach content	Author
Toxopneustes sp.	Crustacea	Van der Heyde (1922)
Sphaerechimus sp.	Crustacea	"
Echinus esculentus	Seaweeds mainly kelp	"
Arbacia punctata	Seaweeds, Ophioidea, Hydrozoa, sponges	"
Arbacia sp.	Fundulus sp.	Parker (1932)
Strongylocentrotus pulcherrimus	Brown algae (Sargassum, Undaria, Ecklonia, etc.), Red algae, Green algae (Ulva, Enteromorpha, Cladophora, etc.), Phyllospadix scouleri Hook.	Kawana (1938)
S. droebachiensis	Mainly brown algae, occasionally Mytilus crassistesta (Lischke), dead fish, putrid flesh	Scattergood (1947)
S. purpuratus	Mainly seaweeds, occasionally Phyllospadix scouleri Hook when starved meat, fruits, fresh vegetables, boiled eggs, boiled potatoes	Lasker & Giese (1954)
S. franciscanus	Seaweeds	"
Lytechinus anamesus		"
Arbacia punctulata	Red algae, brown algae (Laminariales, Fucus), green algae (Ulva), coral polyp, sponges, Clypeastrida and other Arbacia	Harvey (1956)
Lytechinus variegatus	Thalassia	Moore, Jutare, Jones (1963)
S. nudus	Green, brown and red algae, Phyllospadix scouleri Hook, Crustacea, Coelenterata, Balanus, Polyzoa and detritus	Kawamura (1964)
S. intermedius	Kelp, laver, Desmarestiales, calcareous algae, Gelidium Polysiphonia	Kawamura (1964) Fuji (1962)

Table 5 [page 23]. Relationship between shell diameter and contents of digestive tract.

Shell diameter (cm)	Water depth	Main contents of digestive tract	Substances found in small quantities
<1	30 cm	"nomi-hamaguri" (small clam), calcareous algae	Adhering diatoms, Sphacelaria, Ectocarpus, Cladophora and sand
1-3	30 cm	kelp, calcareous algae, Lomentaria	Polysiphonia, Sphacelaria, laver, Cladophora, "nomi-hamaguri" and sand
	1.5 m	Desmarestia and laver	Kelp
	3.0 m	kelp, Desmarestia and laver	Polysiphonia, Sphacelaria, calcareous algae, Gelidium, sand and one item species unknown
3	30 cm	Lomentaria and kelp	Jointed calcareous algae, "nomi-hamaguri", sand and Cladophora
	3.0 m	kelp	Gelidium, Desmarestia, laver and calcareous algae
>4	1.0 m	kelp	Rhodymenia ?, calcareous algae, Creramium, Cladophora, "nomi-hamaguri", Polysiphonia, Crustacea, sand and "isomurasaki"
	1.5 m	kelp and Polysiphonia	Calcareous algae, Desmarestia, Gelidium, sand, Mytilus crassitesta (Lischke) and laver
	3.0 m	kelp	Delesseria, Creramium, laver, Desmarestia, calcareous algae, Cladophora, sand, Gelidium and Polysiphonia
	4.5 m	kelp and Gelidium	Creramium, laver, Delesseria, sand, Polysiphonia, Sphacelaria, Desmarestia, calcareous algae and "isomurasaki".

Table 6. [page 24]. Relationship between the food intake per day and water temperature.

Water temperature (°C)	Food intake per day (wet weight g)	
	March (10.8 ± 0.8)	November (28.6 ± 1.6)
5	3.27 ± 0.07	
10	3.48 ± 0.07	0.74 ± 0.02
15	3.10 ± 0.10	0.68 ± 0.01
20	2.34 ± 0.09	0.56 ± 0.02
23	1.60 ± 0.10	0.35 ± 0.01

Table 7 [page 25]. Water temperature and food intake.

Month	Number of sea urchins	Average water temperature (°C)	*Thalassia* per individual wet weight g/day
Jan.-Mar.	7	21.4	1.36
Mar.-Apr.	4	23.2	3.16
June-July	10	29.8	4.33

Table 8 [page 26]. Food intake.

Type of food	*Strongylocentrotus pulcherrimus* Av. wt. of single individual (W) g	Av. shell diam. of single individual cm	Av. food intake/single individual g: Air dried	Av. food intake/single individual g: Converted to fresh wt. (F)	F/W × 100	*Anthocidaris crassispina* Av. wt. of single individual (W) g	Av. shell diam. of single individual cm	Av. food intake/single individual g: Air dried	Av. food intake/single individual g: Converted to fresh wt. (F)	F/W × 100
Ecklomia cava Kjellm	11.07	2.97	0.370	1.153	10.41	33.19	4.03	0.322	1.004	3.03
Zostera marina L.	11.85	3.04	0.071	0.272	2.30	32.90	4.03	0.056	0.214	0.65
Calcareous algae	11.58	3.04	0.030	0.040	0.35	30.42	3.89	0.098	0.132	0.43
Sargassum sereatifolium C. Ag.	11.28	2.99	0.229	0.917	8.13	28.68	3.88	0.301	1.204	4.20
Gelidium	11.77	3.04	0.177	0.413	3.51	31.30	3.93	0.103	0.240	0.77
Sargassum thunbergii Kuntze						29.26	3.89	0.341	1.619	5.53
Laver						28.67	3.84	0.137	0.384	1.34
Fish meat (mackerel)	15.0	3.40	0.02	0.13	0.87	31.9	4.10	0.14	0.44	1.38
Squid meat	16.2	3.47	0.02	0.12	0.74	37.5	4.29	0.06	0.16	0.43
Beef	18.3	3.62	0.04	0.22	1.20	36.6	4.26	0.07	0.19	0.52
Shellfish (sea mussel)	17.8	3.59	+	+		38.9	4.37	+	+	

In the case of *Strongylocentrotus pulcherrimus* the food intake represents the average value after two days of fasting. In the case of *Anthocidaris crassispina* it is the average value after three days of fasting.

Water temperature: for *Strongylocentrotus pulcherrimus* 17.0 - 18.7°C
for *Anthocidaris crassispina* 22.2 - 24.1°C

Animal food was given for two days after 7 days of fasting. Shellfish were taken in great quantities; however, since they did not become granular in the digestive tract, it was difficult to measure.

Table 9 [page 27]. Type and amount of food eaten by Strongylocentrotus (Fuji, 1962).

Type of food	Month	Food intake (Wet wt. g)	Rate of food intake/day (%)	Food intake (Dry wt. mg)	Amt. of excretion (Dry wt. mg)	Efficiency of assimilation (%)
Laminaria japonica	Jan.	2.71	5.72	258.5	111.8	56.8
" "	June	2.89	5.81	419.6	142.6	66.0
Alaria crassifolia	June	0.97	2.27	214.3	65.5	69.4
Agarum cribrosum	June	0.65	1.36	145.5	39.9	72.6
Sargassum tortile	Jan.	0.60	1.33	117.8	43.7	62.9
S. thunbergii	Jan.	1.04	2.16	193.6	79.9	58.7
Scytosiphon lomentaria	Jan.	1.95	3.84	270.1	44.9	83.4
Ulva pertusa	Jan.	0.45	0.96	115.2	29.5	74.4
" "	June	0.54	1.19	119.8	21.6	81.9
Chondrus ocellatus	Jan.	0.96	1.96	201.6	87.1	56.8
" "	June	1.13	2.21	229.8	88.4	61.5
Pachymeniopsis yendoi	June	0.66	1.31	130.1	41.2	68.3
Rhodymenia palmata	Jan.	0.93	1.84	91.1	23.3	74.4
Rhodoglossum pulchrum	June	0.72	1.43	128.6	30.4	76.4
Phyllospadix iwatensis	June	1.02	2.03	135.6	91.6	32.4

Table 10 [page 28]. Relationship between amount assimilated, amount of increase and amount needed to sustain body weight.

Type of food	Amount of increase in body (mg/day)	Amount for sustenance (Dry weight: mg/day
Ulva pertusa	y = 0.3839x-5.1586	13.44
Alaria crassifolia	y = 0.3368x-5.7934	17.20
Laminaria japonica	y = 0.2019x-3.0663	15.19

Table 11 [page 29]. Assimilation efficiency.

Species	Summer	Winter
Lytechinus	57	54
Tripneustes	56	52

Table 12 [page 30]. Biological minimal shell diameter.

Species	Shell diam. (cm)	Age (year)	Research worker
Strongylocentrotus pulcherrimus	2.6	1.5	Kawana (1934)
	2.4-2.5	3.0	Fukui-Ken Fisheries Experimental Station (1938 - '40)
	2.4		Yoshida et al. (1960)
	1.6-1.7	1-1.3	Matsui et al. (1936)
	1.4		Nakamura and Inoue (1965)
S. intermedius	3-3.5		Fuji (1960)
	1.5		"
S. nudus	3		"
S. nudus	4-4.5		"
Lytechinus variegatus	3		Moore et al. (1963)
Tripneustes ventricosus	3.5♂ 4.0♀		McPherson (1965)

Table 13 [page 32]. Spawning period.

Species	Spawning period	Place and Author
<u>Strongylocentrotus pulcherrimus</u>	Jan. - Apr.	Shima, Sugiyama
	Jan. - Apr.	Sugiyama
	Apr.	Oshima
	Mar. - Apr.	Uchinoumi
	Feb. - Apr.	Matsui
	Dec. - Apr.	Kawana
	Nov. - Mar.	Yoshida
	Feb. - May	Asamushi, Okada, Miyauchi
	Jan. - Mar.	Naruto
<u>S. intermedius</u>	Sept. - Nov.	Shinoji ?
	June - Oct.	Abashiri, Kawamura
	June - Sept.	Saroma-Ko, Kawamura
	Sept. - Jan.	Muroran-Shikoke? Fuji
	Sept. - Oct.	--
<u>S. nudus</u>	Sept. - Nov.	Fuji
<u>Anthocidaris crassispina</u>	July - Aug.	Shima, Sugiyama
	May - June	Oshima
	June - July	Yamaji
	Mid July - mid Aug.	Tokushima, Okada, Miyauchi
<u>Pseudocentrotus depressus</u>	Oct. - Dec.	Shima, Sugiyama
	end Oct.	Oshima
	Oct. - Dec.	Yamaji
<u>Temnopleurus toreumaticus</u>	June - Aug.	Shima, Sugiyama
	June - July	Oshima
	July - Aug.	Yamaji
	end Aug. - end Sept.	Tokushima, Okada, Miyauchi
<u>Mespilia globulus</u>	July - Aug.	Shima, Sugiyama
	end June	Oshima
	end July - mid Aug.	Yamaji
<u>Toxopneustes pileolus</u>	Apr. - June	Oshima

Table 14 [page 34]. Sex ratio.

Species	♀	♂	Sex ratio	Number investigated	Author
Strongylocentrotus pulcherrimus	100	88	1:0.88	188	Kawana (1935)
	2522	2268	1:0.89	4790	Matsui et al (1960)
S. intermedius	193	174	1:0.901	367	Kawamura (1960)
Anthocidaris crassispina	103	83	1:0.709	186	Yamaguchi (1959)
Temnopleurus toreumaticus	1056	1037	1:0.982	2093	Ikeda (1931)
Arbacia sp.	1191	1167	1:0.984	2358	Shapiro (1935)
Tripneustes ventricosus			1:1		McPherson (1965)

Table 15 [page 42]. Course of maturation of Strongylocentrotus pulcherrimus and periods.

Place investigated	Sex	1	2	3	4	5
Shimonoseki-Shi	♀	Mid Feb.- beg. May	Beg. May- beg. Sep.	Sept.- end Oct.	Beg. Nov.- mid Dec.	Mid Dec.- beg. Mar.
Yoshimi	♂	Beg. Feb.- beg. May	End Apr.- mid Aug.	Mid Aug.- mid Oct.	End Oct.- mid Dec.	Mid Dec.- beg. Mar.

Table 16 [page 43]. Time of appearance of various stages in the maturation of gonads shown by area.

Place name	Sex	I Post-spawning recovery period	II Growth period	III Pre-maturation period	IV Maturation period	V Spawning period	Research Worker
Muroran	♀	Nov.-Feb.	Dec.-July	Apr.-Oct.	June-Oct.	Sep.-Jan.	
Ishiya(?)							Fuji
Shinori	♂	Dec.-Mar.	Feb.-June	Mar.-Oct.	Apr.-Nov.	Sep.-Jan.	
Abashiri (1959)	♀	-	-	-	Apr.-Sep.	June-Oct.	Kawamura
	♂	-	-	-	? -Sep.	June-Sep.	
Saroma-Ko (1959)	♀	-	-	-	-	June-Sep.	Kawamura
	♂	-	-	-	-	June-Sep.	
Oshoro (1961)	♀	Oct.-Apr.	Mar.-June	May -Aug.	Sep.	Sep.-Nov.	Hayashi and Kawamura
3 yr sea urchin	♂	Oct.-Jan.	Jan.-June	May -July	June-Sep.	Sep.-Nov.	
Rebun-To	♀	Jan.-May	Feb.-July	July-Aug.	Aug.-Sep.	Sep.	Kawamura
	♂	Mar.-May	Feb.-June	May-July	July-Sep.	Sep.	

Table 17 [page 45]. Gonad coefficient

Month / Area	1	2	3	4	5	6	7	8	9	10	11	12
Yoshimi	9.5	7.9	14.1	15.4	16.1	19.2	19.6					20.7
Matsure-Jima	13.7	10.7	14.3	18.5	18.5	20.3	20.8	21.0	21.2		24.1	

Table 18 [page 45]. Period in which the gonad coefficient shows the maximum and the minimum values by area.

Area	Sex	Period of: Max. gonad coefficient	Period of: Min. gonad coefficient	Period of: Half max. coefficient	Remarks	Research worker
Muroran	♀	Sept.	Oct.	May	In January both in ♀ and ♂ value nearly one half	Fuji
	♂	July	Oct.	May		
Ishiya (?)	♀	July or Aug.	Nov.	Jan.		Fuji
	♂	July or Aug.	Nov.	Jan.		
Shinori	♀	Aug.	Nov.	Jan.	Maximum smaller in comparison to Muroran and Ishiya	Fuji
	♂	Aug.	Nov.	Jan.		
Abashiri (1959)	♀	July	Oct.	..		Kawamura
	♂	July	Oct.	..		
Saroma-Ko (1959)	♀	Aug.	Sept.	..		Kawamura
	♂	Aug.	Sept.	..		
Kushiro (1961) 3 year sea urchin	♀	Aug.	Begin. Dec.	Apr.		Hawashi & Kawamura
	♂	Aug.	Begin. Dec.	Apr.		
Rebun-To	♀	Sept.	Mar.	June		Kawamura

Table 19 [page 46]. Relationship between shell diameter and weight of gonads.

Species	Shell diameter class									
	20 mm	25	30	35	40	45	50	55	60	65
Stronglylocentrotus pulcherrimus	0.3 g	0.8	1.3	2.1	3.2					
Pseudocentrotus depressus-Anthocidaris crassispina			0.4	1.1	2.4	3.8	5.6	7.6	9.7	12.0

The shell diameter of Strongylocentrotus pulcherrimus exceeds 2 cm; those of Anthocidaris crassispina and Pseudocentrotus depressus exceeds 2.5 cm.

Table 20 [page 48]. The gonad coefficients of sea urchins approximately 3 cm in shell diameter by area and by water depth

Area	Depth of water (m)			
	0-0.5	1.5	3.0	4.5
Utonai (?)	1.26	0.43	0.0	0.0
Nishi-Kamidomari (?)	1.14	0.69	0.20	0.0
Sukoton (?)	1.75	0.27	0.32	0.49
Edoya (?)	1.16	1.16	0.18	0.0
Benzaidomari (?)				
Horodomari (?)	0.89	0.86	0.0	
Nankozan (?)	1.69	0.29	0.28	
Higashi-Kamidomari (?)	0.98	0.50	0.10	
Akaiwa (?)	1.08			
Kukiai				0.18

Table 21 [page 50]. Relation between colour and the composition of the food (%).

Colour	Food		
	Green algae	Red and brown algae	Calcareous algae
Orange	13.0	81.7	5.2
Yellowish orange	10.2	85.5	4.1
Yellow	10.8	79.3	9.9

Table 22 [page 53]. Growth in Shimonoseki area. (Shell diameter mm)

Place of origin	Age				Year of measurement
	0.5	1.5	2.5	3.5	
Yoshimi	6-7	17-19	27-29	30-37	1961
Mutsure-Jima	6-8	20-21	30-31	36-37	
Yoshimi	6-7	12-13	28-29	36-37	1960
Mutsure-Jima	8-9	21-22	32-33	41-42	

Table 23 [page 53]. Growth. (Shell diameter mm).

Place of origin and research worker	Age 0.5	1.5	2.5	3.5	4.5
Fukui: Minamizawa (1959)	5	12-13	24-25	35-36	44-45
Yamaguchi: Matsui et al. (1962)	2.8-5.9	12-22	27-33	36-42	
Nagasaki: Yamaguchi et al. (1964)	5-6	15	25-26	35-36	40-41
Kanagawa: Fuji (1963)		10	21	28	34
Indoors: Nakamura et al. (1965)		17.5-25.5			

Table 24 [page 53]. Shell diameters of S. intermedius collected in various locales in the southern section of Hokkaido. (Shell diameter mm).

Place name	Time	No.	I	II	III	IV	V
	Oct. '58	335	...	34.0 ± 4.2	42.1 ± 2.9	50.3 ± 3.9	55.3 ± 5.0
Ishiya	Oct. '59	285	...	35.8 ± 3.0	41.6 ± 2.5	47.7 ± 3.3	54.1 ± 3.7
	Oct. '60	309	...	30.6 ± 5.0	42.9 ± 2.5	49.2 ± 7.7	...
	Oct. '59	289	...	34.6 ± 5.0	43.2 ± 2.0	48.0 ± 2.0	52.0 ± 4.4
Sumiyoshi	Oct. '60	419	...	33.2 ± 4.0	43.1 ± 3.0	49.8 ± 7.4	...
	Oct. '61	325	...	31.5 ± 5.5	41.6 ± 2.4	49.8 ± 2.7	58.1 ± 5.9
	Oct. '59	168	15.0 ± 4.5	33.4 ± 4.6	42.0 ± 2.0	...	...
Ishiya	Oct. '60	157	16.0 ± 4.0	32.4 ± 3.8	45.2 ± 4.4	...	...
	Oct. '61	151	16.1 ± 4.0	32.8 ± 3.3	42.0 ± 4.4	...	...
Average			15.70	33.14	42.63	49.19	54.87

Table 25 [page 54]. Observed and calculated value of shell diameters by age

Age	Shell diameter (mm)	
	Observed values	Calculated values
I	15.70	18.66 ± 6.21
II	33.14	32.30 ± 8.56
III	42.63	42.56 ± 9.80
IV	49.19	49.47 ± 10.62
V	54.87	54.76 ± 11.09

$Pr\{\chi_0^2 > 2.37\} = 0.50$

Table 26 [page 55]. Growth.

Year class	Author			
	Swan N.H. & Me., U.S.A.	Soot-Ryen (1924) Ramfjorde, Norway	Shorygin (1928) Barents Sea	Grieg (1928) Folden and Bals Fjords, Norway
O	.5 - 1.5	6 - 10	-	.5 - 2.5
I	(8 - 10)	12 - 22 (18)	12 - 20	(5 - 6)
II	(24 - 26)	22 - 23 (28)	21 - 31	(15)
III	(40 - 42)	33 - 40 (37-38)	32 - 41	(24 & 32)
IV	(46 - 54?)	43 - 52 (48)	42 - 52	(40?)
V		52 - 60	53 - 60	(50?)

Table 27 [page 56]. Rate of hyperplasia by body tissue.

Av. shell diam. (mm)	Rate of hyperplasia (%)							
	Weight				Protein			
	Shell	Lantern	Digest. tract	Gonads	Shell	Lantern	Digest. tract	Gonads
18	67.0	6.7	1.4	24.9	31.9	3.3	5.1	59.7
29	58.8	5.0	0.7	35.5	22.8	2.0	2.1	73.1
39	37.0	2.6	0.0	60.4	10.8	0.8	0.0	88.4
47	26.5	1.9	0.0	71.6	6.6	0.5	0.0	92.2
55	10.9	0.9	0.0	88.2	2.9	0.2	0.0	96.9

Table 28 [page 56]. Relation between the amount of assimilated food and hyperplasia in the body tissues.

Duration Month (number of days)	Amt. of food taken (g)	Amt. excreted (g)	Amt. assimilated (g)	Amt. of hyperplasia (g)			
				Shell	Lantern	Digest. tract	Gonads
	F	D	F - D				
Feb.-Apr. (60)	11.09	4.06	7.03	0.50	0.04	0.02	0.66
Apr.-June (60)	9.76	3.20	6.55	0.48	0.04	-0.06	1.12
June-Aug. (60)	8.40	2.88	5.52	0.53	0.04	0.004	0.41
Aug.-Sep. (26)	1.22	0.46	0.76	0.11	0.01	0.002	0.02
Sep.-Oct. (30)	3.76	2.00	1.75	0.10	0.01	0.02	-1.88
Oct.-Dec. (60)	7.51	3.03	4.48	0.43	0.03	0.08	0.83
Dec.-Feb. (46)	3.89	1.08	2.81	0.35	0.03	-0.004	0.16

Table 29 [page 57]. Relation between water temperature and growth.

Date of investigation	Water temperature (°C)							
	18 - 20		10 - 12		5 - 7		Near 0°	
	Shell diam. (cm)	Weight (g)	Shell diam. (cm)	Weight (g)	Shell diam. (cm)	Weight (g)	Shell diam. (cm)	Weight (g)
Dec. 6	3.03	12.4	2.95	11.6	3.05	12.7	2.97	11.7
Jan. 11	3.05	12.5	3.05	13.3	3.11	13.9	2.98	12.0
Feb. 7	3.07	12.9	3.21	14.9	3.19	15.5	2.97	12.1
Mar. 7	3.06	12.9	3.32	16.6	3.34	17.1	3.03	12.9
Apr. 6	3.11	13.5	3.37	17.1	3.49	19.4	3.24	15.2
May 4	3.16	14.1	3.56	19.7	3.69	21.3	3.37	16.1
Oct. 3	3.09	12.8	3.72	20.8	3.79	21.5	--	--

Table 30 [page 58]. Growth by food.

Type	Number of individuals	Shell diameter (mm)		
		Extent of variations	Average	Standard deviation
Before experiment	25	3.5 - 6.1	5.0	± 0.63
Ascophyllum	11	11.8 - 18.6	15.4	± 2.07
Laminaria	11	14.7 - 27.7	22.1	± 4.08

Table 31 [page 60]. Relationship between the growth of pluteus larvae and the specific gravity of water.

σ_{15}	Size of pluteus*	Remarks
23.5	576 μ	
23.0	561	
20.5	500	
18.0	439	Those in the prism period are also present.
15.5	427	Many individuals in the prism period are present.

* 3 days after the larvae in the prism period were brought into the laboratory.

Table 32 [page 61]. Rearing records of larvae (fertilized December 9, 1961 to January 19, 1962).

Developmental stages of larvae	Number of rearing days	Size	Survivor	Yield
6 arm stage	8	640μ	50	100%
8 arm stage	13	800	50	100
Time of appearance of pedicellaria	20	830	43	86
Time of appearance of ambulacral feet	34	810	25	50
Metamorphosis completed	40	380*	21	42

* Diameter of the main body.

Table 33 (page 62). Developmental history.

Strongylocentrotus pulcherrimus			*Anthocidaris crassispina*		
Date	Length of time	Remarks	Date	Length of time	Remarks
1964			1964		
Mar. 12		Fertilized	July 10		Fertilized
Mar. 21	(After 9 days)	6 arm period	July 17	(After 7 days)	8 arm period
Apr. 3	(" 22 ")	8 arm period	July 30	(" 20 ")	Ambulacral feet and spines appear
Apr. 20	(" 39 ")	Initial ambulacral feet appear	Aug. 2	(" 23 ")	Sinking and adhering start
Apr. 26	(" 45 ")	Sink and adhere	Aug. 8	(" 29 ")	Young sea urchin
May 18	(" 67 ")	Young sea urchin	Aug. 12	(" 33 ")	Shell diameter 1 mm (semi-flowing-water type rearing initiated)
May 25	(" 74 ")	Shell diameter 1 mm (semi-flowing-water type rearing initiated)	Sept. 4	(" 56 ")	Shell diameter 2 mm
July 10	(" 4 months)	Shell diameter 4.0-5.0 mm, 3 individuals	Dec. 21	(" 5 months)	Shell diameter 6 mm
Sept. 19	(" 6 ")	Shell diameter 8.0, 8.5, 10.0 mm.			
Dec. 21	(" 9 ")	Shell diameter 13.0, 15.0, 17.0 mm			

Continued ......

Table 33 - continued

Strongylocentrotus pulcherrimus			*Anthocidaris crassispina*		
Date	Length of time	Remarks	Date	Length of time	Remarks
1965			1965		
Jan. 28	(After 10 months)	Shell diameter 14.5, 18.0, 19.5 mm	Jan. 28	(After 6 months)	Shell diameter 8.5 mm
Mar. 25	(" 12 ")	Shell diameter 17.5, 23.5, 25.5 mm	Mar. 25	(" 8 ")	Shell diameter 9.5 mm
Apr. 12	(" 13 ")	Shell diameter 18.5, 24.5, 26.5 mm			

Table 34 [page 63 & 64]. Concentration of various chemicals which affect the development of Echinoidea.

Chemicals		Species: *Anthocidaris crassispina* (27°C)		*Strongylocentrotus pulcherrimus* (11-16°C)	
		Affected	Not affected	Affected	Not affected
$CuSO_4$	(Cu ppm)	0.1	0.032	0.032	0.01
CH_3COOCu	(Cu ppm)	0.1	0.032	0.032	0.01
$HgCl_2$	(Hg ppm)	0.032	0.01	0.032	0.01
$FeCl_3$	(Fe ppm)	10	3.2		
$MnCl_2$	(Mn ppm)	32	10		
$ZnSO_4$	(Zn ppm)	0.32	0.1		
$Cr_2(SO_4)_3$	(Cr ppm)	10	3.2	1.0<	
NaCN	(CN ppm)	0.1	0.032	0.1	0.032
K_2CrO_4	(CrO_4 ppm)	10	3.2	10	3.2
NH_4Cl	(NH_4 ppm)	10	3.2	10	3.2
CH_3COONH_4	(NH_4 ppm)	10	3.2		
I_2	(ppm)			3.2	1.0
No_2SO_3	(ppm)	3200	1000	32	10
Chrome alum	(ppm)	100	32		
Picric acid	(ppm)	100	32	32	10
Tannic acid	(ppm)			10	3.2
Phenol	(ppm)				
Paration	(ppm)			1.0	0.32
Uranium	(ppm)			32	10
Rhodamine B	(ppm)			32	10
Alcohol	(vol. %)	1.0	0.32		
Acetone	(vol. %)	1.0	0.32	3.2	1.0
(20°C) chloroform saturate water	(vol. %)			10	3.2
Semi chemical pulp waste liquor	(COD ppm)	13	4	13	4
Crude gas liquor	(COD ppm)	10	3.2		

Table 35 [page 66]. Relationship between length of time sperm is preserved and the rate of fertilization (Mixner, 1957).

	Fresh seminal fluid	Period preserved			
		7-14 days	6 months	12 months	24 months
Number fertilized	175	99	97	102	102
Rate of conception (%)	68	66.7	70.1	65.7	65.7

Table 36 [page 67]. Speed of movement.

Species	Speed mm/min Max.	Min.	Aver.	Remarks	Authors
Arbacia punctulata	40	35	22.2	Mature body	Jackson (1939)
			3	Size 6 mm	Harvey (1953)
Echinus sphaera			152	Horizontal	Romanes (1881)
Paracentrotus lividus			6.3	Vertical	Romanes & Ewart (1881)
Echinus esculentus			5.1	In air	Gemmill (1912)
Psammechinus miliaris	18.3	15.4			"
Echinarachnius parma	18	13.7			Parker (1927)
Lytechinus variegatus	137	82		Horizontal	" (1936)
" "	12	1.8		Vertical	"
Strongylocentrotus pulcherrimus	100			Horizontal	Matsui et al (1960)

Table 37 [page 71]. Respiratory volume of body tissues.

Tissues	O_2 cc/hr/g dry weight
Digestive tract	1.54
Spines, shell, ambulacral feet, water vascular system, etc.	1.47
Ovary	0.24
Testes	0.30

Table 38 [page 72]. Sea urchin catch (weight of gonads) and amount processed.

	Amt. of catch (tons)			Amt. processed (tons)		
	1961	1962	1963	1961	1962	1963
Total amount	14,071	16,474	19,297	1,233	1,535	2,039
Area						
Hokkaido						
Total amount	8,201	7,583	8,859	469	253	330
Northeastern section	5,314	4,083	4,444	231	131	247
Southern section	941	1,493	2,633	35	57	4
Western section	1,946	2,007	1,782	203	65	79
Pacific Ocean						
Total amount	4,054	4,982	5,377	133	120	186
Northern section	3,945	4,520	4,876	132	114	180
Central section	83	183	132	0	..	..
Southern section	26	279	369	1	6	6
Japan Sea						
Total amount	724	1,002	861	594	991	1,259
Northern section	..	1	..	1	16	1
Southern section	724	1,001	861	593	975	1,258
Eastern China Sea	1,058	2,736	4,120	34	86	154
Inland Sea of Japan	34	171	80	3	85	110

Remarks:

Hokkaido: Northeastern section (Soya, Abashiri and Nemuro),
Southern section (Kushiro, Hidaka, Tanshin(?) and Toshima),
Western section (Rumoi, Ishikari, Koshi (?) and Hiyama)

Pacific Ocean: Northern section (Aomori —> Ibaragi)
Central section (Chiba—>Mie)
Southern section (Wakayama—>Miyazaki)

Japan Sea: Northern section (Niigata and Toyama)
Southern section (Fukui—>Yamaguchi)
Eastern China Sea: (Fukuoka—>Kagoshima)
Inland Sea of Japan: (Osaka—>Oita)

Table 39 [page 73]. Production of processed, bottled sea urchins.

	1960	1961	1962	1963	1964	1965
Production (10,000 bottles)	650	700	750	800	800	850
Value (10,000,000 yen)	85	90	95	100	100	105

Calculated on the assumption that a single medium size bottle contains 120 g. Data supplied by Yamaguchi-Ken Uni Seizo Kogyo Kumiai (Yamaguchi-Ken Sea Urchin Processing Co-operative Association).

Table 40 [page 73]. Production by year and place of origin (Tons).

Place of origin	1962	1963	1964	1965
Within Ken (Prefecture)	75	83	94	95
Shikoku	9.4	9.4	9.4	9.4
Kyushu	75	75	75	75
Sanriku	75	75	75	75
Hokkaido	225	188	188	188
Korea	75	113	150	262

Table 41 [page 74]. Rate of increase or decrease and proportion of survival by age during fishing season.

Age	Shell diameter (mm)	No. of individuals: Before fishing season	No. of individuals: After fishing season	Proportion surviving	Increase or decrease
0.5	<15	16	52	3.25	+1.06
1.5	16-25	294	227	0.77	-0.26
2.5	26-30	109	26	0.24	-1.23
3.5	31-35	35	8	0.23	-1.26
4.5	>36	2	0	0	-2.00

Table 42 [page 75]. Age composition at the beginning of the fishing season.

Age	Shell diameter (mm)	1956	1957	1958	Average
0.5	<15	3.8	3.7	3.5	3.7
1.5	16-25	63.3	59.0	64.5	62.3
2.5	26-30	24.8	29.4	23.9	26.0
3.5	31-35	7.6	6.9	7.7	7.4
4.5	>36	0.4	1.0	0.4	0.6

Table 43 [page 75]. Survival rate after one month's fishing.

Year class	1.5	2.5	3.5
Survival rate	0.76	0.24	0.23

Table 44 [page 79]. Number of <u>Strongylocentrotus</u> <u>pulcherrimus</u> (Number of individuals/3.3 m^2).

Date investigated	Number of individuals Min.	Max.	Aver.	Investigator (place)
July 25, 1948	54	181	113	Fukui-Ken Fisheries Experimental Station (Fukui-Ken)
Oct. 14, 1948	34	126	80	" "
July 31, 1953	57	80	69	" "
July 28, 1954	16	51	35	" "
July 24, 1955	23	73	48	" "
July 21, 1956	30	105	55	" "
July 26, 1956	11	102	69	" "
June 21-July 8, 1962	18	47	26	" "
July 11-16, 1963	23	86	86	Matsui et al (Shimonoseki area)
May 28, 1963	106	175	142	" "
June 10, 1963	125	191	145	" "
July 12, 1963	23	244	125	" "
Aug. 22, 1963	46	106	76	" "
Sept. 1, 1963	53	119	86	" "
	11-125	47-244	26-145	

Table 45 [page 80]. Number of sea urchins by depth (per m^2).

Depth (m)	Minimum	Maximum	Average	Remarks
0.3	24	662	214	Figures are based on the data of Kawamura (1965) and Kawamura and Taki (1965).
1.5	15	452	166	
3.0	9	224	47	
4.5	1	92	24	

Table 46 [page 81]. Increase in yield due to building artificial reefs.

Fishing area	Rock added		Yield before introduction of practice 1935 (g)	Yield after introduction of practice 1936 (g)		Increase in yield		
	No. (rocks)	Value (Yen)		Yield	Adjusted amt.	Quantity (g)	Value (yen)	Proportion against cost (%)
Kaji	3,900	158	81,937.5	117,656.3	103,725.0	21,787.5	95.86	60.7
Umeura	2,500	170	13,687.5	31,837.5	30,330.0	16,642.5	66.57	39.4

Remarks: Quantities are expressed in g of sea urchins.

Adjusted amount: 1936 was a good year. In comparison to that of the previous year there were increases of 17% at Kaji and 11% at Umeura; thus, the figures were adjusted.

Table 47 [page 81]. Effects of building artificial reefs.

Area	I	II	III	Average
Himuki - 1957 rocks added	64	10	96	56.7
" - No rocks added	11	2	49	20.6
Saki - Rocks added	31	65	257	117.6
" - No rocks added	42	2	23	22.3

Table 48 [page 82]. Production of sea urchins (kg) and number of rocks added (individual rocks).

Fisheries Association		1953	1954	1955	1956	1957
Kaji	Production	352.5	311.25	337.5	303.75	352.5
	Quantity of rocks added	1,500	1,500	3,000	4,000	5,000
Saki	Production	375.0	487.5	461.25	592.5	607.5
	Quantity of rocks added	3,500	2,500	2,800	5,000	5,000
Yasushima	Production	487.5	825.0	862.5	825.0	787.5
	Quantity of rocks added	1,455	1,500	3,000	4,000	5,000
Sugahama	Production	337.5	393.75	378.75	375	450.0
	Quantity of rocks added	0	4,000	4,000	5,000	0
Hayase	Production	48.75	31.88	52.5	48.75	39.38
	Quantity of rocks added	0	6	0	0	0
Himuki	Production	450.0	345.0	656.25	712.5	768.75
	Quantity of rocks added	4,000	4,000	4,000	4,000	4,000
Minami Sugau	Production	232.5	288.75	318.75	300	326.25
	Quantity of rocks added	4,000	4,000	4,500	4,000	0

Page 232, Table 2, Fukui Fisheries Experimental Station (1956), (Adjustments made based on later data. Original figures given in "Kan" (translator's note: a Japanese unit of measurement) converted to kg).

Table 49 [page 83]. Calculated number of rocks needed.

Fisheries Association	a	b	Annual average quantity of rocks added
Kaji	333.75 kg	-0.20	3,000 rocks
Saki	333.75	+15.2	3,760
Yasushima	577.5	+16.0	2,991
Sugahama	313.88	+ 6.5	2,600
Hayase	44.81	-0.05	0
Himuki	285.0	+26.8	4,000
Himuki Sigau	233.63	5.3	2,500

Table 50 [page 86]. Transplant experiment at Akawa.

Species	Before transplant (Outer sea) Shell diam.	Av. shell diam.	Yield*	After transplant (inner bay) Shell diam.	Av. shell diam.	Yield*
	(mm)	(mm)	(%)	(mm)	(mm)	(%)
Strongylocentrotus pulcherrimus	30.0-27.0	26.3	13.9	43.0-29.5	34.2	16.7
Pseudocentrotus depressus	59.0-53.0	55.4	8.8	41.5-35.5	37.6	9.1
Anthocidaris crassispina	60.0-47.5	52.5	6.7	57.0-46.0	52.6	14.1

*Yield = (Weight: gonads)/(Total weight)

Table 51 [page 86]. Comparison of various characteristics of transplanted sea urchins and those at Kukiai and Horotomari.

Shell diameter		Weight gonads (g)	Gonad coefficient	Degree of fatness	Digestive tract content coefficient	Shell wt. coefficient	Ratio shell height to shell diam.
	Nursery	0.35	0.18	6.57	1.57	2.89	0.53
3.50-3.99	Transplant	1.6	0.79	6.98	1.30	3.74	0.57
	Prohibited area	3.6	1.57	8.14	1.35	4.52	0.50
	Nursery	0.8	0.28	6.27	1.53	3.41	0.54
4.00-4.49	Transplant	3.7	1.12	7.19	1.48	3.96	0.54
	Prohibited area	4.2	1.52	7.64	1.41	4.40	0.50
	Nursery	1.8	0.44	6.61	1.58	3.28	0.53
4.50-4.99	Transplant	6.1	1.45	7.73	1.55	4.09	0.50
	Prohibited area	6.5	1.70	8.15	1.43	4.37	0.46
5.00-5.47	Nursery	3.1	0.51	6.15	1.42	2.78	0.54
	Transplant	7.8	1.41	7.46	1.36	3.99	0.53

Table 52 [page 87]. Comparison of gonad coefficients.

Area	Date of investigation	Transplant at nursery	Transplant	Local
Shukutsu, Otaru-Shi	1963. 5. 31	0.51	2.21	2.45
" "	1964. 7. 8	1.27	2.50	2.79
Funatomari, Rebun-To	1963. 6. 29	0.41	1.33	1.62
" "	1964. 6. 23	...	1.07	1.10

Table 53 [page 87]. Gonad coefficient due to transplant.

	Date of investigation	Transplanted sea urchin	Local sea urchin
At time of transplant	1965. 7. 3	0.43	2.46
After transplant	1965. 9. 10	1.52	2.52

Table 54 [page 92]. Restriction on fishing season.

Area	Species	Duration	Remarks
Hokkaido	S. intermedius	July 1 - Sept. 30	Offshore areas under the jurisdictions of Tokachi, Kushiro, Nemuro and Abashiri Branch Offices of Hokkaido Government.
		Sept. 1 - Oct. 31	Offshore areas under jurisdictions of other Branch Offices.
	S. nudus	July 15 - Sept. 30	Offshore areas under jurisdiction of Tokachi, Kushiro, Nemuro and Abashiri Branch Offices.
		Sept. 15 - Oct. 31	Offshore areas under jurisdiction of other Branch Offices.
Aomori		Aug. 20-Dec. 31	By association members only. Method of fishing (Uchiseami (transl. note: type of drag net): less than 6 cm). Fishing prohibited by mutual agreement.
Fukushima		Oct. 1 - Apr. 31	
Fukui		Aug. 21 - July 20 of following year	
Kanagawa		Generally no restrictions except the period Oct. 1 - Mar. 31	Method of fishing by various associations (use of diving equipment), fishing season
Hiroshima		Apr. 1 - Oct. 30	Use of diving apparatus prohibited by Kurahashi-jima Association only.
Iwate			Opening date by agreement among all associations in the prefecture.
Tokushima		Jan. 1 - Aug. 19	By agreement among Shiwaki, Higashi-Yuki and Nishi-Yuki Associations
Shimane			Opening date in the sea near Tagi-Mura, Hirukawa-Gun by agreement
Tottori	S. pulcherrimus	Sept. 1 - June 30	
	A. crassispina	Mar. 1 - Nov. 30	
Yamaguchi			Opening date for outer sea by agreement among associations.
Fukuoka		July - Mar.	Aijima, Wakita, Oshima, Genkai-Jima, Akutaya and Kanezaki Associations
Nagasaki			Agreement among associations

Table 55 [page 93]. Restrictions on catch and plans for propagation in fishing areas along the coast of Hokkaido.

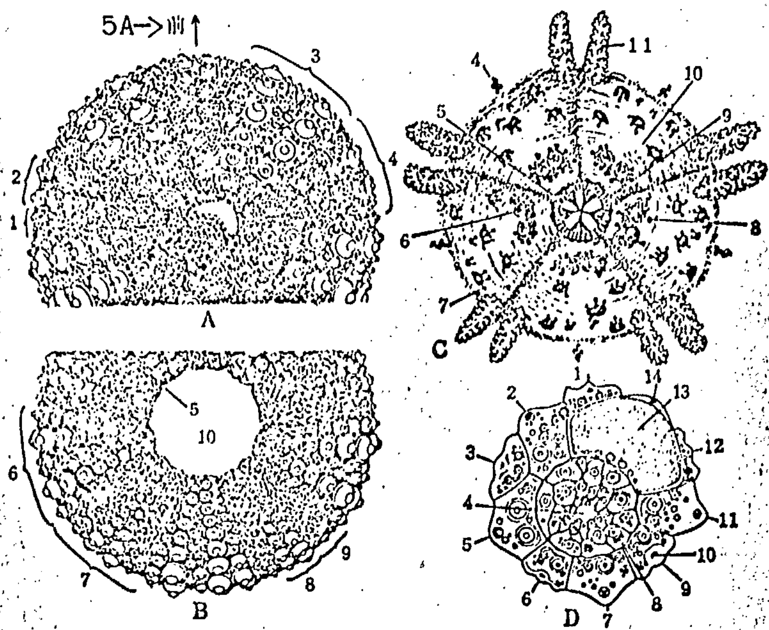
Fishing area	Closed season	Restriction on shell diam. (mm)	Method of propagation and transplant
Funadomari	Aug. 21 - June 24	40	Transplant, closed area
Oshidomari	Aug. 1 - June 20	..	Transplant
Oniwaki	Sept. 1 - June 24	50	Closed area
Senhoshi	Oct. 1 - May 31	50	
Kutsugata	Sept. 25 - June 15	..	
Koetoi	Sept. 1 - Apr. 30	60	Transplant
Soya	Aug. 10 - May 10	..	
Esashi	-	50	
Abashiri	Aug. 21 - Oct. 9	..	Transplant
Rausu	July 1 - Feb. 28	60	Transplant
Shimae(?)	Apr. 1 - Sept. 30	..	Transplant
Occhishi	May - Sept.	..	
Erimo	June 1 - Sept. 30	..	
Toyo	July 20 - Jan. 20	50	Artificial reefs
Hagifushi	July 1 - Sept. 30	..	
Aritama(?)	June 1 - June 30, Aug. 1 - Aug. 30	..	Transplant
Toyora	-	..	Rotation
Tanhoge	June 1 - Oct. 31	50	Transplant
Kikonai	-	60	Transplant, artificial reefs
Fukushima	Aug. 1 - June 30	..	Artificial reefs
Osawa	Apr. 1 - June 30	60	
Eyoshi	-	..	Rotation
Minami Okujiro	Aug. 1 - June 30	30	Transplant
Nishijimamaki	Sept. 1 - June 30	..	Transplant
Suttsu	-	..	Transplant
Tomari	July 13 - Aug. 12	60	Transplant
Kamienai(?)	Sept. 1 - July 10	..	Transplant
Yakijiri	Aug. 20 - June 10	60	Transplant
Mashike	Aug. 1 - June 19	..	Transplant

Table 56 [page 94]. Shell diameter restriction.

Area	Species	Shell diam.	Remarks
Hokkaido	S. pulcherrimus	Less than 4 cm	There are areas where by agreement among associations there is a limitation on size to specimens over 60 mm as shown in Table 55.
	S. intermedius	Less than 5 cm	
Fukushima	S. pulcherrimus	Less than 3.5 cm	However, this excludes the case of seedlings.
Fukui	S. pulcherrimus	Less than 3.5 cm	

Table 57 [page 94]. Increase in shell diameter-gonad weight when catch is delayed by a year.

Species	Shell diam. range (cm)	Gonad weight	
		Weight (g)	Rate of increase (times)
S. pulcherrimus	2.0 - 2.5	0.50	3.1
	3.0 - 3.5	1.55	
P. depressus	3.5 - 4.0	1.35	2.8
	4.5 - 5.0	3.76	
A. crassispina	4.0 - 4.5	1.91	2.0
	5.0 - 5.5	3.85	



殻の両極面

A：反口側 1. 孔帯 2. 間孔帯 3. 間歩帯 4. 歩帯
B：口側 5. 鰓隙 6. 間歩帯 7. 歩帯 8. 間孔帯 9. 孔帯 10. 囲口部
C：囲口部 4. 球状体 5. 歯 6. 口縁管足 7, 8 叉棘 9. 唇 10. 囲口膜 11. 外鰓
D：1. 第3眼板 2. 第3生殖板 3. 第4眼板 4. 肛門 5. 第4生殖板 6. 第5眼板 7. 第5生殖板 8. 囲肛板 9. 第1眼板 10. 眼点孔 11. 第1生殖板 12. 第2眼板 13. 第2生殖板(穿孔板) 14. 生殖腺開孔

第1図 外部構造

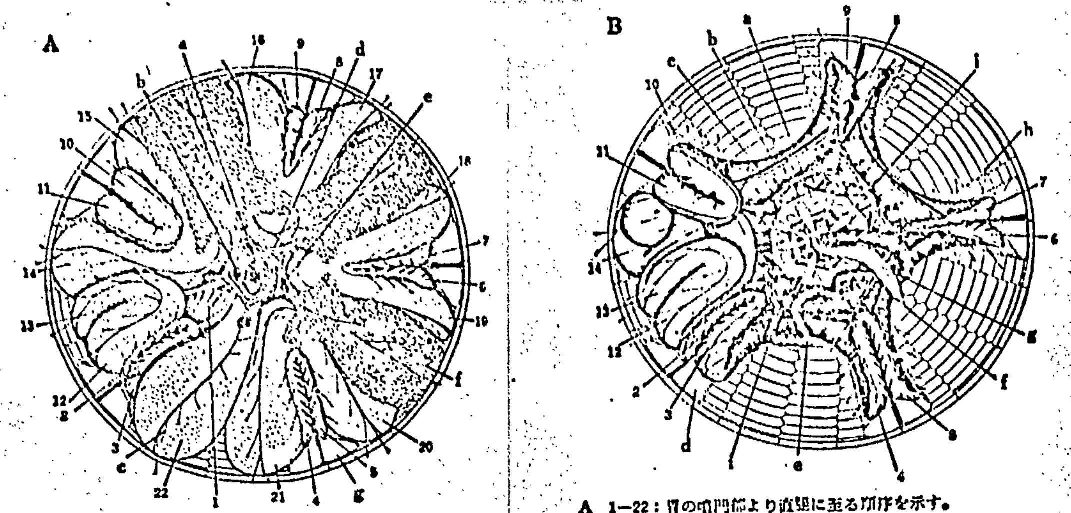
Fig. 1. External features. Two polar surfaces of the shell. [page 3]

A. Aboral pole
- 1. Pore plates
- 2. Non-pore plates
- 3. Adambulacral zone
- 4. Ambulacral zone
- 5A. Front

B. Buccal side
- 5. Peristomal gill cleft
- 6. Adambulacral zone
- 7. Ambulacral zone
- 8 Non-pore plates
- 9. Pore plates
- 10. Peristome

C. Peristome
- 4. Spheroid body
- 5. Teeth
- 6. Mouth edge ambulacral feet
- 7.
- 8. Pedicellaria
- 9. Lip
- 10. Peristomal membrane
- 11. External gill

D.
- 1. Third ocular plate
- 2. Third genital plate
- 3. Fourth ocular plate
- 4. Anus
- 5. Fourth genital plate
- 6. Fifth ocular plate
- 7. Fifth genital plate
- 8. Periproct plate
- 9. First ocular plate
- 10. Eye spot aperture
- 11. First genital plate
- 12. Second ocular plate
- 13. Second genital plate (Madreporic plate)
- 14. Gonad opening



A 1—22：胃の噴門部より直腸に至る順序を示す。
a：肛門 b：石管頂端 c：懸糸 d：反口環 e：生殖腺開口
f：生殖腺 g：胆嚢

B 1—14：胃の噴門部より腸前半部に至る順序を示す。
a：アリストートルの提灯 b：腹血管 c：胃気管 d：胆嚢
e：食道 f：石管頂端 g：中軸器官 h：懸糸 i：背血管

第2図 内部構造

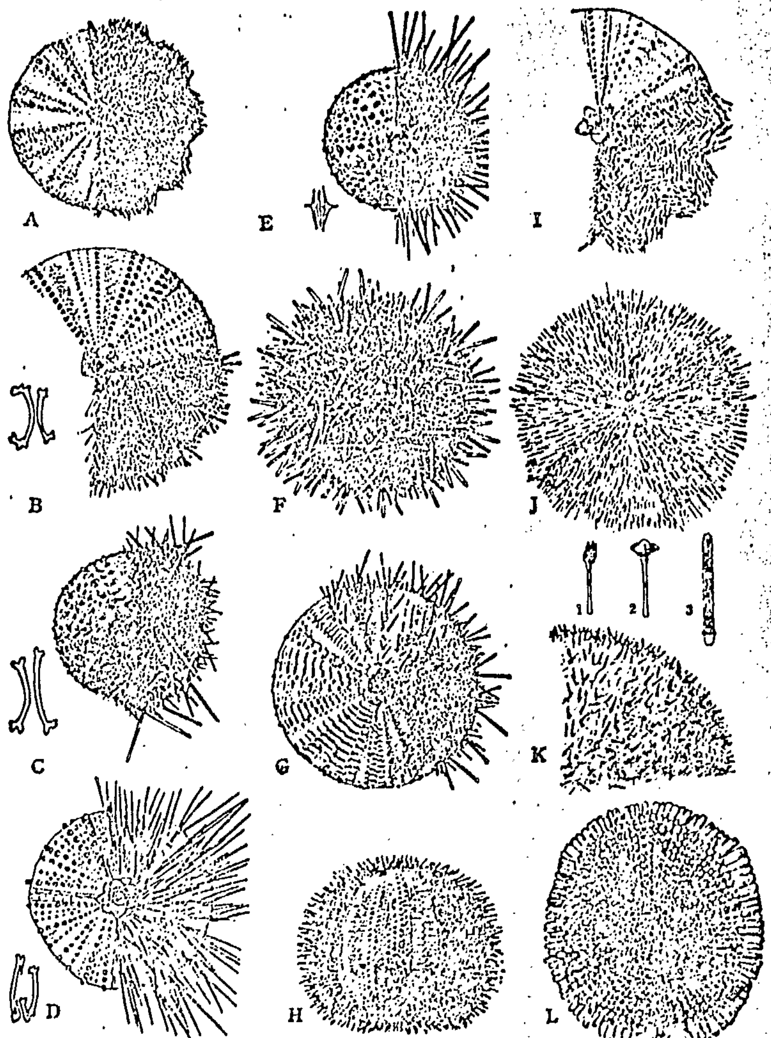
Fig. 2 [page 4]. Internal structure.

A - 1-22: shows the sequence from the cardiac orifice of the stomach to the rectum.

- a - anus
- b - the apex of the stone canal
- c - mesentery
- d - aboral ring
- e - gonad opening
- f - gonad
- g - gall bladder

B - 1-14: shows the sequence from the cardiac orifice to the front half of the intestine.

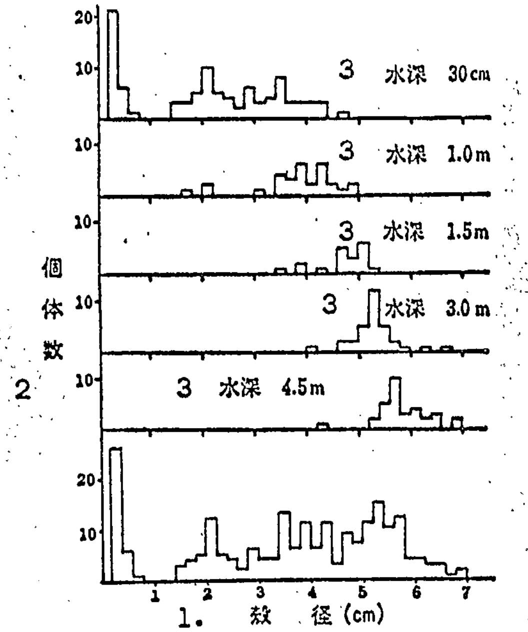
- a - Aristotle's lantern
- b - ventral blood vessel
- c - siphon
- d - gall bladder
- e - esophagus
- f - apex of stone canal
- g - axial organ
- h - mesentery
- i - dorsal blood vessel



A *Strongylocentrotus pulcherrimus* (A. Agassiz) バフンウニ
B *Strongylocentrotus intermedius* (A. Agassiz) エゾバフンウニ
C *Strongylocentrotus nudus* (A. Agassiz) キタムラサキウニ
D *Strongylocentrotus franciscanus* (A. Agassiz) ハリナガオオバフンウニ
E *Anthocidaris crassispina* (A. Agassiz) ムラサキウニ
F *Pseudocentrotus depressus* (A. Agassiz) アカウニ
G *Temnopleurus toreumaticus* (Leske) サンショウウニ
H *Mespilia globulus* (Linné) コシダカウニ
I *Tripneustes gratilla* (Linné) シラヒゲウニ
J *Pseudoboletia maculata* (Troschel) マダラウニ
K *Toxopneustes pileolus* (Lamarck) ラッパウニ
L *Colobocentrotus mertensii* (Brandt) ジンガサウニ

第3図 食用ウニの種類

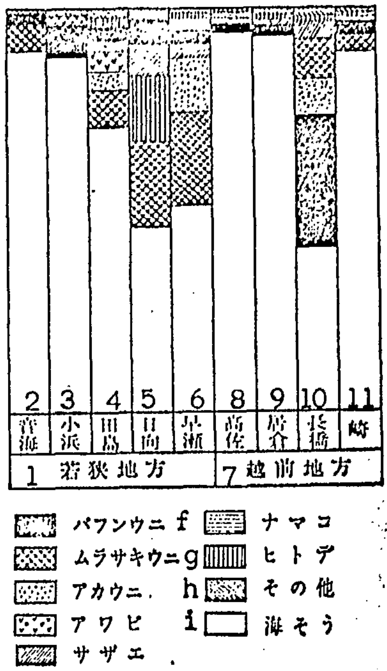
Fig. 3 [page 8]. Species of edible sea urchins.



第4図 エゾバフンウニの殻径の大きさと水深との関係 (礼文島 川村, 1964)

Fig. 4 [page 17]. Relation between the size of shell of *S. intermedius* and water depth. (Rebun-To Kawamura, 1964)

1. Shell diameter (cm)
2. Number of individuals
3. Water depth



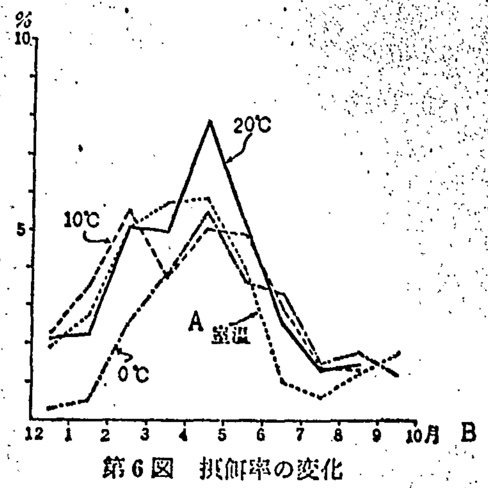
第5図 福井県浅海漁場における
大型底棲生物量

(滝・東田)

Fig. 5 [page 19]. Volume of large size benthos in shallow fishing grounds in Fukui-Ken. (Taki, Higashida)

1. Wakasa district (Translator's note: western section of Fukui-Ken)
2. Otoumi
3. Kohama
4. Tashima
5. Hinata
6. Hayase
7. Echizen district (Translator's note: eastern section of Fukui-Ken)
8. Takasa
9. Ikura
10. Nagahashi
11. Saki

a. Strongylocentrotus pulcherrimus
b. Anthocidaris crassispina
c. Pseudocentrotus depressus
d. Haliotis gigante Gmelin
e. Turbo (Batillus) cornutus (Solander)
f. Sea cucumber
g. Starfish
h. Others
i. Seaweeds

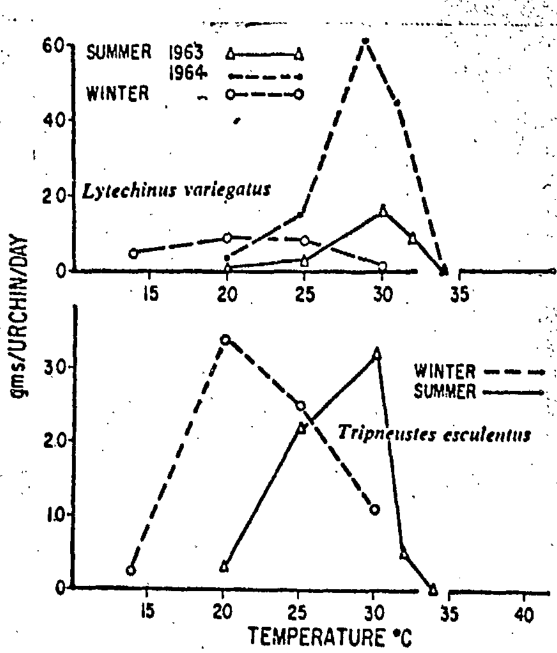


第6図 摂餌率の変化

Fig. 6 [page 24]. Variation in rates of food intake.

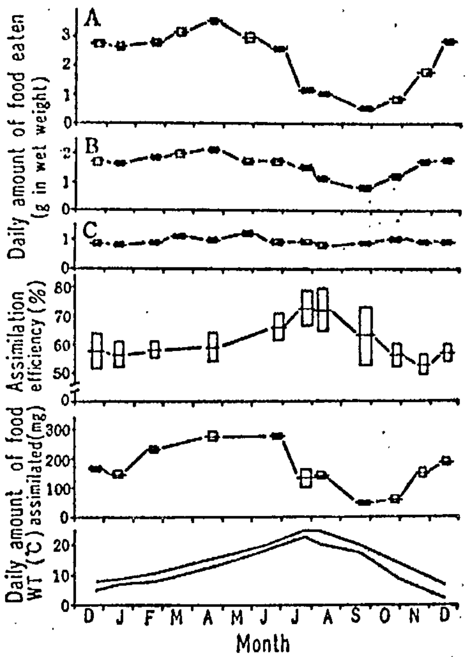
A. Room temperature

B. Month



第7図 水温，季節別の *Thalassia* を餌とする摂餌率
(McPherson, 1965)

Fig. 7 [page 25]. Relationship between rate of food intake, water temperature and season, using Thalassia as food. (McPherson, 1965).



A：殻径 55mm　B：殻径 40mm　C：殻径 20mm

第8図　エゾバフンウニの殻径別摂餌率，摂餌量の季節的変動

(富士，1962)

<– A – Shell diameter 55 mm

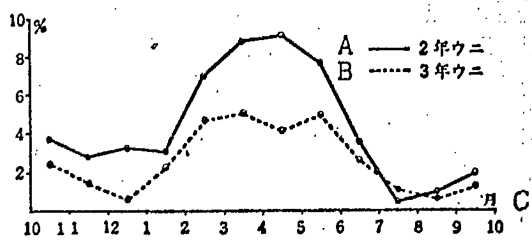
<– B – Shell diameter 40 mm

<– C – Shell diameter 20 mm

Fig. 8 [page 28]. Seasonal variation in the rate and amount of food intake by <u>Strongylocentrotus pulcherrimus</u>.

(Fuji, 1962)

一栄　養一 29



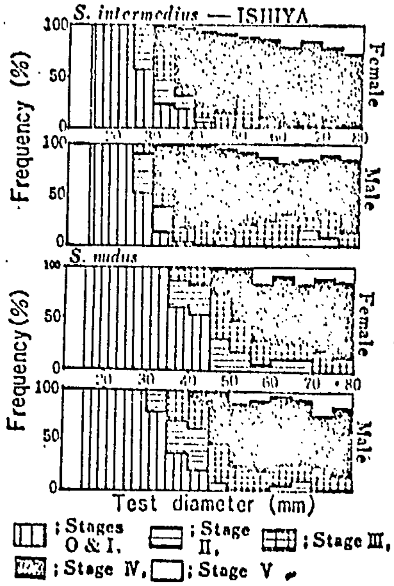
第9図　飼育ウニの1日平均摂餌率の変化

Fig. 9 [page 29]. Variations in the average daily food intake.

A. Two year old sea urchin

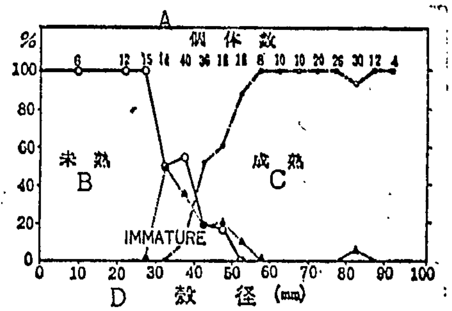
B. Three year old sea urchin

C. Month



第10図　エゾバフンウニとキタムラサキウニの殻径と生殖腺の発達段階の出現頻度

Fig. 10 [page 31]. Frequency of appearance of shell diameters and of the developmental stages in Strongylocentrotus pulcherrimus and Anthocidaris crassispina.

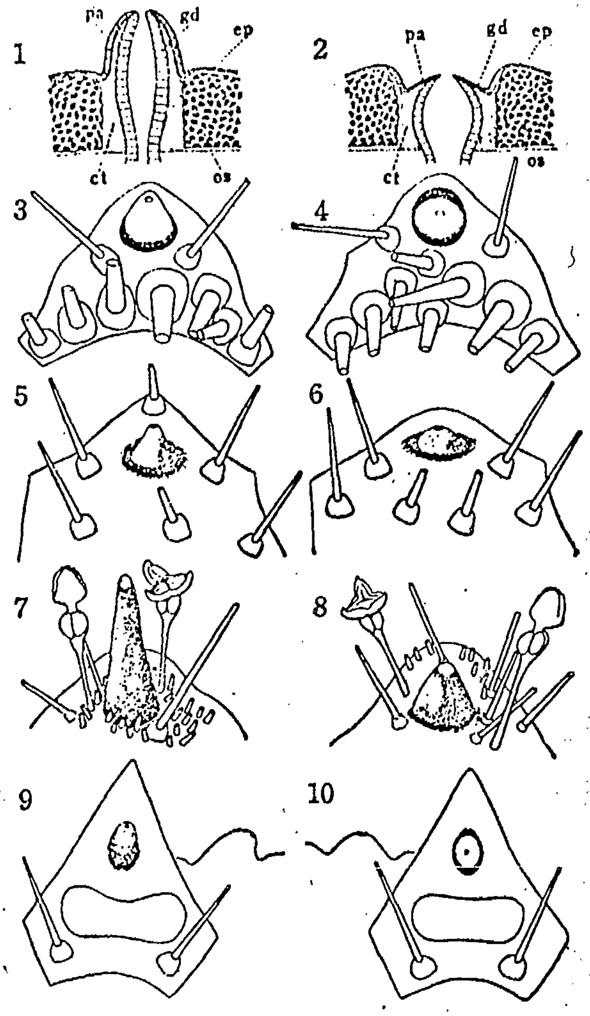


第11図　殻径と成熟との関係

(McPherson, 1965)

Fig. 11 [page 31]. Relationship between shell diameter and maturity. (McPherson, 1965).

A. Number of specimens
B. Immature
C. Mature
D. Shell diameter (mm)



1, 2 *Mespilia globula* の生殖乳頭断面
ct……結締組織, gd……生殖腺壁, ep……殻,
pa……乳頭壁, os……生殖腺
3, 4 *Mespilia globulus* の生殖乳頭断面
5, 6 *Echinostrephus aciculatus* の生殖乳頭断面
7, 8 *Tripneustes gratilla* の生殖乳頭断面
9, 10 *Diadema setosum* の生殖乳頭断面

第12図 生殖器の雌雄差 (奇数：♀, 偶数：♂)

1, 2. Cross-section of the genital papilla of <u>Mespilia globula</u>.

ct - connective tissues
gd - gonad wall
ep - shell
pa - papilla wall
os - gonad

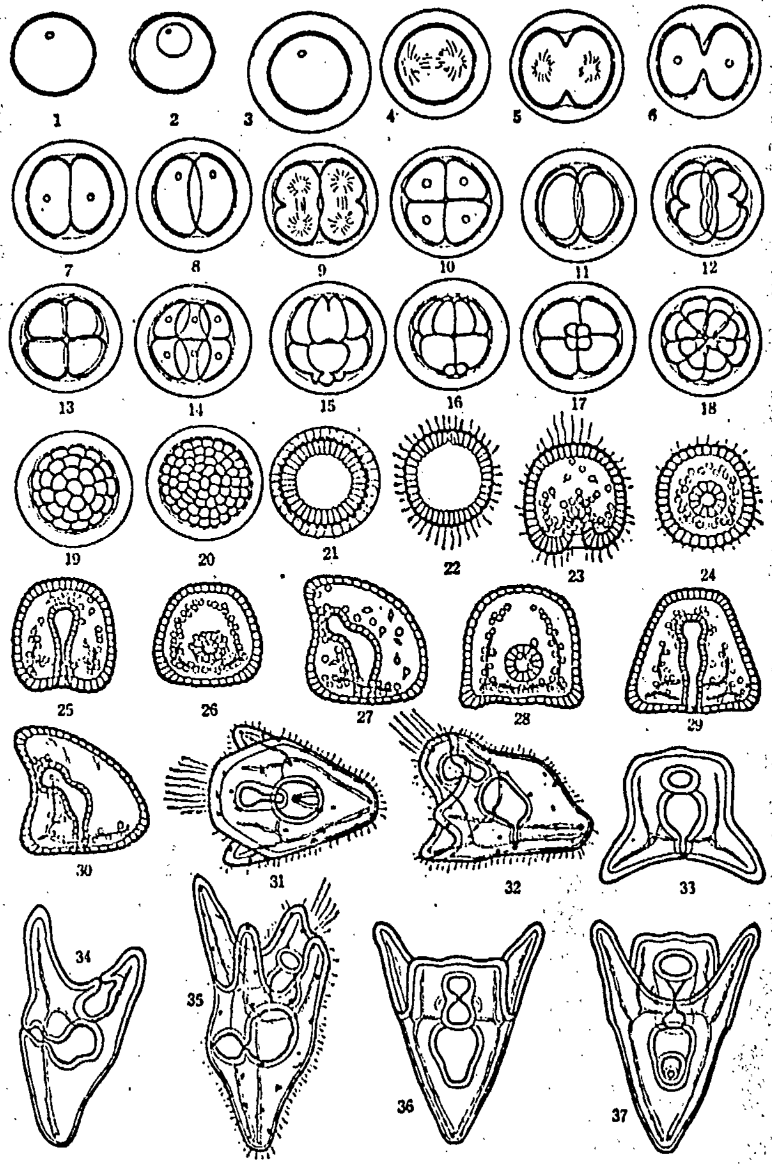
3, 4. Cross-section of the genital papilla of <u>Mespilia globulus</u>.

5, 6. Cross-section of the genital papilla of <u>Echinostrephus aciculatus</u>.

7, 8. Cross-section of the genital papilla of <u>Tripneustes gratilla</u>.

9,10. Cross-section of the genital papilla of <u>Diadema setosum</u>.

Fig. 12 [page 33]. The sexual difference in the reproductive organs (odd number - females; even number - males).



1　未受精卵（卵径80～90μ）
2　成熟卵（卵径90～100μ）20～30μ の厚さのジェリー層が卵膜の外側にある。
3　受精卵。媒精後10～15秒，受精膜形成完了，ヒアリン膜明瞭。

Fig. 13 [page 38]. Larval development in Strongylo-centrotus pulcherrimus. (Okada and Miyauchi).

.... cont'd

Fig. 13 (Legend)

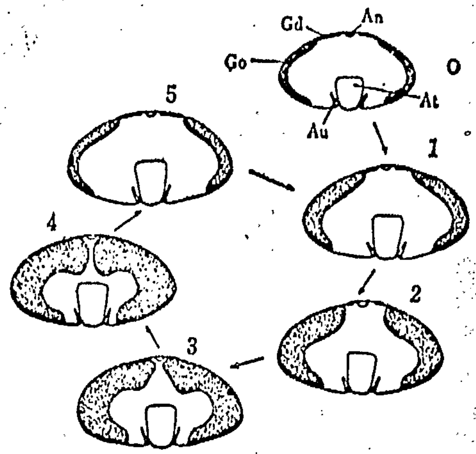
1. Unfertilized egg (diameter 80-90 μ)
2. Mature egg (diameter 90-100 μ). The exterior of the egg membrane is covered by a gelatinous layer 20-30 μ in thickness.
3. Fertilized egg, 10-15 sec. after insemination. The formation of the fertilization membrane is complete. The hyaline layer clear.
4. The first cleavage. The period when the asters due to fissure of nucleus appear (1.5-2.0 hours after insemination).
5. Asters formed. Five seconds after; an orthograph of the animal pole.
6. The first cleavage. An orthograph of the animal pole during the period of division of the cell body.
7. An orthograph of the animal pole during the period of completion of two cell embryos.
8. A lateral view of the above (2-2.5 hours after insemination; blastomere 45-50 × 90-100 μ).
9. An orthograph of the animal pole during the initial period of the second cleavage.
10. An orthograph of the animal pole in the period of completion of 4 cell embryos.
11. A lateral view of the above (3-4 hours after insemination; blastomere 50 × 70 μ).
12. An orthograph of the animal pole taken at an angle during the initial period of the third cleavage.
13. Period of completion of 8 cell embryos.
14. A lateral view of the above (4-5 hours after insemination; blastomere 50 × 50 μ).
15. A lateral view of the initial period of the fourth cleavage. The separation of the micromeres at the vegetal pole starts.
16. A lateral view of the period of completion of 16 cell embryos.
17. An orthograph of the vegetal pole of the above (5-6 hours after insemination).
18. An orthograph of the animal pole of 28 cell embryos (6-7 hours after insemination).
19. An orthograph of the animal pole during the 64 cell embryo period in the morula stage (9 hours after insemination; blastomere 10-12 μ).
20. The early embryo stage. The number of cells approximately 160 (14-16 hours after insemination).
21. Blastula during the hatching period. Cross-section of the blastula immediately before hatching (20 hours after insemination).
22. The blastula prior to floating. Vertical cross-section (cilia at the animal pole somewhat longer; 23 hours after insemination).

.... cont'd

Fig. 13 (cont'd)

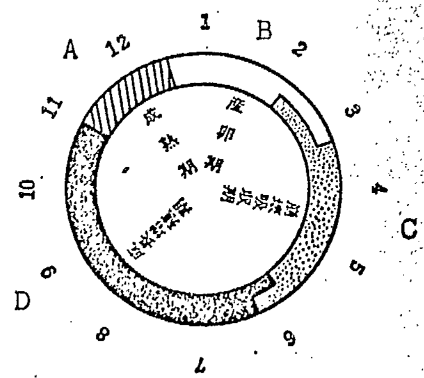
23. A front view of the gastrula in the second period (32 hours after insemination; the size of the embryo 140 × 130 μ).
24. Cross-sectional view of the gastrula in the third period (42 hours after insemination).
25. A front view of the gastrula during the completion period in the fourth period.
26. An orthograph of the animal pole of the above (52 hours after insemination).
27. The pyramid type larval I period (dipleurula); a left lateral view.
28. As above; a dorsal view (64 hours after insemination).
29. A front ventral view of the pyramid type larval II period.
30. As above; a left lateral view (76 hours after insemination).
31. A dorsal view of the Pluteus type larval I period.
32. As above; a left lateral view (86 hours after insemination; red pigments appear; 200 μ in length).
33. A front view of the Pluteus type larval II period.
34. As above; a left lateral view (100 hours after insemination; 270 μ in length).
35. As above; the III period.
36. As above; a dorsal view.
37. As above; a ventral view (120 hours after insemination; 300 μ in length).

The sequence noted above was carried out under the following environmental conditions: water temperature 10-15°C; left standing at the room temperature; pH 8.1-8.2, salinity Cl = 17-18‰.



第14図　成熟周期模式図
(富士)

Fig. 14 [page 41]. Schematic diagram of the maturation periods. (Fuji).

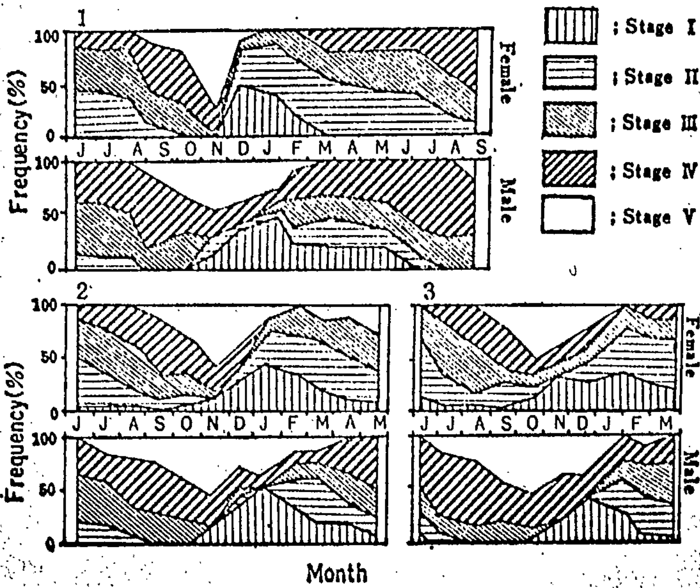


第15図　成熟周期と月との関係図
(数字は月を示す)

4期成熟期，第5期産卵期の5期に分け

Fig. 15 [page 42]. Relation between maturation period and month. (The numerals show months)

A. Maturation period
B. Spawning period
C. Disintegration and absorption period
D. Growth and multiplication period

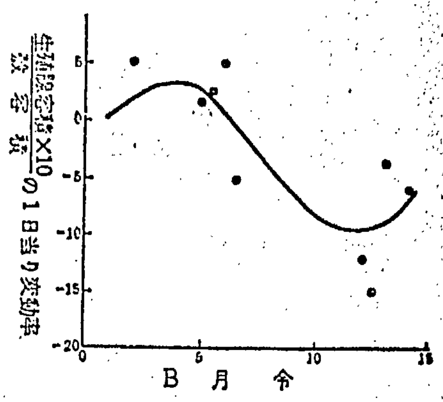


1. 石屋 2. 志苔 3. 室蘭

第16図 生殖腺の成熟度の季節的変化

Fig. 16 [page 43]. Seasonal variation in the degree of maturity of the gonads.

1. Ishiya(?)
2. Shinori
3. Muroran

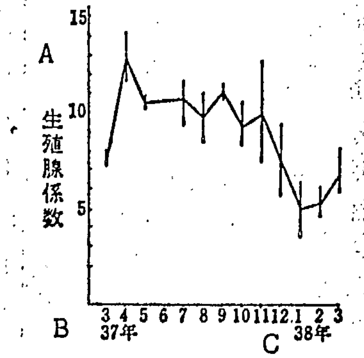


第17図 月令と生殖腺係数との関係

Fig. 17 [page 44]. Relation between phase of the moon and the gonad coefficient.

A. Rate of variation in $\frac{\text{volume of gonad} \times 10}{\text{volume of shell}}$ per day.

B. The phase of the moon.



第18図 バフンウニ生殖腺の月別変動

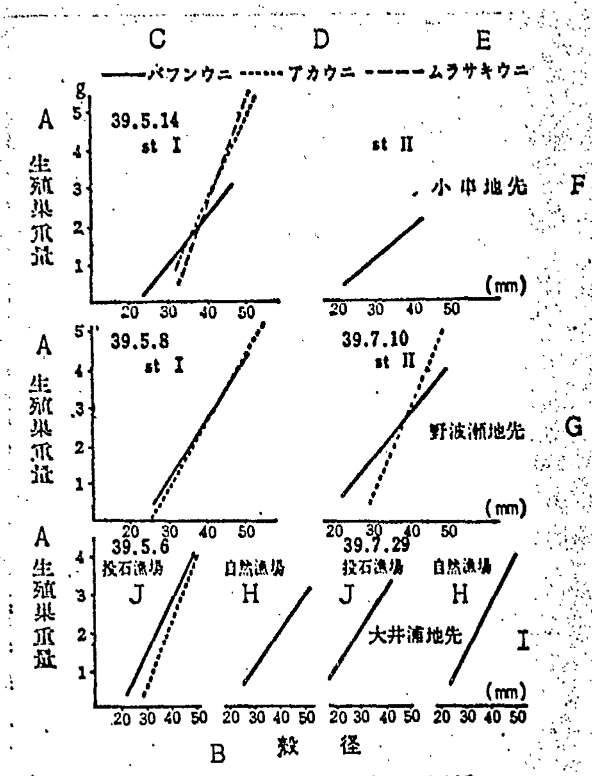
Fig. 18 [page 45]. Monthly variation of gonad in Strongylo-centrotus pulcherrimus.

A. Gonad coefficient

B. 37 year - 1962

C. 38 year - 1963

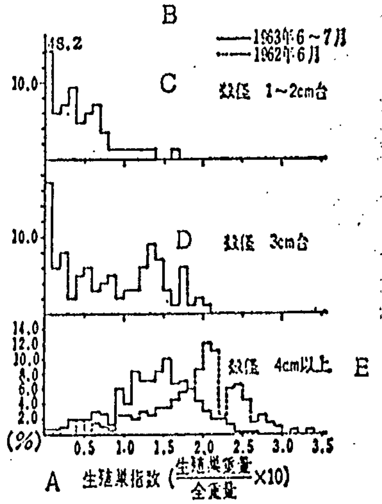
(Standard error 95% confidence degree)



第19図 殻径と生殖巣重量の関係

Fig. 19 [page 46]. Relationship between shell diameter and weight of gonad.

A. Weight of gonad
B. Shell diameter
C. <u>Strongylocentrotus</u> <u>pulcherrimus</u>
D. <u>Pseudocentrotus</u> <u>depressus</u>
E. <u>Anthocidaris</u> <u>crassispina</u>
F. Off the shore of Ogushi
G. Off the shore of Nohase(?)
H. Natural fishing ground
I. Off the shore of Oiura
J. Rocky fishing ground



第20図 大きさ別生殖巣指数の度数分布 (%)

A. Gonad coefficient $\frac{\text{Weight of gonad}}{\text{Total weight}} \times 10$

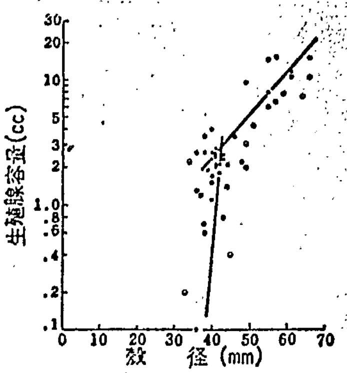
B. ———————— June-July, 1963
-------- June, 1962

C. Shell diameter: approximately 1 - 2 cm

D. Shell diameter: approximately 3 cm

E. Shell diameter: approximately over 4 cm

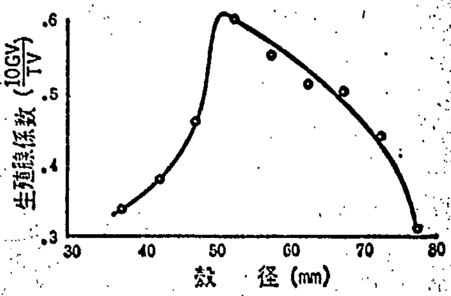
Fig. 20 [page 47]. Frequency distribution (%) of gonad coefficient by size.



第21図 *Lytechinus* の殻径と生殖腺容積との関係

Fig. 21 [page 47]. Relation between the shell diameter and the volume of the gonads.

Ordinate - Volume of gonad (cc)
Abscissa - Shell diameter (mm)



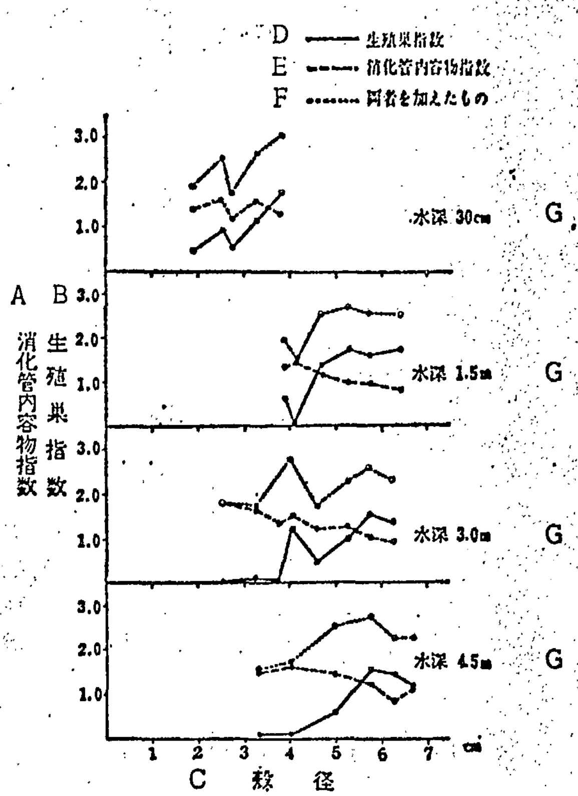
第22図　殻径と生殖腺係数

$\left(\frac{\text{生殖腺容量} \times 10}{\text{殻容量}}\right)$との関係

Fig. 22 [page 47]. Relation between the shell diameter and the gonad coefficient $\left(\frac{\text{Volume : gonad} \times 10}{\text{Volume : shell}}\right)$.

Ordinate - Gonad coefficient $\left(\frac{10\ GV}{TV}\right)$

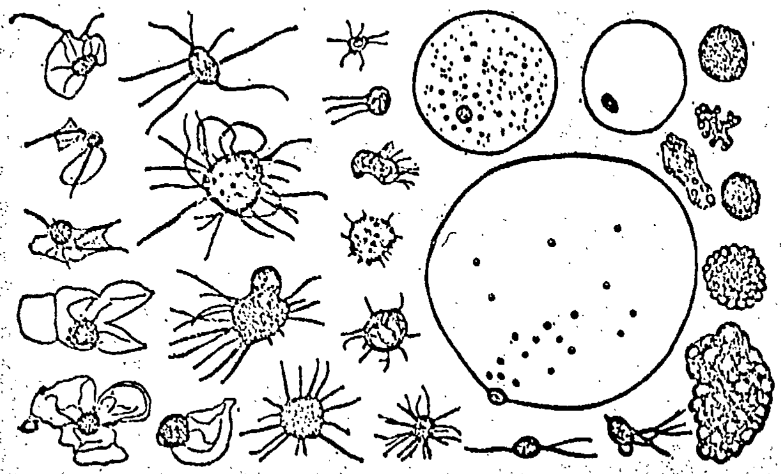
Abscissa - Shell diameter (mm)



第23図 西上泊 水深別，生殖巣指数と
消化管内容物指数

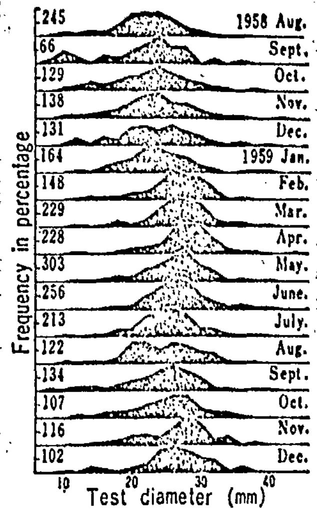
Fig. 23 [page 49]. Gonad coefficient and digestive tract content coefficient at different water depths at Nishi-Kamidomari.

A. Digestive tract content coefficient
B. Gonad coefficient
C. Shell diameter
D. Gonad coefficient
E. Digestive tract content coefficient
F. Sum of the two
G. Water depth



第24図 アメバー状細胞

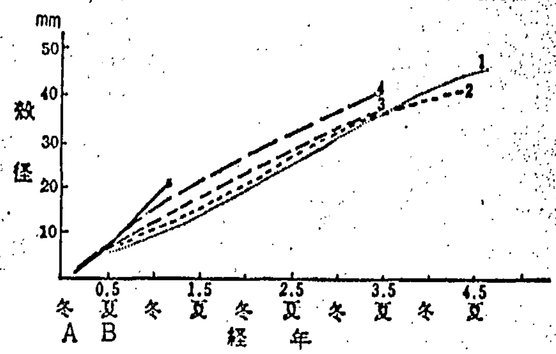
Fig. 24 [page 50]. Amoeboid cells.



第25図 バフンウニの殻径の月別出現頻度
(1958年8月より1959年12月まで)

Fig. 25 [page 52]. Frequency in monthly number and variations of shell diameters in Strongylocentrotus pulcherrimus.

(From August 1958 to December 1959)



1. 福井 2. 長崎 3. 山口(吉見) 4. 山口(六連) 5. 室内飼育

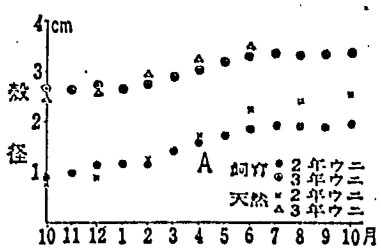
第26図 バフンウニの成長

Fig. 26 [page 52]. Growth in Strongylocentrotus pulcherrimus.

A. Winter
B. Summer

Ordinate - Shell diameter
Abscissa - Time in years

1. Fukui
2. Nagasaki
3. Yamaguchi (Yoshimi)
4. Yamaguchi (Mutsure)
5. Raised indoors



第27図　飼育と天然との成長比較

Fig. 27 [page 54]. Comparison of growth between laboratory reared and natural groups.

Ordinate - Shell diameter
Abscissa - Month

A.. Raised
- ● 2 year sea urchins
- ⊙ 3 year sea urchins

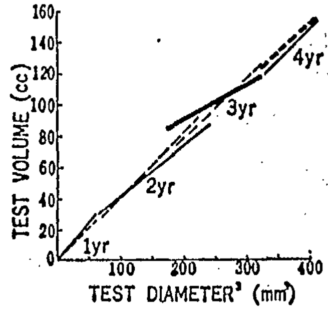
Natural
- x 2 year sea urchins
- Δ 3 year sea urchins

第28図　殻高/殻径の月別変化

Fig. 28 [page 54]. Monthly variations in shell height/ shell diameter ratio.

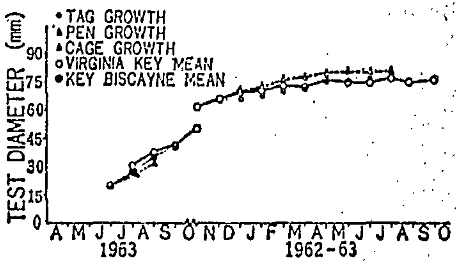
Abscissa - Month

A. Yoshimi
B. Todai-Shita
C. Mutsure
D. Wareishi



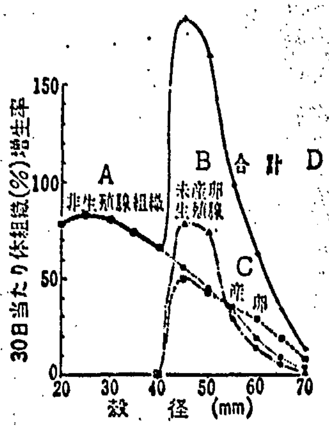
第29図 年令別殻径と容量
との関係

Fig. 29 [page 55]. Relation between shell diameter and volume by age.



第30図 *Tripneustes ventricosus*
の環境別成長の比較

Fig. 30 [page 55]. Comparison of growth in <u>Tripneustes</u> <u>ventricosus</u> in different environments.



第31図 殻径に対する体組織増生との関係

Fig. 31 [page 57]. Relation between hyperplasia in body tissues and shell diameter.

Abscissa: Shell diameter (mm)

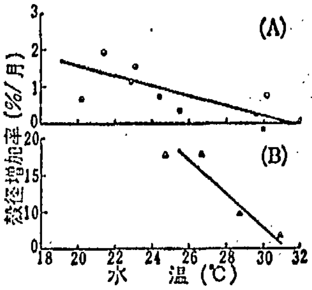
Ordinate: Rate of hyperplasia (%) in body tissues per 30 days

A. Non-gonadic tissues

B. Gonad not yet spawned

C. Spawned

D. Total

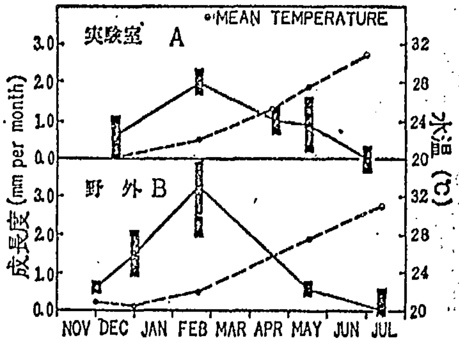


第32図 実験室(A)と野外(B)における成長度(30日当り殻径%)と水温との関係

Fig. 32 [page 58]. Relation between the degree of growth (shell diameter % per 30 days) and water temperature in laboratory (A) and outdoors (B).

Abscissa - Water temperature (°C)

Ordinate - Rate of increase in shell diameter (per cent/month)

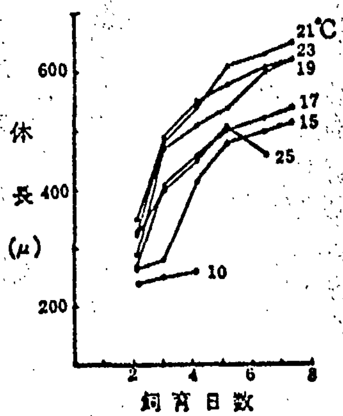


第33図 成長度(月当り殻径 mm)と水温との関係

Fig. 33 [page 58]. Relation between degree of growth (shell diameter per month) and water temperature.

Left ordinate - Degree of growth (mm per month)
Right ordinate - Water temperature (°C)

A - Laboratory
B - Outdoors



第34図　水温と成長との関係

Fig. 34 [page 60]. Relation between water temperature and growth.

Abscissa - Number of rearing days

Ordinate - Body length (μ)

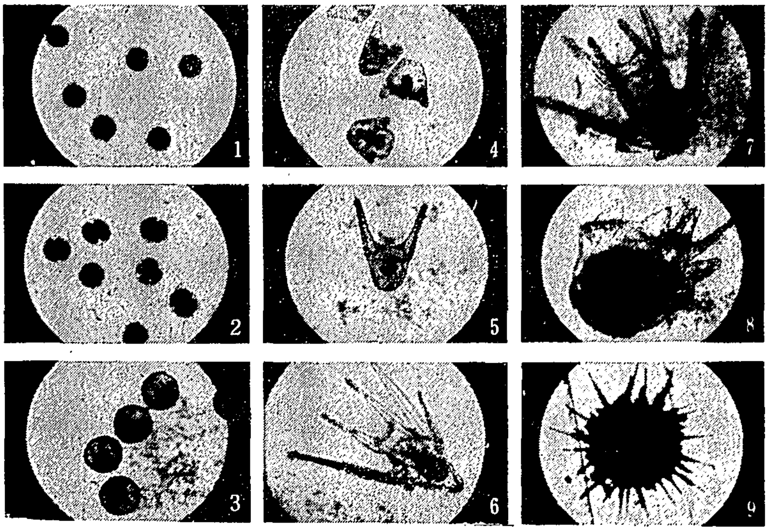
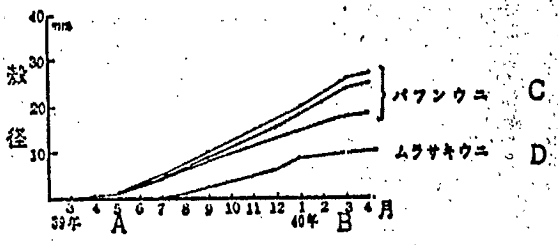


Fig. 35 [page 61]. Development of Strongylocentrotus pulcherrimus.

1. Immediately after fertilization
2. 2 hours after
3. 20 hours after
4. 2 days after
5. 3 days after; 4 arm period
6. 10 days after; 6 arm period
7. 26 days after; 8 arm period
8. 36 days after
9. 74 days after. Young sea urchin; shell diameter 1 mm



第36図 バフンウニ，ムラサキウニ幼生の成長

Fig. 36 [page 62]. Growth of young Strongylocentrotus pulcherrimus and Anthocidaris crassispina.

Abscissa - Month

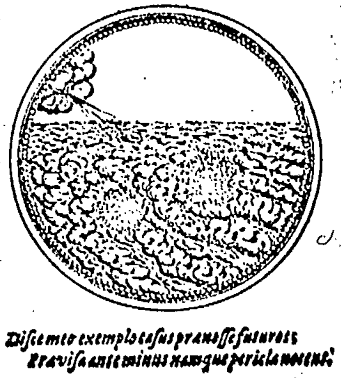
Ordinate - Shell diameter

A - 1964

B - 1965

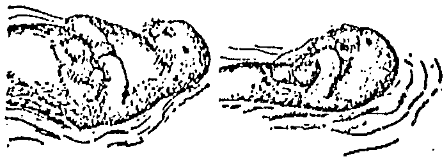
C - Strongylocentrotus pulcherrimus

D - Anthocidaris crassispina



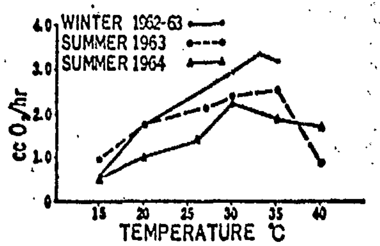
第37図　荒天とウニ

Fig. 37 [page 67]. Storms and sea urchins.



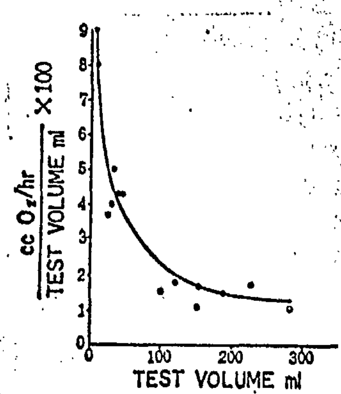
第38図　ウニを食べているラッコ
(Barabash-Nikiforov, 1933)

Fig. 38 [page 68]. Sea otters eating sea urchins (Barabash-Nikiforov, 1933).



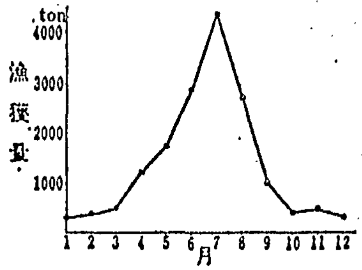
第39図　水温と酸素消費量

Fig. 39 [page 70]. Oxygen consumption and water temperature.



第40図　殻容量と呼吸量

Fig. 40 [page 70]. Respiratory volume and capacity of shell.

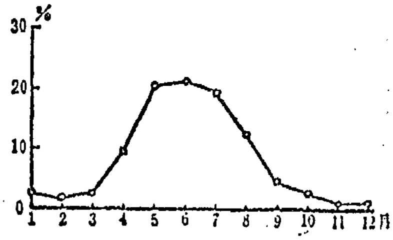


第41図　ウニの漁獲量の月別変化

Fig. 41 [page 71]. Monthly variation in the catch of sea urchins.

Abscissa - Month

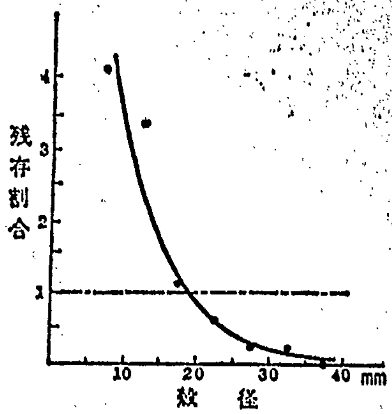
Ordinate - Catch



第42図　月別漁獲量

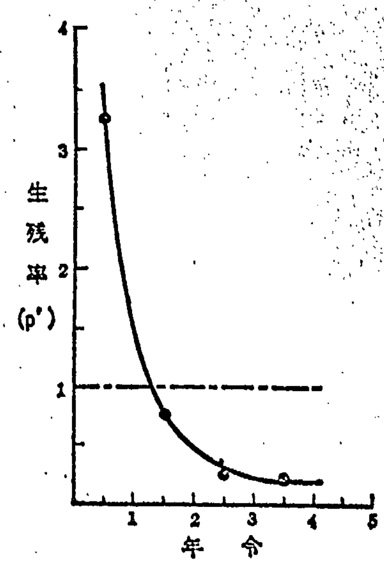
(3種のウニの合計。年漁獲量［生殖巣重量］を100%とする)

Fig. 42 [page 71]. Catch by month. (Total of three species. Annual catch (weight of gonads) is taken as 100%).



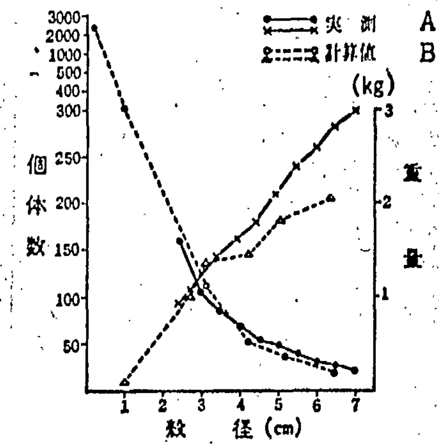
第43図　殻径と残存割合との関係

Fig. 43 [page 74]. Relation between shell diameter and survival.
Abscissa - Shell diameter
Ordinate - Proportion surviving



第44図　年令と生残率の関係

Fig. 44 [page 75]. Relation between age and survival rate.
Abscissa - Age
Ordinate - Survival rate (p')



第45図 殻径別群居密度 (1m²)
(川村)

Fig. 45 [page 76]. Gregarious density by shell diameter (1 m^2) (Kawamura).

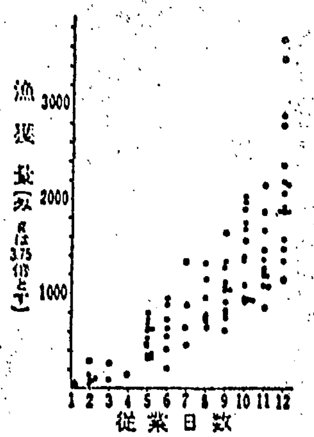
Abscissa - Shell diameter (cm)

Ordinate - Left scale - Number of individuals

- Right scale - Weight

A - Observed values

B - Calculated values

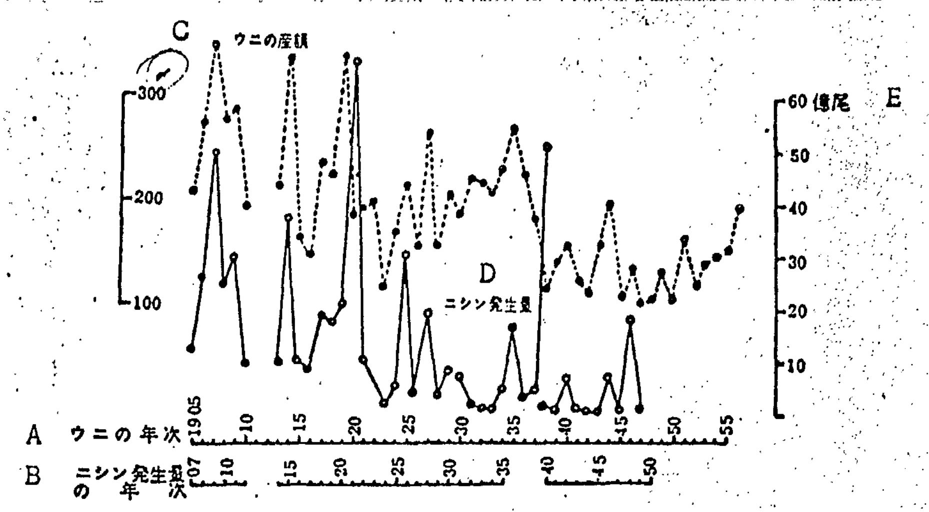


第46図 従業日数と漁獲量との関係

Fig. 46 [page 77]. Relation between working days and catch.

Abscissa - Number of working days

Ordinate - Amount of catch (in "monme": quantity in g is obtained by multiplying by 3.75).



第47図 ウニ産額とニシン発生量

Fig. 47 [page 77]. Quantity of herring and production of sea urchins.

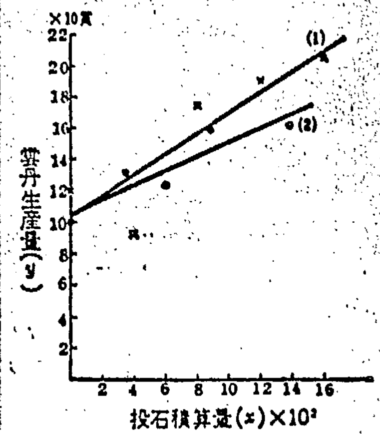
A - Years for sea urchins

B - Years for occurrences of herring

C - Production of sea urchins

D - Quantity of herring

E - 10,000,000 fish



(1) 日向 $(y=103.44+0.00662x)$
(2) 﨑 $(y=105.52+0.00453x)$

第48図 投石量と生産量との関係

Fig. 48 [page 84]. Relationship between amount of rocks added and production.

Abscissa - Cumulative quantity of rocks added $(x) \times 10^2$

Ordinate - Production of sea urchins (y)

A - Kan*

(1) Himuki $(y = 103.44 + 0.00662x)$

(2) Saki $(y = 105.52 + 0.00453x)$

*Translator's note: A Japanese unit of weight - One kan is equivalent to 3.759 kg

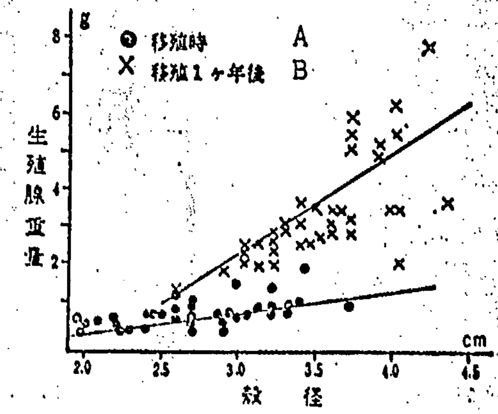
Fig. 49 [page 84]. Artificial reef construction near Echizen-Machi in Fukui-Ken. (Presented by Mr. Samon).

Left upper - Size of rock

Left lower - Loaded on a ship

Right upper - Before dumping into the sea

Right lower - Dumping operation



第50図 移殖による生殖腺重量増加

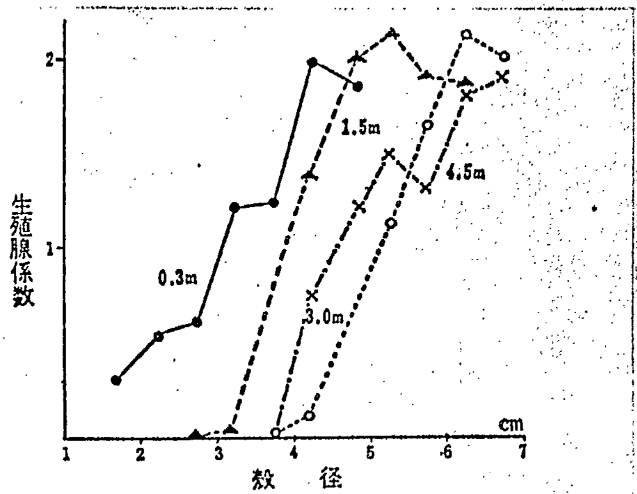
Fig. 50 [page 85]. Increase in weight of gonads after transplanting.

Abscissa - Shell diameter

Ordinate - Weight: gonads

A - At the time of transplant

B - A year after transplant

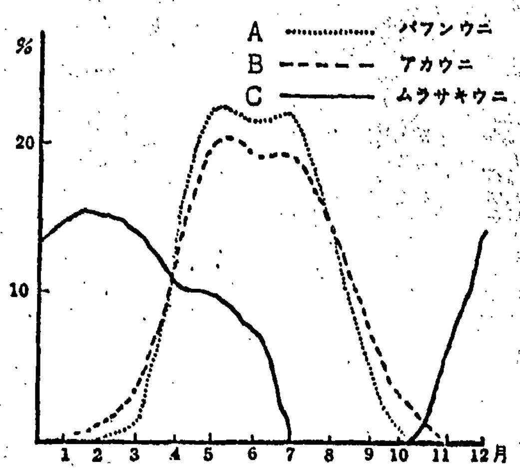


第51図 殻径と生殖腺係数との関係

Fig. 51 [page 87]. Relationship between shell diameter and gonad coefficient.

Abscissa - Shell diameter

Ordinate - Gonad coefficient



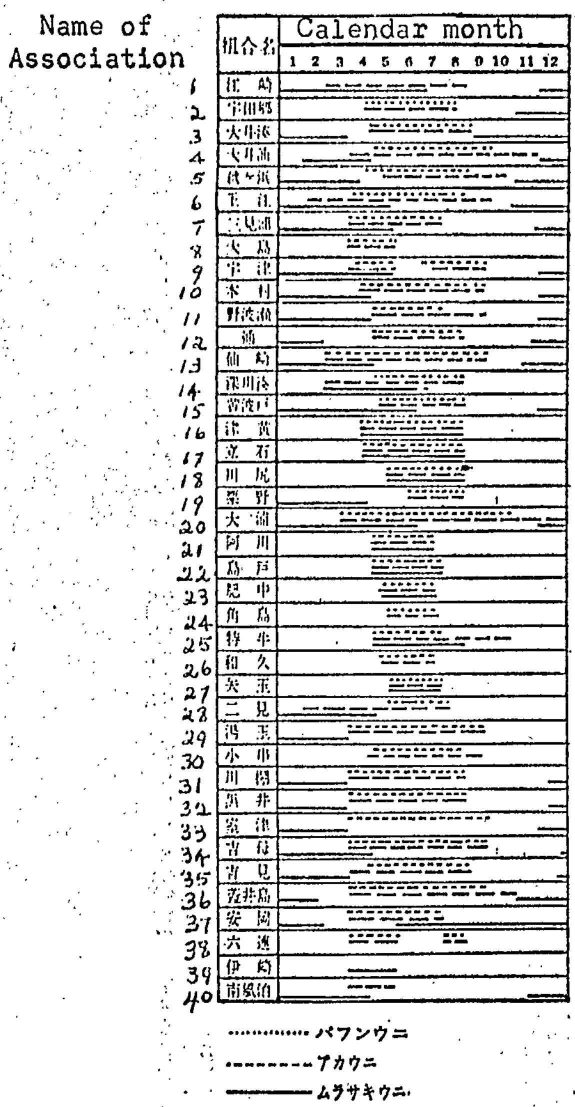
第52図　月別漁獲割合

Fig. 52 [page 90]. Proportion of catch by month.

A - S. pulcherrimus

B - P. depressus

C - A. crassispina



第53図　組合別採取時期

Fig. 53 [page 91]. Time of harvest by Association.

.... S. pulcherrimus

---------- P. depressus

—————— A. crassispina

.... cont'd

Fig. 53 (cont'd)

1. Esaki
2. Udago
3. Oiminato
4. Oiura
5. Koshigahama
6. Tamae
7. Mitsumiura
8. Oshima
9. Utsu
10. Motomura
11. Nonamise
12. Tori
13. Senzaki
14. Fukagawaminato
15. Kinamito
16. Tsuki
17. Tateichi
18. Kawajiri
19. Kurino
20. Oura
21. Akawa
22. Shimato
23. Hichu
24. Tsunoshima
25. Tokugyu
26. Waku
27. Yadama
28. Futami
29. Yudama
30. Kogushi
31. Kawadana
32. Kuroi
33. Murotsu
34. Yoshihaha
35. Yoshimi
36. Futaoijima
37. Yasuoka
38. Mutsure
39. Izaki
40. Minami Kazedomari

Fig. 54 [page 91]. Opening day in Koshino-Mura, Tansei-Gun, Fujui-Ken.

Upper - Preparation

Middle - Distant view of fishing ground

Lower - Actual fishing scene