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BIOLOGICAL STUDIES ON THE POPULATION OF THE STARFISH, *ASTERIAS AMURENCIS*, IN SENDAI BAY

By

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Although efforts have been made to eliminate the enemies or the competitors of useful fish in the fresh water area or those of shell-fish in the coastal waters to increase production, in the sea this problem has been rather neglected. Such predators as sharks, skates and dolphins, and other competitors as porcupine fish, starfish, sea-urchins, sea-anemones and jelly-fish are usually situated at the terminals in the food web of the marine community. To utilize most advantageously the natural production of the sea, it is necessary to first clarify their true role in the ecosystem. Burkenroad (1) stated in his general discussion of problems involved in starfish utilization that some tentative calculations concerning the energy-budget of Long Island Sound, based upon Riley's production figures and Petersen's and Lindeman's trophic-dynamic equivalents, suggest that the starfish may serve as a sort of biological governor, in the absence of which the balance of the ecosystem might shift in unforseen directions.

It has been known that the starfish predate on shell-fish, especially oysters, cockles and other clams, and destroy the bait or the catch of setline and hooks, and many studies have been published concerning them (2, 3, 4, 9, 10, 11). Since the starfish feed almost exclusively on bottom dwellers, their effects on the production of bottom fish must be considered to be serious. The feeding experimets (6) showed that the plaices in Sendai Bay would grow more rapidly if they were fed sufficiently in nature, and it was suggested that the starfish might be responsible for curtailing the natural feeds. At present in Sendai Bay, the starfish are caught abundantly by trawl-net in company with the bottom fishes (Fig. 1), but returned to the sea immediately after capture. The selecting catch of the commercial fish in Sendai Bay may result in some reconstruction of the species composition of the community and aid in promoting the increase of futile animals as the starfish. For these reasons, their increase in population can not be overlooked.

Since 1956, the most common starfish (**Asterias amurensis**) among the major five species of Asteroids in Sendai Bay was selected for the present studies. This species is distributed in both side of the North Pacific and in Japan it occurs from Hokkaido in the north to Kii Peninsula in the south on the Pacific side and to Toyama Bay on the Japan Sea side. It is well known that this starfish caused a great damage to the shell-fish culture in Tokyo Bay in 1953.

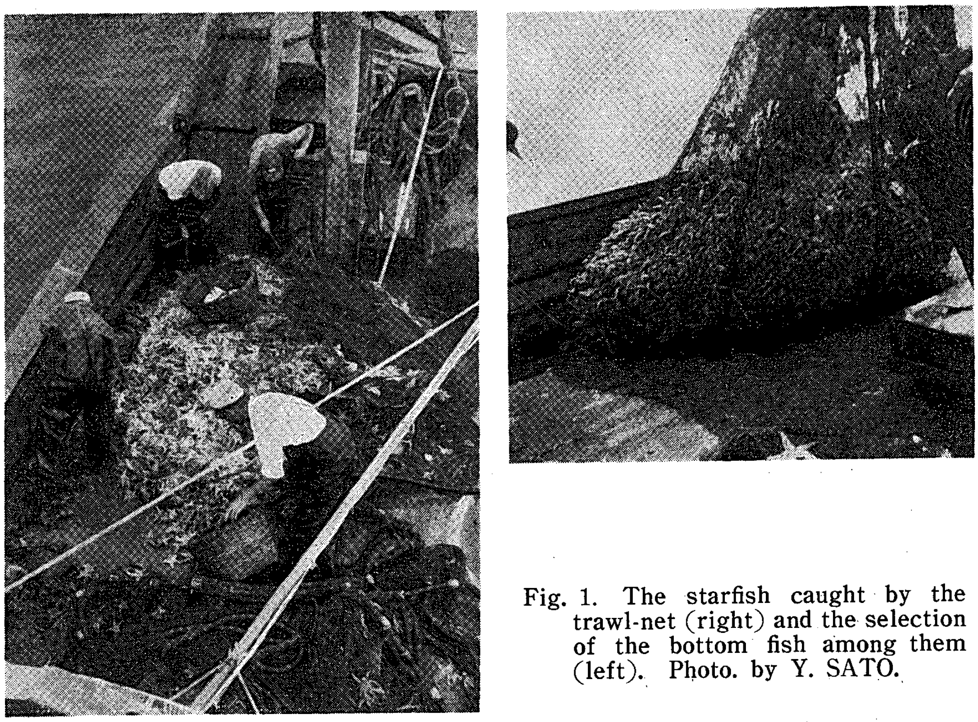

Fig. 1. The starfish caught by the trawl-net (right) and the selection of the bottom fish among them (left). Photo. by Y. SATO.

Before proceeding we thank the Captain of the S.S. Kyoeimaru for collecting the material and Mr. Y. Takahashi, the Director of Matsushima Aquarium for his kind cooperation during the feeding experiments. This study was supported by a grant from the Bureau of Fisheries of the Ministry of Agriculture and Forestry.

1. Life History

1. 1 *Spawning season*

Thirty-two samples, including 3,345 individuals, were collected from the catches by trawl-net in the fishing ground in Sendai Bay during the period from August, 1956, to February, 1958, for the investigation on the spawning season. Measurements or weighing were made on the arm-length, the body weight and the length of the gonads and the stomach contents.

The reproductive glands of the starfish develop in nearly equal size being paired in each arm. They increase in weight and length with growth and fully develop to the tip of arm when the spawning occurs. With the approach of the spawning, the female gonads become orange-colored, while the male ones yellow-grey, thereby the sexes are easily discernible. The length between the base and the tip of the gonads is easily measured and indicates satisfactorily the maturing process.

The rates in length of the gonads against the arm or the rates in weight of the gonads against the body were previously used for the investigation of the spawning season (9). But these rates include an inconvenience because they increase slightly with size even at the same maturing stage. Here the rate of group maturity for each sample was inferred from the coefficient (a) in the linear regression ($GL=a\ AL+b$) between the arm-length (AL) and the gonads length (GL), and its seasonal variation is shown in Table 1. A high value in "a" indicates a sample comprising many matured gonads.

Table 1. The seasonal variation of the coefficient "a" in the linear regression between the arm length and the gonads length for each sample.

Dates of collections	Numb.	Range of the arm length cm	Range of the gonads length cm	Regression coef. "a"
Aug. 23, 1956	185	5.1～13.5	0.4 ～ 6.6	0.1500
Sept. 14, 〃	101	7.6～18.0	0.4 ～ 3.3	0.2050
Oct. 1, 〃	96	6.1～15.4	0.5 ～ 4.3	0.1608
Oct. 13, 15, 〃	90	6.7～18.3	0.7 ～ 7.2	0.4224
Nov. 20, 1957	100	4.0～13.4	0.2 ～ 5.3	0.3276
Dec. 18, 1956	200	4.2～ 9.5	0.5 ～ 5.9	0.6882
Jan. 28, 1957	195	5.5～12.4	0.8 ～ 6.6	0.6649
Feb. 22, 〃	101	5.3～14.2	0.8 ～ 6.4	0.5258
Mar. 16, 〃	101	7.1～10.7	0.7 ～ 6.0	0.1868
Apr. 28, 〃	109	4.0～11.2	1.1 ～ 4.2	0.1471

The values of "a" become gradually high in and after September, reach the maximum in December and January, and then decrease toward a minimum during the period between April and August. This is coincident with the appearances of the gonads, namely the matured gonads are observable among the gonads collected in and after November, the fully matured ones in January, some spawned ones at the end of January and all are found withered in and after April. Therefore, the starfish in Sendai Bay spawn during the period from January to March, in water temperatures ranging between 9.8 and 12.3°C at the bottom and between 8.4 and 10.7°C at the surface.

The minimum size group among the collected samples caught by the trawl-net was found in the range of the arm-length between 3.5 and 4.3 cm on April 28. This is consistent with the above mentioned spawning season considering from the growth rate which will be stated later.

1. 2 *Fecundity*

The seasonal variation in the frequency distribution of ovarian egg diameter was investigated to know more precisely the maturing process and the frequency of spawning. Since the numerical distributions of the matured eggs were uniform in various parts of the gonads, an egg mass containing about 100-200 eggs taken out of the middle part of the gonads was used for the egg diameter frequency. The materials consist of 58 ovarries collected during the period between the end of October, at the beginning of maturation, and the end of January, at the flourishing of spawning.

The immature ovarian eggs measure nearly 9μ in a modal diameter in October and gradually grow as the maturation proceeds. Their frequencies showed no clear sign of existence of modal values like the case in the saury (5) and developed to the size range between 40 and 260μ in the fully matured ovary and then larger sized eggs exceeding nearly 170μ are lost by the first spawning, a large amount of the immatured eggs remaining, which will soon becom matured (Fig. 2). Thus, during the spawing season the matured eggs

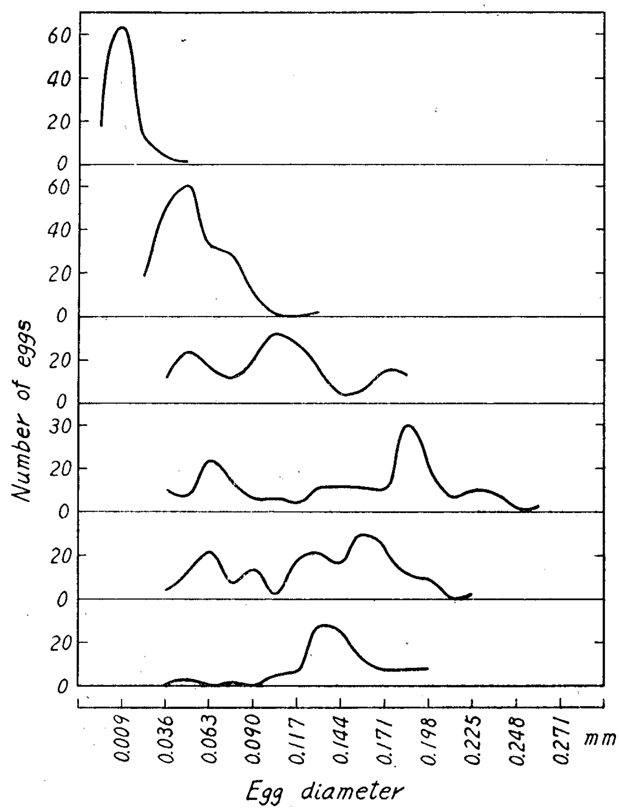

Fig. 2. The egg diameter frequencies showing the maturing process and the spawning of the matured eggs as the season advances.

will be spawned successively several times. This will be consistent with the fact that a slight decrease in the values of "*a*" occures in and after the middle part of December (Table 1).

Among the specimens collected in December and January, the matured individuals were found at the rates between 60 and 90 per cent of the females, and between 40 and 80 per cent of the males for the size range between 7.5 and 11.5 cm, and they were 100 per cent for the size exceeding 12.5 cm in the females and 14.5 cm in the males. The biological minimum size was 5.5 cm in the arm-length (20 g in the body weight, 1.2 g in the gonads weight) for the female and 5.6 cm (11 g, 1.0 g) for the male.

The total egg production was estimated by the number of eggs contained in a precisely weighed fraction (ca 0.1 g) taken from the middle part of the matured gonads. Acurate estimations will not be expected for the total egg production, because the matured eggs will be lost by the successively occuring spawning and also all the ovarian eggs do not necessarily become matured. The total egg production roughly estimated on each female is shown in Table 2. The one-year old females measuring 8.5–9.1 cm in arm-length will produce approximately 0.4–2.8 million eggs and the two-year old ones 5.3–15.5 million eggs. The starfish is noticeably prolific in the reproductive potential.

Table 2. The number of eggs in the matured ovaries of the starfish.

Date of collection	Body weight g	Arm length cm	Gonads weight g	Gonads length cm	Number of ovarian eggs 10^3
Nov. 28, 1956	56	8.5	1.6	2.1	400
Feb. 3, 1957	63	9.1	4.8	5.2	2,100
Nov. 28, 1956	75	8.9	6.6	4.6	2,800
Feb. 3, 1957	115	11.0	11.2	5.9	5,300
" , "	170	14.0	16.4	6.1	10,700
" , "	135	12.2	21.6	8.5	13,900
Jan. 14, "	175	11.8	43.0	9.0	15,500

The sex ratio was investigated with samples collected during the reproductive period between October and March. For the one-year old starfish, 256 males were found against 248 females and for the two-year old 90 males against 121 females. For either age group, the 1 : 1 ratio is acceptable.

1. 3 *Growth*

Several investigations were made to determine the year marks of the starfish, if obtainable, on the forms of the abactinal spines, the number of superomarginal spines, the number of abambulacral spines, the papulae and the pedicellariae. But none of them were found to be satisfactory for the age estimation. The growth of the starfish was determined from the seasonal varations in the frequency distributions of the arm-lengths. The arm-length frequencies are more suitable for the estimation than the body weight frequencies since the former are less variable than the latter.

For the estimation, 34 samples, including 5,147 starfish, were used. These were collected from the catches by the trawl-net in Sendai Bay during the period between August 23, 1956, and February 3, 1958. Presuming that the arm-length frequencies belonging to the same year class are conformable to the normal distributions, the composite distribution was divided into each component normal curve applying the probability paper. Since the net selections may effect the catch of the smaller sized individuals, corrections were made to approximate the doubtful distribution to the normal curve.

The mean and its fiducial limit (at 95 per cent level) of the arm-length for each sample was obtained from the corrected frequency curve and they are shown in Fig. 3 according to the dates of collections. From Fig. 3, with

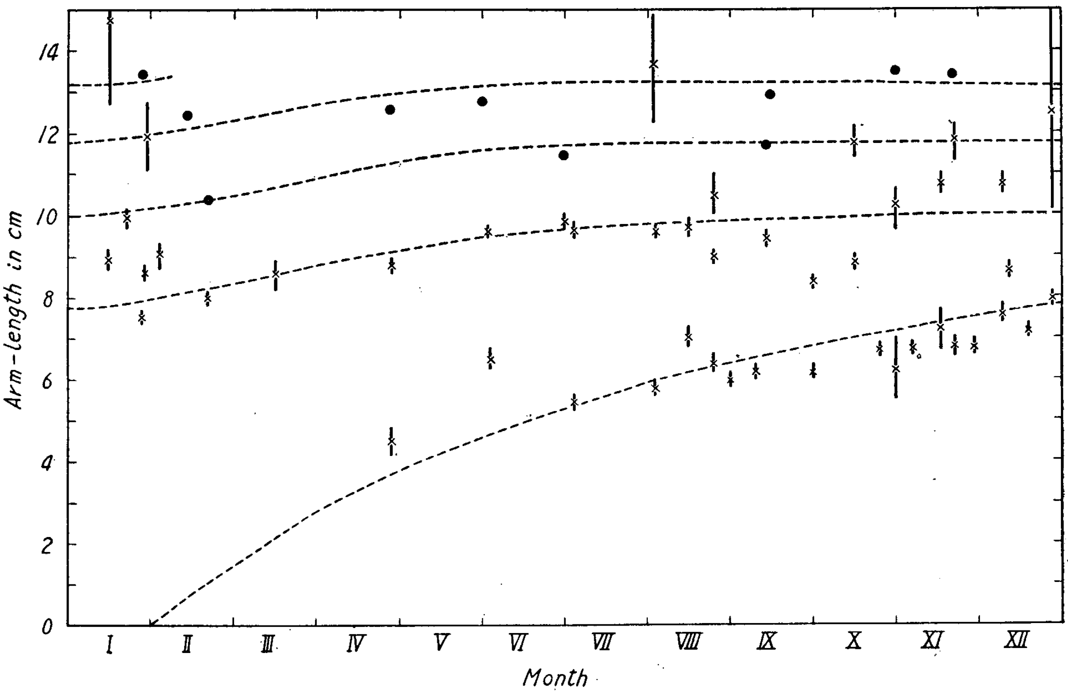

Fig. 3. Growth curve of the starfish. The means (×) and their 95 per cent fiducial limits of the arm-length for each sample arranged according to the dates of collections. (•) indicates the mode in the arm-length frequency.

due considerations for the spawning season, the starfish will attain 7.8 cm in the arm-length at one year after hatching, 10.0 cm at the age of two, 11,8 cm at the age of three and 13.1 cm at the age of four. The largest individual collected was 18.6 cm in the arm-length. The body weight will attain to 45, 85, 125 and 165 g respectively for each age at the end of year.

The relation between the arm-length (A) and the body weight (W) was represented by the equation: $W=aA^b$, and the monthly averages of the value of "b" and their fiducial limits were calculated and are shown in Fig. 4. The value of "b" was nearly at 2.5 throughout the year. When the relation of the arm-length to the remnant (W') of the body weight substracted the gonads weight was expressed by the equation: $W'=aA^{b'}$. The values of "b'" decreases remarkably during the most proliferous spawning period between January and March, and it retraces the level in the pre-spawning state in and after April.

The maturity and spawning will certainly encumber the increase in body weight. The rate in weight of the gonads to the body showed approximately 10 per cent.

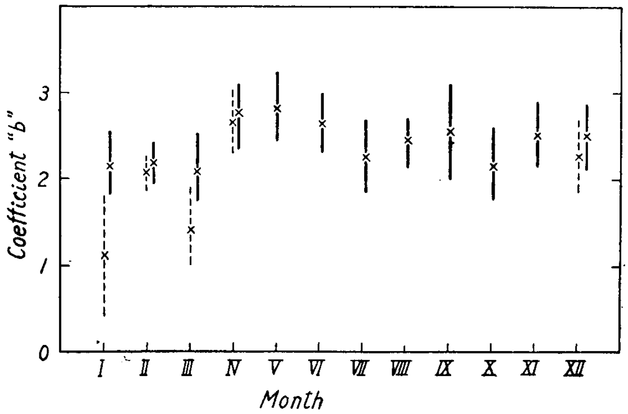

Fig. 4. The seasonal variation of the monthly averages of the coefficient "b" and "b'" (indicated by broken line) and their fiducial limits. Explanation in text.

1. 4 *Stomach contents*

The specimens, including nearly 3,300 indiduals, were used for the investigation of the stomach content, but none of the stomachs were found to be fully filled. This may be caused by the habit to disgorge the contents when the starfish is taken out from the sea bottom. The starfish were often observed to eject the stomach contents when weighing them in the air during the feeding experiments. This will also be related to the feeding habits that they digest the food in their extroversed stomach outside of the body.

In the 19 samples out of the 34, stomach containing small crabs (0.6–1.0 cm in carapace width) were found at the rates of 1–45 per cent regardless of the seasons. And in the 11 samples out of the same, the stomachs containing small shrimps were found in 1–9 per cent. Also in nine samples small clams occured at the rates of 1–4 per cent. Beside these food items, the sand lance, the anchovy and various lamellibranchs were also found but in small numbers. Since the specimens consist of rather larger sized starfish collected from the depth of 10–50 m, the present results will be somewhat different from the previous observations made in shallow waters (2). The feeding activity appears to become voracious in spring and autumn and continues during the spawning season.

Since the starfish quite resemble in their principal foods the bottom fish in Sendai Bay, especially *Paralichthys olivacaeus, Eopsetta grigorgjewi, Kareius bicoloratus, Limanda yokohamae* and *Microstomus achne* (5), it will certainly act as a serious competitor to these bottom fish for foods.

2. Feeding Experiments

The feeding experiments of the starfish were undertaken to know the relation of the food consumed to the growth made. The living starfish were collected by the trawl-net in Sendai Bay and transported to the Matsushima Aquarium in a livewell. The concrete aquarium, kept always with running water, were divided by a plastic screen of rough mesh into eight compartments, each 45 cm in width, 30 cm in length and 45 cm in depth. The stafish was kept separately one to each compartment, for the purpose to eliminate as much as possible the mutual interferences in feeding activities and also to make easy the estimation of the food consumed. The experiments were performed during the period between November 11, 1956, and November 18, 1957, using 195 individuals, the weight range of which was between 39 and 256 g, and the temperature ranged between 3.0 and 23.7°C.

For food the shucked clam, *Venerupis japonica*, was used and a known amount was given sufficiently once a morning. The residual food was weighed in the following morning, and again the fresh food was replenished. Thus the daily amount of food consumed by the individual starfish were obtained. The clam, which is easily obtainable, is quite suited for food of the starfish, but the stomach contents in nature consisted mainly of small crustaceans. The efficiency of food conversion on gram-weight base differs, of course, with different kinds of food, but it may be convertible by making calculations on calorie base, so all the results of feeding are based on the gram weight of the shucked clam.

Since the growth made by the given foods varies greatly with individuals, the weighing intervals, to observe the growth were standardized by examining the area of the rejection eclips of the two variates, the ration and the daily growth. The area become smaller as the intervals become larger, so that the longer intervals are the better. But the water temperatures during these intervals gradually changed, hence, with due consideration of this factor, the weighing intervals were set at 7 or 15 days during the season of autumn and winter, and at 30 days for the other seasons.

A rapid growth was made during the period from April to the beginning of June under the temperature of 6.2–15.1°C. Thereafter until the end of September under the high temperature of 14.1–24.2°C, the body weight decreased. Before the end of November therefrom, under the temperature of 12.5–7.6°C, a slow growth was observed and then in and after December, under the low temperature between 4.7 and 3.0°C, the starfish lost weight again.

Since the temperature appeared to be a most important factor for the growth of the starfish, the results of the feeding experiments will be arranged so as to understand the temperature effects on the feeding, the growth and the efficiency of conversion. The details of the feeding experiments are shown in the annexed tables and they are abstracted in Table 3.

Feeding rate, Growth rate and Efficiency of conversion

The rate of the daily ration against the mean body weight during the experimental period was called the daily rate of feeding, the rate of the daily growth against the mean body weight the daily rate of growth and the rate of the growth against the food consumption the efficiency of conversion.

The results of the feeding experiment, made during the period of the 30 days between May 9 and June 7, under the temperature of 13.7° ±1.31°C, showed the daily rate of feeding of 2.71 per cent, the daily rate of growth at 1.03 per cent and the efficiency of conversion at 37.8 per cent on an average for the 17 individuals ranging in body weights from 110 to 228 g. The feeding rate in this case was the highest value obtained and the growth rate showed as high as 5 to 10 times that in nature. Since the foods were given as much as they will eat under a high temperature within the optimum scope, the starfish may perhaps surfeit themselves in this experiment and as a result did not manifest the best efficiency in food conversion. The most efficient conversion rate was obtained, showing as high as 55.5 per cent, from the experiment made during the period of the 30 days between April 9 and May 8, under the temperature of 9.40±0.76°C; 17 individuals weighing between 72 and 177 g were used. In this case, the feeding rate was at 1.90 per cent and the growth rate at 1.06 per cent. In any case, the starfish has a quite high efficiency of food conversion compared with those of the marine fish (7). The feeding rate, the growth rate and the efficiency of conversion was curtailed under the temperatures exceeding the range between 9 and 13°C.

The results of the feeding experiment, during the period of the 30 days between July 23 and August 21, under the high temperature of 21.7±2.00°C, showed a low rate of growth being at −0.35 per cent, and the feeding rate at 0.51 per cent, and the efficiency of conversion at −119.0 per cent on an average for the 15 individuals ranging in body weight between 47 and 214 g. And also the experiment, during the period of the 30 days between August 22 and September 20, under the high temperature of 22.0±0.61°C, showed the growth rate at −0.25 per cent under the feeding rate of 0.38 per cent on an average for the 12 individuals ranging between 47 and 193 g. Under these extremely high temperatures, the starfish obviously loses their body weight.

As the result of the experiment, made during the seven days between December 12 and December 18, under the low temperature of 3.92±0.93°C, the lowest rate of feeding was obtained at 0.09 per cent, showing also the lowest growth rate at −1.37 per cent, on an average for the 18 individuals weighing between 52–134 g.

Table 3. The results of the feeding experiments of the starfish, fed with the clam at various temperatures.

	Duration of experiment	Range of water temp. °C	Average water temp. °C	No. of indiv.	Range of body weight g	Ave. body weight g	Ave. ration g	Ave. daily growth g	Ave. effic. %	Ave. rate of feeding %	Ave. rate of growth %
1	Apr. 9~May 8	6.2~11.4	9.40 ±0.76	17	72~177	108.8	2.07	1.15	55.5	1.90	1.06
2	May 9~June 7	11.8~15.1	13.7 ±1.31	17	110~228	148.6	3.93	1.50	37.8	2.71	1.03
3	June 8~July 7	14.1~19.1	17.0 ±2.31	9	151~216	178.4	2.68	0.32	11.9	1.48	0.17
4	July 23~Aug. 21	19.9~23.7	21.7 ±2.00	15	47~214	126.8	0.42	−0.35	−119.0	0.51	−0.35
5	Aug. 22~Sept 20	19.2~24.2	22.0 ±0.61	12	47~193	118.5	0.38	−0.31	− 81.6	0.38	−0.25
6	Sept. 21~Oct. 19	19.3~14.9	17.2 ±0.91	8	51~198	107.4	1.27	0.42	33.1	1.27	0.36
7	Oct. 20~Nov. 18	14.8~11.2	13.1 ±0.84	12	48~230	123.7	2.23	0.97	47.9	1.91	0.72
8	Nov. 12~Nov. 26	12.5~ 7.6	9.91 ±1.94	18	42~133	84.4	0.84	0.06	7.1	1.03	0.09
9	Nov. 27~Dec. 11	7.6~ 4.9	6.21 ±0.55	15	49~139	85.5	0.50	0.08	16.0	0.60	0.15
10	Dec. 12~Dec. 18	4.7~ 3.0	3.92 ±0.93	18	52~134	81.9	0.053	−0.09	−209.4	0.09	−1.37

Table 4. The results of the calculations on the amount of foods consumed by the starfish population in Sendai Bay.

Age	k	i	g	e^g-1	June, 1957			Average during the year				Food consumed by indiv. g	Food consumed by Population kg
					Population number	Indiv. weight g	Population weight kg	e^g-1/g	Population weight kg	Indiv. weight g	Population number		
0	3.81	1.848	1.962	+6.113	35,453,000	15	531,790	3.12	1,659,200	45	36,871,000	180	6,636,780
1	0.64	1.848	−1.208	−0.700	18,700,300	65	1,215,520	0.58	705,000	85	8,294,000	180	1,492,920
2	0.39	1.848	−1.458	−0.707	1,392,800	105	146,242	0.48	70,200	125	561,000	200	112,200
3	0.28	1.848	−1.568	−0.791	39,300	145	5,698	0.50	2,900	165	17,000	212	3,600
					55,585,400		1,899,250				45,743,000		8,245,500

Under the extremely low as well as high temperatures, the starfish eat only a small amount of food once or twice for ten days, apparently being in unfavorable conditions. But under natural conditions in Sendai Bay, such an extreme temperature does not usually occur, and if it occurs, the starfish will avoid it.

The two experiments in autumn, the one during the period of the 30 days between October 20 and November 18, under the temperature of 13.1±0.84°C, on the 12 individuals ranging in weight between 48 and 230 g, and the other during the period of 15 days between November 12 and November 26, under the temperatures of 9.91±1.94°C, on the 18 individuals ranging between 42 and 133 g, showed, notwithstanding that they were under nearly the same conditions of temperatures with those in spring, apparently showed a lower rate of growth (0.72 and 0.09 per cent respectively), while the feeding rate remained not so much different (1.91 and 1.03 per cent respectively). This will perhaps be caused from the reproductive cycle as the starfish become matured.

3. Food Consumption by Population

3. 1 *Population size, Growth rate and Mortality rate*

Since the starfish is not, at present, fished for in Sendai Bay, the catch statistics or the marking experiment are not available for the estimation of the population size. Here, the abundance were estimated from the density of the starfish obtained by the experimental cruises, performed mainly in the fishing ground of the trawl fisheries. Using the records of catch per haul of the trawl-net, the usual fishing implement for the bottom fish in Sendai Bay, operated during the period between April and August, 1957, the zones of equal density of distribution are shown in Fig. 5. The starfish distributed compactly around Hashima, the entrance to Matsushima Bay, and as the depth increased their number gradually decreased and became quite rare beyond the depth of 50 meters, where the inhabitant was displaced with another species, *Asterias nippon.*

Since the trawl-net, whose width between the wings measures 7.5 meters, is operated for two hours at the speed of 2 knots per hour, a unit haul will cover the bottom area of 0.06 km^2. The efficiency of the catch by the trawl-net were assumed to be 50 per cent basing on the personal information from Dr. Ino. The standing amount of the starfish during the investigational period was calculated from the zones of the equal density, multiplying each area, and the result was approximately 1900 tons. The amounts were divided for each age group by the age composition of the collected samples and the numbers were obtained from the average body weights of each age group in June. The results are shown in Table 4.

The instantaneous growth rate (k) was obtained from the increase in the body weight expressed in logarithm for each age group at the beginning of the year. The body weight of the 0–age group was presumed a value (2 g) at the beginning of the bottom life (Table 4).

The annual mortality rate (a) was determined at 0.85 from a linear regression found between the age and the number of each age group. Using the

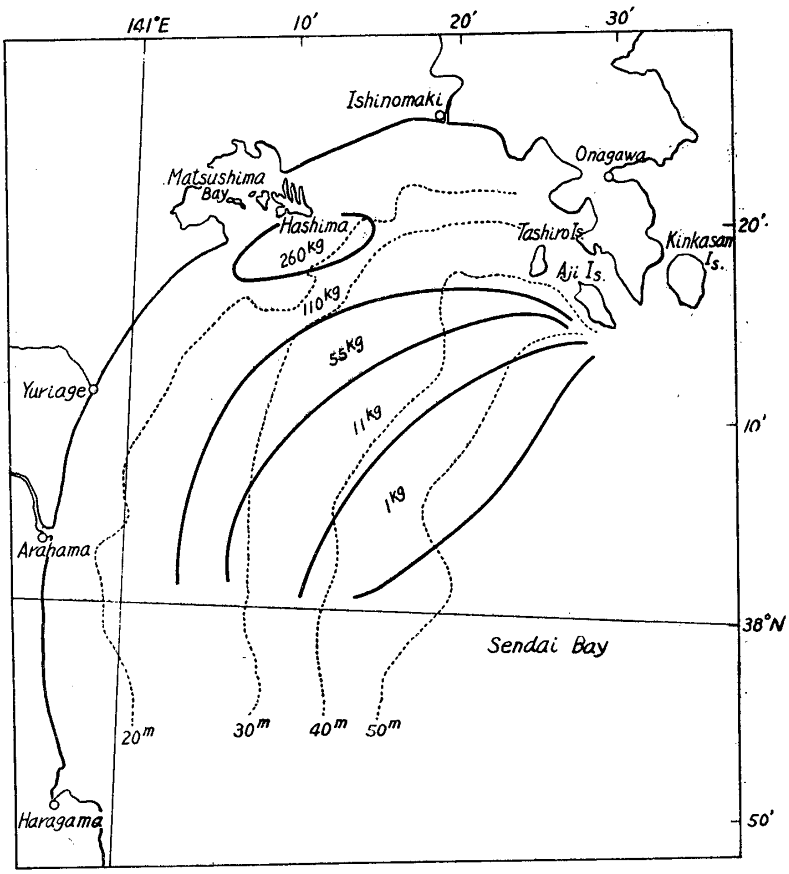

Fig. 5. The zones of the equal density of distribution of the starfish in Sendai Bay during the period from April to August, 1957. The figures indicate the catch-per-haul.

equation $a=1-e^{-i}$, the instantaneous mortality rate (i) was calculated to be 1.848. Since the starfish population stands out of the exploitation, the high mortality rate is considered to be attributed to the natural death.

3. 2 *Food consumption by the population*

The monthly average temperatures in the inhabiting waters of the starfish in Sendai Bay varied between 9.8 and 19.3°C. The efficiency of food conversion corresponding to each monthly temperatures was presumed from the results of the feeding experiments as shown in the following table.

Month	1	2	3	4	5	6	7	8	9	10	11	12	ave.
Temp. °C	12.3	10.2	9.8	12.2	15.0	17.5	18 7	19.3	18.9	17.5	15.0	12.7	
Effi. %	38	56	30	38	22	22	20	0	0	22	22	38	25.6

The average efficiency during a year was determined at 25 per cent, considering from the seasonal growth and the weight loss by the spawning. Hence, the annual amount of food necessary for the yearly growth were calculated from this figure as shown in Table 4.

Basing on the Ricker's method (12), the amount of food consumed by the starfish population in Sendai Bay were calculated applying the above mentioned figures, and are shown in Table 4. In this table, $k-i=g$ is the net instantaneous rate of increase in weight of an age group, e^g-1 the fractional net increase in weight of an age group and $[(e^g-1)\times$initial weight of an age group$]/g$ is the average weight of an increasing age group. The total amount of food consumed by the starfish population were obtained, multiplying the amount of food consumption necessary for the increase in weight to the average number of the population, at approximately 8,200 tons corresponding to the clam annually. The main part of this consumption is attributable to the 0-age group in the coastal waters shallower than 30 meters in depth.

When the amounts of the catch of the starfish and those of the bottom fish (the five species), obtained by the same haul of the trawl-net, were converted, in accordance with Barnes's method, into the logarithmic expression, then the correlation coefficient between them showed a statistical significance, indicating $r=-0.5038$ $[F=71.3>F^1_{216}$ (0.05) 3.89$]$. Namely, these bottom fish inhabit in small number on the ground where the starfish is abundant. The differential distribution between the starfish and the bottom fish will be caused by various origins (for instance, the differential response to the inorganic environmental stimulus or the different efficiencies of fishing on the ground at different densities of the starfish, etc.), but the competition between the said species for food and space will also supply a reason for this fact. Experimental studies on this problem are now proceeding.

4. Discussion and Conclusions

The starfish (*A. amurensis*) in Tokyo Bay is reported to spawn between the end of February and the beginning of March (9) or again during the period from February to April at the temperature between 6.2 and 13.6°C (2). In Sendai Bay, as already mentioned, the spawning occurs between January and March at the bottom temperature between 9.8 and 12.3°C. In Akkeshi Bay, Hokkaido, the starfish (*A. amurensis*) spawns in July (8) and the temperatures of that time ranges between 6 and 14°C. The spawning season occurs scatteredly with localities, but the temperature of spawning are similar within these localities.

The percentage in weight of the gonads to the body during the spawning season in Tokyo Bay is stated to be at 20 or 30 per cent for the starfish of 8 cm or 9 cm in length respectively. However, in Sendai Bay, the rate was 14 or 12 per cent respectively for the same sizes in Tokyo Bay. And the ovarian egg diameter is measured at 150μ on an average in Tokyo Bay, while it is 185μ in Sendai Bay. This is consistent with Thorson's finding (14) that the egg diameter of most marine invertebrate species change with localities, showing larger size in the north and smaller in the south.

In Sendai Bay, the egg production is not so numerous because of the smaller gonads weights and the larger egg diameter, showing nearly 2.1 million eggs for the starfish of 9 cm in the arm-length, as compared with the case in Tokyo Bay (9.8 – 10 millions). As Svärdson suggested (13), it is conceivable that the population occupying the extreme region of the species distribution such as Tokyo Bay will produce more eggs than that in the more central region as Sendai Bay to withstand the environmental conditions.

The optimum temperature for the starfish was found to be in the range between 9 and 13°C, in which the efficiencies of food conversion attained a maximum. In Tokyo Bay, the physiological optimum temperature was determined basing on the digestive velocity to be in the range between 15 and 17°C. The digestive power will increase as the temperature becomes high within the optimum range.

The dorsal integument of the starfish become distinct in yellowish-grey color of the ground substance as the starfish grows larger, fading to a purple color in the young. In Tokyo Bay, the purple color vanishes at the arm-length of 3 cm and over, while it still remains at the length of 9 cm in Sendai Bay and at 13 cm in Saroma Bay, Hokkaido.

The starfish in Sendai Bay feeds mainly on small crustaceans and according to Vevers (15), the European species (*Asterias rubens*) eats lamellibranchs when young but the adults mainly feed on worms, crustaceans, other echinoderms and many other lamellibranchs. Hence, the adult starfish is not entirely depend on lamellibranchs.

As mentioned before, the starfish is situated at a terminal in the food web of the marine community and is not utilizable on commercial base, therefore their enormous consumption of food substances is more injurious than useless. According to the tentative calculations, the amount of foods consumed by the populations of bottom fish in Sendai Bay will not perhaps exceed 10,000 tons annually, hence the consumption amounting to approximately 8,000 tons by the starfish population have clearly an important bearing upon the production of the useful fish. If the plaices, which are checked in their growth by the shortage of foods, secure a small share of foods of the starfish, their increase in production will be expected as much.

Since the greater part of the foods are consumed by the 0-year starfish, the total consumption by the population will be controlled by the amount of the yearly broods, however the broods regulation is not attainable at present.

And also we can not forecast to what directions the ecosystem will be changed as a result of removing the starfish population. The artificial interfences, namely the thinning out of the useful fish by the fishing operations, are now proceeding in Sendai Bay. So that it will be proper, to say at least, to carry out a regulation that the starfish which were caught by the trawl-nets together with the bottom fish, must be landed or killed not to be returned to the sea in the living conditions.

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The Annexed Tables

The details of the feeding experiments of the starfish

Exp. 1. Number of the starfish used : 17
Period : 30 days (Apr. 9-May 8, 1957)
Water temp. : 6.2-11.4°C (9.40±0.76°C)
Food : Clam.

Initial weight g	Final weight g	Ave. weight g	Food eaten g	Daily rate of feeding %	Daily rate of growth %
60	84	72.0	34.8	1.61	1.14
64	101	82.5	61.8	2.50	1.49
70	90	80.0	47.6	1.98	0.84
79	122	100.5	71.4	2.37	1.42
80	81	80.5	14.5	0.60	0.05
80	122	101.0	87.0	2.86	1.39
87	114	100.5	54.7	1.82	0.90
87	115	101.0	61.1	2.02	0.92
87	122	104.5	49.6	1.58	1.12
89	120	104.5	50.8	1.63	1.00
93	132	112.5	48.4	1.43	1.16
94	147	120.5	89.6	2.48	1.47
100	149	124.5	76.6	2.04	1.32
107	159	133.0	84.2	2.08	1.30
109	156	132.5	82.4	2.08	1.16
115	131	123.0	60.6	1.64	0.44
155	199	177.0	83.7	1.58	0.85
91.5	126.1	108.8	62.3	1.90	1.06

Exp. 2. Number of the starfish used : 17
Period : 30 days (May 9-June 7, 1957)
Water temp. : 11.8-15.1°C (13.7±1.31°C)
Food : Clam.

Initial weight g	Final weight g	Ave. weight g	Food eaten g	Daily rate of feeding %	Daily rate of growth %
81	139	110.0	110.4	3.35	1.75
84	127	105.5	108.9	3.44	1.35
90	144	117.0	107.4	3.25	1.54
101	140	120.5	113.4	3.14	1.08
114	150	132.0	97.8	2.47	0.91
115	152	133.5	84.9	2.12	0.92
120	152	136.0	93.9	2.27	0.77
122	151	136.5	100.5	2.47	0.71
122	165	143.5	131.1	3.04	0.99
122	175	148.5	152.3	3.43	1.19
131	180	155.5	91.0	1.95	1.05
132	186	159.0	143.1	3.00	1.13
147	190	168.5	124.9	2.46	0.85
149	200	174.5	144.6	2.76	0.91
156	192	174.0	122.2	2.33	0.69
159	210	184.5	138.8	2.50	0.92
199	256	227.5	140.2	2.06	0.83
126.1	171.1	148.6	118.0	2.71	1.03

Exp. 3. Number of the starfish used: 9
Period: 30 days (June 8-July 7, 1957)
Water temp.: 14.1-19.1°C (17.0±2.31°C)
Food: Clam.

Initial weight g	Final weight g	Ave. weight g	Food eaten g	Daily rate of feeding %	Daily rate of growth %
139	162	150.5	89.7	1.99	0.51
140	130	135.0	39.9	0.99	−0.24
152	157	154.5	48.7	1.05	0.11
165	210	187.5	111.8	1.99	0.80
175	192	183.5	98.2	1.78	0.31
190	188	189.0	102.3	1.80	−0.03
192	222	207.0	83.7	1.35	0.48
200	166	183.0	27.6	0.50	−0.62
210	222	216.0	120.8	1.86	0.19
173.7	183.2	178.4	80.3	1.48	0.17

Exp. 4. Number of the starfish used: 15
Period: 30 days (July 23-Aug. 21, 1957)
Water temp.: 19.9-23.7°C (21.7±2.00°C)
Food: Clam.

Initial weight g	Final weight g	Ave. weight g	Food eaten g	Daily rate of feeding %	Daiyl rate of growth %
45	49	47.0	46.5	3.30	0.28
70	63	66.5	22.3	1.11	−0.35
81	67	74.0	0.6	0.03	−0.62
107	95	101.0	17.8	0.58	−0.40
108	95	101.5	18.2	0.60	−0.42
108	97	102.5	2.8	0.09	−0.36
109	115	112.0	35.0	1.04	0.18
139	120	129.5	4.5	0.12	−0.49
143	129	136.0	3.7	0.09	−0.34
151	138	144.5	10.5	0.30	−0.30
166	153	159.5	2.2	0.04	−0.27
173	157	165.0	5.9	0.12	−0.32
180	135	157.5	1.0	0.02	−0.95
207	177	192.0	3.1	0.05	−0.52
228	200	214.0	13.1	0.21	−0.44
134.3	119.3	126.8	12.5	0.51	−0.35

Exp. 5. Number of the starfish used : 12
Period : 30 days (Aug. 22-Sept. 20, 1957)
Water temp. : 19.2-24.2°C (22.0±0.611°C)
Food : Clam.

Initial weight g	Final weight g	Ave. weight g	Food eaten g	Daily rate of feeding %	Daily rate of growth %
49	45	47.0	15.0	1.06	−0.28
63	60	61.5	10.4	0.57	−0.16
67	62	64.5	6.2	0.33	−0.26
95	90	92.5	9.7	0.35	−0.18
115	115	115.0	38.0	1.10	0.00
129	127	128.0	13.6	0.35	−0.05
135	113	124.0	11.6	0.31	−0.59
138	125	131.5	2.1	0.05	−0.33
153	135	144.0	8.2	0.18	−0.42
157	145	151.0	5.8	0.13	−0.26
177	165	171.0	5.8	0.11	−0.23
200	185	192.5	10.2	0.18	−0.26
123.2	113.9	118.5	11.1	0.38	−0.25

Exp. 6. Number of the starfish used : 8
Period : 30 days (Sept. 21-Oct. 19, 1957)
Water temp. : 19.3-14.9°C (17.2±0.907°C)
Food : Clam.

Initial weight g	Final weight g	Ave. weight g	Food eaten g	Daily rate of feeding %	Daily rate of growth %
45	57	51.0	21.9	1.43	0.78
60	55	57.5	9.3	0.54	−0.29
62	65	63.5	19.7	1.03	0.16
90	118	104.0	62.5	2.72	0.90
115	119	117.0	36.5	1.04	0.11
125	125	125.0	18.4	0.49	0.00
127	160	143.5	71.5	1.66	0.99
185	210	197.5	72.3	1.22	0.42
101.1	113.6	107.4	39.0	1.27	0.36

Exp. 7. Number of the starfish used: 12
Period: 30 days (Oct. 20-Nov. 18, 1957)
Water temp.: 14.8-11.2 (13.1 ±0.842°C)
Food: Clam.

Initial weight g	Final weight g	Ave. weight g	Food eaten g	Daily rate of feeding %	Daily rate of growth %
55	40	47.5	6.3	0.44	−1.05
57	64	60.5	69.8	3.85	0.38
76	117	96.5	82.8	2.86	1.41
87	120	103.5	52.5	1.69	1.06
93	125	109.0	82.9	2.53	0.98
105	157	131.0	88.4	2.25	1.32
107	162	134.5	70.5	1.75	1.36
113	160	136.5	84.6	2.07	1.15
118	145	131.5	76.4	1.94	0.68
130	166	146.5	79.1	1.80	0.82
160	155	157.5	34.1	0.72	−0.11
210	250	230.0	74.2	1.07	0.58
109.2	138.4	123.7	66.8	1.91	0.72

Exp. 8. Number of the starfish used: 18
Period: 15 days (Nov. 12-Nov. 26, 1956)
Water temp.: 12.5-7.6°C (9.91 ±1.94°C)
Food: Clam.

Initial weight g	Final weight g	Ave. weight g	Food eaten g	Daily rate of feeding %	Daily rate of growth %
39	45	42.0	15.6	2.48	0.95
61	67	64.0	21.3	2.16	0.62
68	66	67.0	6.9	0.67	−0.20
70	63	66.5	7.0	0.90	−0.62
73	68	70.5	3.9	0.37	−0.44
75	82	78.5	19.8	1.68	0.52
80	77	78.5	3.5	0.48	−0.25
81	80	80.5	7.9	0.66	−0.07
81	86	83.5	15.5	1.23	0.36
85	76	80.5	0.8	0.06	−0.74
86	90	88.0	9.3	0.70	0.24
87	85	86.0	4.5	0.35	−0.14
87	88	87.5	7.9	0.65	0.07
94	99	96.5	18.3	1.26	0.32
97	104	100.5	11.3	0.75	0.41
106	109	107.5	17.3	1.08	0.20
108	108	108.0	33.8	2.09	0.00
130	136	133.0	20.3	1.02	0.30
83.8	84.9	84.4	12.5	1.03	0.09

Exp. 9. Number of the starfish used : 18
Period : 15 days (Nov. 27-Dec. 11, 1956)
Water temp. : 7.6-4.9°C (6.21±0.55)
Food : Clam.

Initial weight g	Final weight g	Ave. weight g	Food eaten g	Daily rate of feeding %	Daily rate of growth %
45	53	49.0	11.4	1.55	1.08
63	64	63.5	9.4	1.00	0.09
66	72	69.0	9.4	0.91	0.58
67	73	70.0	9.1	0.87	0.57
68	72	70.0	6.1	0.59	0.37
76	78	77.0	5.4	0.47	0.17
77	77	77.0	4.2	0.36	0.00
80	78	79.0	0	0.00	0.16
82	86	84.0	11.3	0.90	0.31
85	72	78.5	1.3	0.12	−1.10
86	89	87.5	6.2	0.47	0.23
88	87	87.5	3.3	0.25	−0.07
90	97	93.5	10.2	0.73	0.51
99	105	102.0	11.5	0.75	0.39
104	106	105.0	9.3	0.59	0.12
108	101	104.5	0	0.00	−0.39
109	98	103.5	6.1	0.39	−0.54
136	141	138.5	19.4	0.93	0.24
84.9	86.0	85.5	7.4	0.60	0.15

Exp. 10. Number of the starfish used : 18
Period : 7 days (Dec. 12-Dec. 18, 1956)
Water temp. : 4.7-3.0°C (3.42±0.93°C)
Food : Clam.

Initial weight g	Final weight g	Ave. weight g	Food eaten g	Daily rate of feeding %	Daily rate of growth %
53	51	52.0	5.0	1.36	−0.58
64	56	60.0	0	0	−1.83
72	66	69.0	0	0	−1.30
72	63	67.5	0.5	0.10	−1.92
72	70	71.0	0	0	−0.42
73	64	68.5	0	0	−1.89
77	68	72.5	0	0	−1.79
78	75	76.5	0.6	0.01	−0.52
78	76	77.0	0	0	−0.39
86	79	82.5	0	0	−1.29
87	77	82.0	0	0	−1.74
89	83	86.0	0	0	−1.04
97	95	96.0	1.2	0.17	−0.31
98	80	89.0	0	0	−2.92
101	95	98.0	0	0	−0.92
105	94	99.5	0	0	−1.62
106	82	94.0	0	0	−3.61
141	126	133.5	0	0	−1.57
86.0	77.8	81.9	0.4	0.09	−1.37