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STUDIES ON THE BIOLOGY OF THE SEA URCHIN

III. Reproductive Cycle of Two Sea Urchins, *Strongylocentrotus*

nudus and *S. intermedius*, in Southern Hokkaido

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Investigations on the breeding season have been primarily concerned with relative breeding intensities. The term "breeding season" means the period when the majority of individuals liberate the most gametes; this is preceded by a period of wide spread gonad development and is followed by a period of active appearance of free swimming larvae.

Natural spawning of the sea urchin is not readily visible and there is no certain way of knowing from which local population the free swimming larvae have been derived, as they may be carried away by the action of currents from the area in which they were spawned. It is possible, however, by regular sampling of the population, to determine whether there is a sudden sustained decrease in the percentage of ripe gonads; such an occurrence may be interpreted as a major spawning.

The present paper describes an attempt to follow the cycle of gonad changes which occur throughout the year in each population of two sea urchin species, *Strongylocentrotus nudus* and *S. intermedius*, collected in southern Hokkaido.

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Material and Method

The materials used in this study consist of regular monthly samples from the large group of sea urchins (over 40 mm in test diameter) collected at three localities (viz., Muroran, Ishiya and Shinori) in southern Hokkaido, over the period of June 1956 to May 1959. Total number of animals employed is about 2,500 specimens.

The animals were subjected to anatomical and histological examination detailed in a previous paper (Fuji, 1960).

Result

Annual reproductive cycle of two sea urchins

Observation included two examinations; the first one undertook to determine the seasonal variation of gonad coefficient showing the superficial appearance of gonad maturity, and the other, using histological methods, was carried out to analyse the process of gameto-

genic development and depletion.

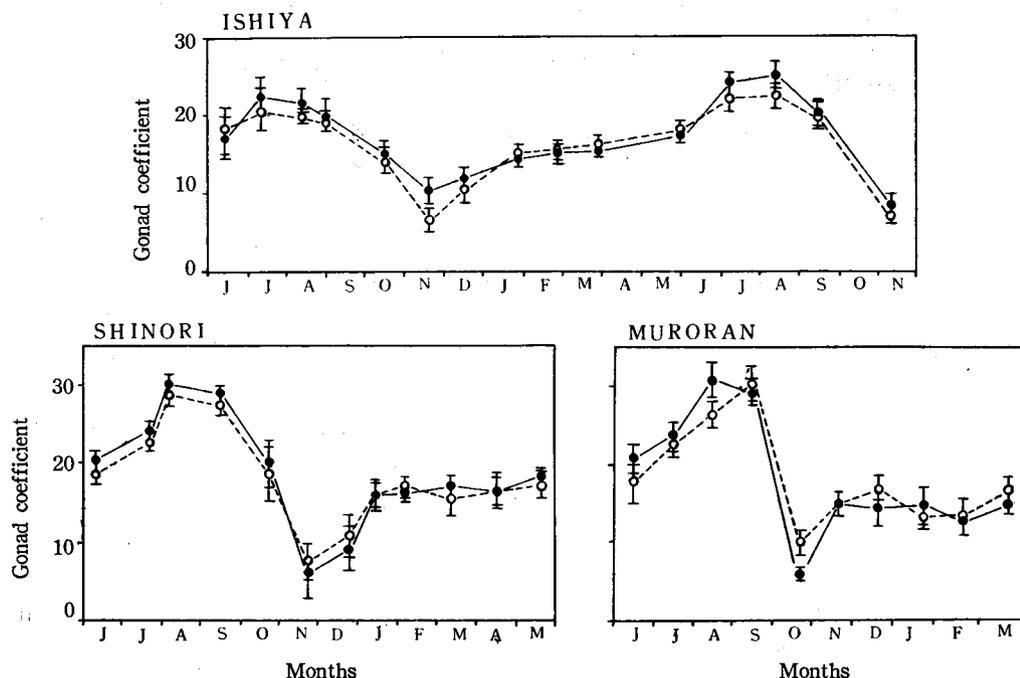


Fig. 1. Cyclic changes of the gonad coefficient in both sexes of *S. intermedius*. Each vertical bar indicates the range of plus or minus in standard error of mean. ● ; Male population, ○ ; Female population

Seasonal variation of gonad coefficient. Figures 1 and 2 represent how the gonad coefficient of male and female urchins in both species varies at the different seasons of the year. From the above figures, it is firstly noticed that the average gonad coefficient throughout the year, especially from December to May, indicates a considerable difference between *S. nudus* and *S. intermedius*.

The gonad coefficient of *S. intermedius*, for September, represents a significantly lower value than that for August. The minimum value (ca. 10) of the average gonad coefficient is calculated from the animals collected in November. After this month the value increases slightly, and attains approximately 15 in January or February. Gradual increment of the coefficient value continues steadily during the months between February and May. The value of the gonad coefficient begins to increase strongly from June or July followed by the peak in August. Such seasonal pattern of the gonad coefficient shows a similar trend in the population of sea urchins collected from all localities selected in this observation.

In *S. nudus*, the gonad coefficient increases markedly from June to August when the average coefficient shows a peak value, followed by a comparatively rapid decrease of the

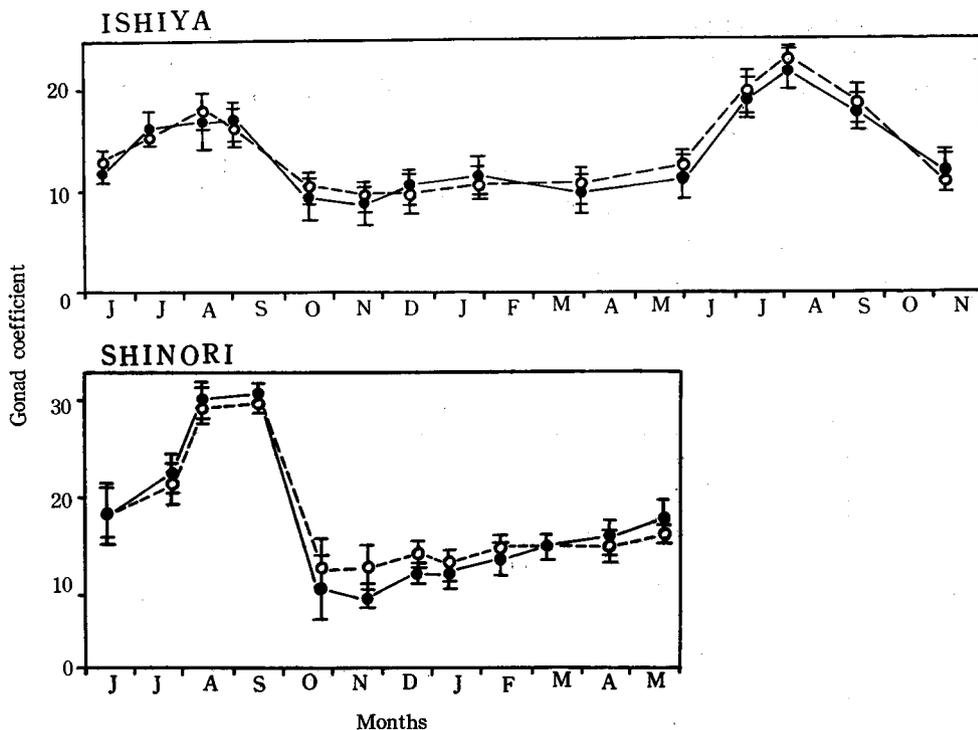


Fig. 2. Cyclic changes of the gonad coefficient in both sexes of *S. nudus*
Each symbol is the same as those in Fig. 1

coefficient during September and October. From December, the gonad coefficient shows a constantly low level until the following April or May, after which the average value indicates about 10.

No significant difference in relative gonad volume between male and female urchins has been recognized in *Strongylocentrotus purpuratus* (Bennett & Giese, 1955). On the other hand, in *Echinocardium cordatum*, Moore (1935) has pointed out that the relative gonad volume of female urchins shows an expansion about twice that of male urchins throughout the entire year. From the data presented (see Figs. 1 and 2), it is clearly indicated that the similarities in seasonal variations of the average gonad coefficient between male and female urchins are more striking than the differences in the two species used in this observation, though the gonad coefficient always fluctuates even in the animals taken at the same period. The most striking difference in the peak value of the gonad coefficient between the 1956 and 1957 seasons is the much higher value for the latter year in both species collected from Ishiya. Moreover, it is noticed that the comparison of the average gonad coefficients of the two urchins collected from three different localities reveals a considerable difference between them. Although the cause of such difference is uncertain,

on the basis of anatomical observation, either discrepancy of the growing process of gametes or the difference of genital crop may be said to account for it.

Gametogenic cycle. As has previously been stated (Fuji, 1960), the gametogenic cycle of the adult sea urchins of the two species under consideration consists of five histological stages of gonad activity. There are; Stage I (Recovering spent), Stage II (Growing), Stage III (Pre-mature), Stage IV (Mature), and Stage V (Spent).

The percentage of each of the five stages of gonadal development and depletion is plotted against the month in Figures 3 and 4. From observation of the graphs it is evident that the cyclic processes of sexual maturity in the two species of urchins run a considerably different course.

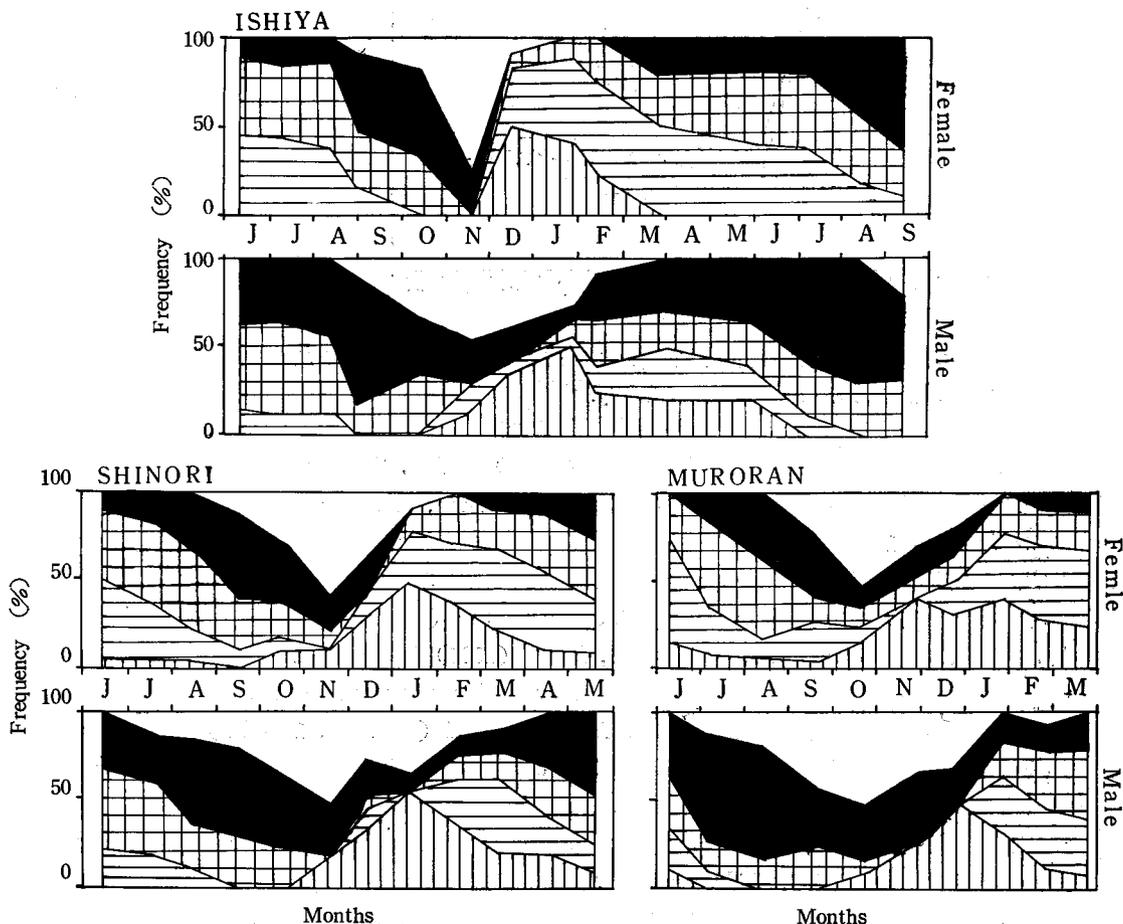


Fig. 3. Diagram showing the relative proportion (%) of animals in each gonad stage of *S. intermedius*

▨ ; Stage I, ▤ ; Stage II, ▩ ; Stage III, ■ ; Stage IV, □ ; Stage V

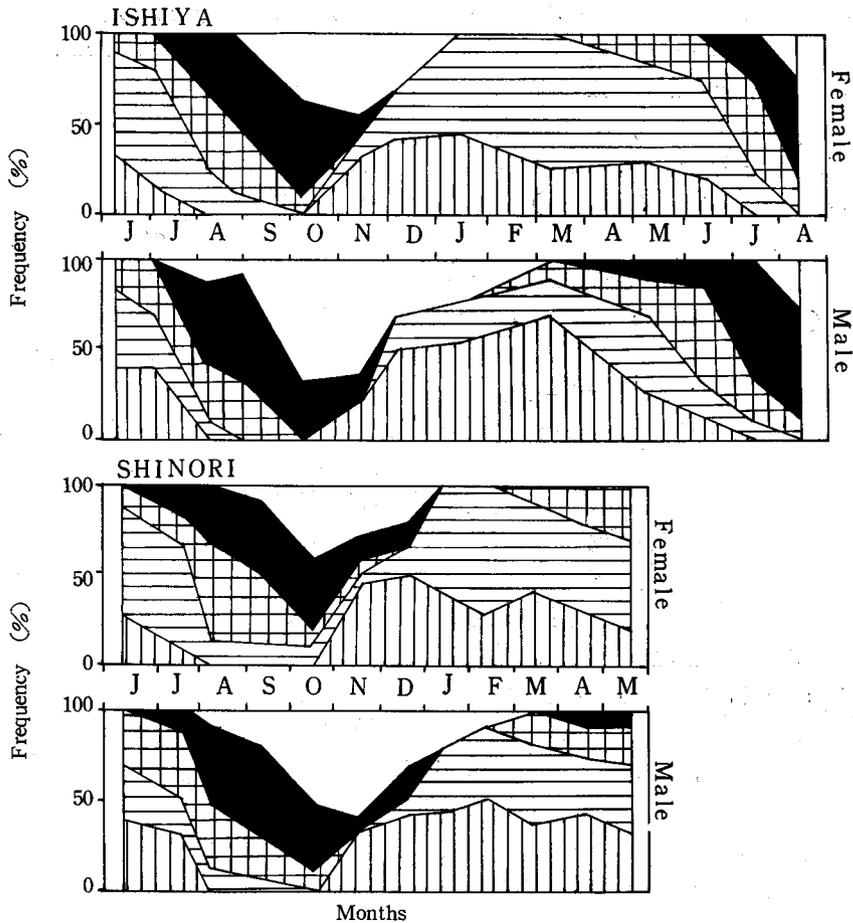


Fig. 4. Diagram showing the relative proportion (%) of animals in each gonad stage of *S. nudus*
All symbols are the same as those in Fig. 3

In August and September, individuals of *S. intermedius* of Stage IV show a comparatively high proportion in their frequency (ca. 50 % in female and ca. 70 % in male), afterward a rapid drop of the frequency lasts until November. From September the spent animals increase vigorously in frequency and attain to a maximum proportion (40 - 60 %) in November. After this month, simultaneously with the sluggish diminution of the spent individuals, the animals of Stage I (Recovering spent) become conspicuous by their augmentation; nearly half of the animals collected in January possess Stage I gonad. After January, a diminution of Stage I animals is accompanied by a gradual augmentation of Stages II and III animals; such trend is more strongly manifested in the male population than in the others. The mature urchins (Stage IV) provide 20 - 30 % of the population from March and increase gradually until July and August.

In *S. nudus*, individuals in Stages I and II are found in over 70 % of the entire number of animals examined in June or July, and remainder show Stage III. Afterward the animals of Stages I and II decrease markedly in their frequency, and disappear in October. On the other hand, the animals of Stages III and IV increase rapidly during the period of August - September, and attain to about 40 % among the animals collected in October. Spent individuals (Stage V) are almost not found amongst the animals collected in every month, and their maximum number is limited to about 60 % in October. After November the animals of Stage I increase gradually, and they keep a relatively high proportion (ca. 40 - 50 %) until following April or May, although they are accompanied by individuals which are developing to more advanced condition (viz., Stages II and III) in the successive months. In mid-March the male urchins of Stage IV (Mature) are already found, but their appearance is limited to very low percentages (ca. 6 %). After early June, in both male and female population, the percentage of Stage IV animals increases rapidly with the passage of time.

As regards the seasonal difference of sexual maturity between male and female urchins, it has been pointed out respecting several sea urchins that the male population possesses the mature gametes in an earlier period than the female population (in *Echinus esculentus*, Stott, 1931; Moore, 1934; in *Strongylocentrotus purpuratus* and *S. franciscanus*, Lasker & Giese, 1954; Bennett & Giese, 1955). Such tendency coincides with the conclusion reached from observation of the two sea urchin species employed in this study. Therefore, it may be suggested that male gametes are available virtually throughout the entire year, while female fertilizable gametes are recognized only within some limited term.

Spawning season

The data which indicate that most individuals of the two urchin species are in the shedding condition are diagrammatically given in Figures 3 and 4, which include information on the onset of spawning for several localities in southern Hokkaido.

Sometime between the middle of August and the beginning of September, a comparatively rapid change from the full mature condition to the spent phase takes place. Mean monthly sea temperature in various localities is shown in Figure 5. In comparison between the relative proportion of animals in each gonad stage and the mean monthly sea temperature, spawning of the female urchins seems to have commenced simultaneously at all stations towards the end of September when water temperature is about 17°C, while in male urchins the shedding condition takes place from late July to mid-September.

In view of these items of information, it is concluded that the breeding seasons of the present two sea urchin species in southern Hokkaido are prolonged, extending from early August, and that the majority of the individuals spawn in October or November, although the breeding would be commenced at somewhat different times in various localities.

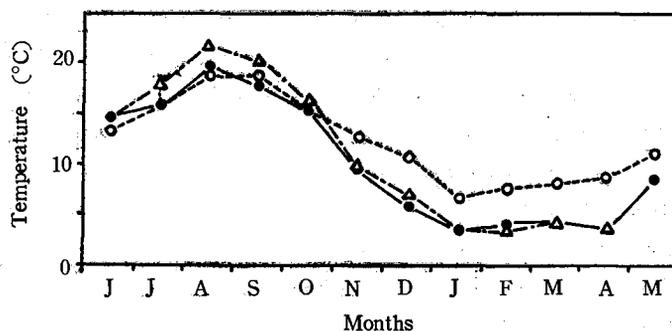


Fig. 5. Seasonal variation of water temperature at various localities in southern Hokkaido ● ; Ishiya, △ ; Muroran, ○ ; Shinori

Spawning was not caused by the attainment of a definite temperature only, but occurred at several temperature in the range of 15–20°C.

Discussion

It has already been mentioned that the increase of the gonad coefficient has been accompanied by increase of reproductive substances (Fuji, 1960). In view of the fact that the seasonal changes of the gonad coefficient are concomitant with the variation in the appearance of each gonad stage, all things considered, the annual reproductive cycle in the present two sea urchin species may be roughly divided into the following three different processes ;

- a) June - August : Vigorously developing season.
- b) September - November : Spawning season.
- c) December - May : Sluggishly developing season.

Figure 6 summarizes schematically the relationship lying between the value of the gonad coefficient and the duration of active appearance of each gonadal stage. During the sluggishly developing season, the pattern of gonadal maturity runs a clearly different course in the two sea urchins used in these observations. Such difference is reasonably considered to result from the sexual phenomena furnished by themselves.

The only observation on the breeding season of *S. intermedius* has been made by Kinoshita (unpublished data) for regular samples collected from Usu along the coast of Volcano Bay in southern Hokkaido. He proposed that there are two main spawnings a year, the one in October to November, the other in April. In another species, *S. pulcherrimus*, Kawana (1938) has reported that the major spawnings take place in the term from January to March. Bennett & Giese (1955) have stated that both *S. franciscanus* and *S. purpuratus* possess a single reproductive cycle. As shown in Figures 3 and 4, the spent individuals reach a high proportion of the total population in October or November. Therefore, so far as the present investigation is concerned, it may be concluded that the

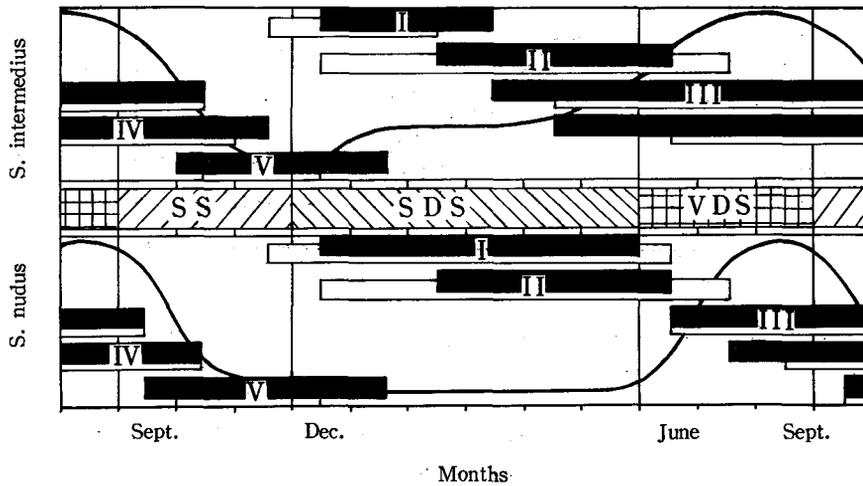


Fig. 6. Schematic illustration of the relation between the seasonal variation of gonad coefficient and the duration of active appearance of each gonad stage ██████████; Male population, ; Female population, VDS; Vigorously developing season, SS; Spawning season, SDS; Sluggishly developing season

seasonal trends of the reproductive process of the present two sea urchins show clearly one distinct cycle having the peak in October or November.

As to *Echinus esculentus*, *Strongylocentrotus pulcherrimus*, *S. purpuratus* and *S. franciscanus*, some variations of the relative gonad weight or volume have been shown between the different habitats and years. And it has been presumed that such variations are attributable to the fluctuation of the algal crop furnished in each habitat and year (Moore, 1934; Kawana, 1938; Lasker & Giese, 1954; Bennett & Giese, 1955). On another Echinodermata, *Asterias rubens*, Vevers (1949) has reported that a poorly fed population shows no or little gonad maturity, whereas a well fed population reveals vigorous development of the gonads.

The causative factors involved in the development of the gonads may be numerous. However from the above items of information concerned with the influence of feeding conditions upon gonadal development, it is reasonably presumed that such variation indicated between different localities and years is provoked by seasonal variation of physico-chemical and some biological factors which exert indirect effects upon the urchins by making possible a great production of algae, associated with other many unknown factors. Although none of the presented data deal with the production of algae and other various environmental factors in the course of the present observation, it may be suggested that the influence of feeding condition and of environmental factors upon the gonadal maturity of adult and young urchins provides some unknown problems in various ecological and physiological aspects.

Summary

(1) No significant difference is found between male and female urchins in seasonal variation of the gonad coefficient. The gonad coefficient exhibits a peak value in July or August, and shows minimum value in October or November in both species.

(2) After spawning, the average coefficient value indicates a considerable difference between the two urchins; the average coefficient value of *S. intermedius* increases gradually and shows somewhat higher value than that of *S. nudus* which holds a constantly low level until April.

(3) The gametogenic cycle seems to run a considerably different course between the two species; in *S. intermedius* the duration of active appearance of Stage I (Recovering spent) animals is relatively short, moreover, the presence of stage IV (Mature) extends over a long term. On the other hand, in *S. nudus*, the predominant presence of the animals with Stage II (Growing) gonad covers the early half-year.

(4) The male population of both species possesses mature gametes for a greater part of the year than does the female population.

(5) The annual reproductive cycle in the two sea urchins may be broadly divided into the following three different processes according to the course of seasonal variation of the gonad coefficient and of gametogenesis:

- a) June - August : Vigorously developing season.
- b) September - November : Spawning season.
- c) December - May : Sluggishly developing season.

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