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CONTRIBUTIONS TO THE BIOLOGY OF LITTORAL SEA URCHINS I.
MEASUREMENTS OF CLINGING POWER AND OBSERVATIONS ON STABILITY OF SEA URCHIN COLONIES[1]

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With 7 Text-figures and 1 Table

Contents

Introduction

There are distributed many sea urchins such as *Anthocidaris crassispina* (A. AGASSIZ), *Echinostrephus aciculatus* (A. AGASSIZ), *Echinometra mathaei* (BLAINVILLE), *Tripneustes gratilla* (LINNAEUS), *Toxopneustes pileolus* (LAMARCK), *Mespilia globulus* (LINNAEUS), and some others along the rocky reef around Tôshima Islet that lies at the mouth of Tanabe Bay near the Seto Marine Biological Laboratory. Especially large numbers of *A. crassispina*, *E. aciculatus* and *E. mathaei* are found forming together sea urchin colonies in tide pools of the rocky shore and at hsallow places of the sublittoral zone of the area. Moreover, the appearance of these sea-urchin colonies seems to keep some regularity; particularly the ratio between the individual numbers of *A. crassispina* and *E. aciculatus* in respective colonies is seemingly related to the wave action in the places. Being interested in this, we made our mind to take up "the biological studies of littoral sea urchins" as the theme of our short-term research during our ten-day

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stay at Seto in the summer of 1970 and to carry out some measurements of the cling-
ing power of sea urchins and to confirm whether or not the colonial stability is existing.

The clinging power of sea urchins must be closely related with the mode of life of
respective species; so far as they are living similarly exposed, a certain species living
in a place of strong wave action should be provided with the clinging power much
stronger than that of other species living in sheltered sites.   The first of our works was
to measure the clinging power of sea urchins of different kinds and sizes gathered from
the tide pools and shallow sublittoral places around Toshima Islet and compare them
one another, and then to see the biological significance of the clinging power for the
life of respective species of sea urchins.   The last of the above-mentioned works bases
largely on the appearances of the sea urchin colonies in the area studied, which then
must be maintained stable in respective sites to be available for this purpose.   Thus
the confirmation of the stability of sea urchin colonies formed the other important part
of our works.

The tide pools, harbouring sea urchin colonies, on the rocky shore around Tôshima
Islet are provided each with a number of small pits or excavations which are respec-
tively occupied by an individual of sea urchins.   The first step to confirm the stability
of sea urchin colonies was to see whether or not sea urchins in the colony go out of
their niches in the night flood tide; at least during the low water in the summer day-
time no sea urchins would show any sign of migration.   If they go out at night, do
they show a homing behaviour?   For the maintenance of the stability, they have to at
least return to their own colonies.   The end of their crawling may be to graze, most
probably some algal foods.   Then, how do they feed if they do not go out of their niches
for feeding?   To learn these, the stomach contents were examined in some sea urchins.

Although the whole data obtained during our stay so limited are never satisfactory,
the clinging power showed a clear difference between some sea urchins, especially
A. crassispina and *E. aciculatus*.   And this led us to some discussions about the dif-
ferences in composition of sea urchin colonies with the degrees of wave action.   This
paper is, thus, prepared to present the above-mentioned data and some preliminary
considerations made on them.

Circumstances around the sea urchin colonies observed

So-called Tôshima Islet consists really of two islets standing on a roughly V-
shaped rocky reef, open to the northwest and there facing the open sea, which pro-
jects out north from the north edge of the tip of Banshosaki Cape to border southerly
the mouth of Tanabe Bay.   Two arms of the reef are respectively 150 and 250m in

length and both up to 40m in width at the low tide. The reef will be submerged only
only at the flood tide and thus there will be left a number of tide pools of different sizes
and depths at the low tide. The distal area of the reef was chosen as the place for
observations, as the waves wash the reef surface very differently around this area
(Fig. 1); the side west to the end of this area is exposed to the open sea of stronger
wave action, while the east side faces a considerable protected water of much less
wave action. More than ten pools are found there; nine of them were selected as the
places for examinations, seemingly with different degrees of wave action, and signed
respectively by A, B, C,......to I. Most of these pools are rather small, about 1m²
in extent, except the pool A which is much larger, about 12m² in extent, but rather
shallow, 5 to 20cm deep, in most parts excepting the deeper central part of about 1m²,
and harbours more than two thousand of sea urchins, including *A. crassispina, Echinostre-
phus aciculatus* and *Echinometra mathaei*, mostly 1–5cm in diameter.

This pool is situated at the level about 1 m above the low-water mark, and thus
the water temperature of the pool in the surface 15 cm layer reached 33.0°C at 10:00
on July 29, when the surface water temperature was around 28°C throughout the neri-
tic waters of the region. For the above-mentioned conditions, the tide pool A seemed
to fit best the place of our observations and the source of sea urchins, especially of
E. aciculatus, with which the clinging power was experimented and on which the
stomach contents were examined

The stability of sea urchin colonies was examined on those found in pools A and C.
The grades of wave action, perceived by our eyes, in respective tide pools examined
are shown in comparative signs, together with the specific composition of each colony,

Table 1. Composition of sea urchin colonies and seeming wave action in tide pools on
the reef around Tôshima Island.

Tide pool	Wave action*	Number of individuals			E. aciculatus / A. crassispina ratio
		Echinostrephus aciculatus	Anthocidaris crassispina	Echinometra mathaei	
A	+	1384	722	38	1.92
B	+	52	24	2	2.18
C	++	23	31	5	0.74
D	++	6	8	3	0.75
E	++	26	29	5	0.90
F	+++	4	14	7	0.29
G	+++	3	16	5	0.19
H	+++	28	66	7	0.42
I	++++	5	32	2**	0.16

*Without any adequate apparatus to measure the absolute strength of wave action, the seeming
strength at respective pools was ranked tentatively in four grades from + (least) to ++++ (largest)
on their site, level, and topography.
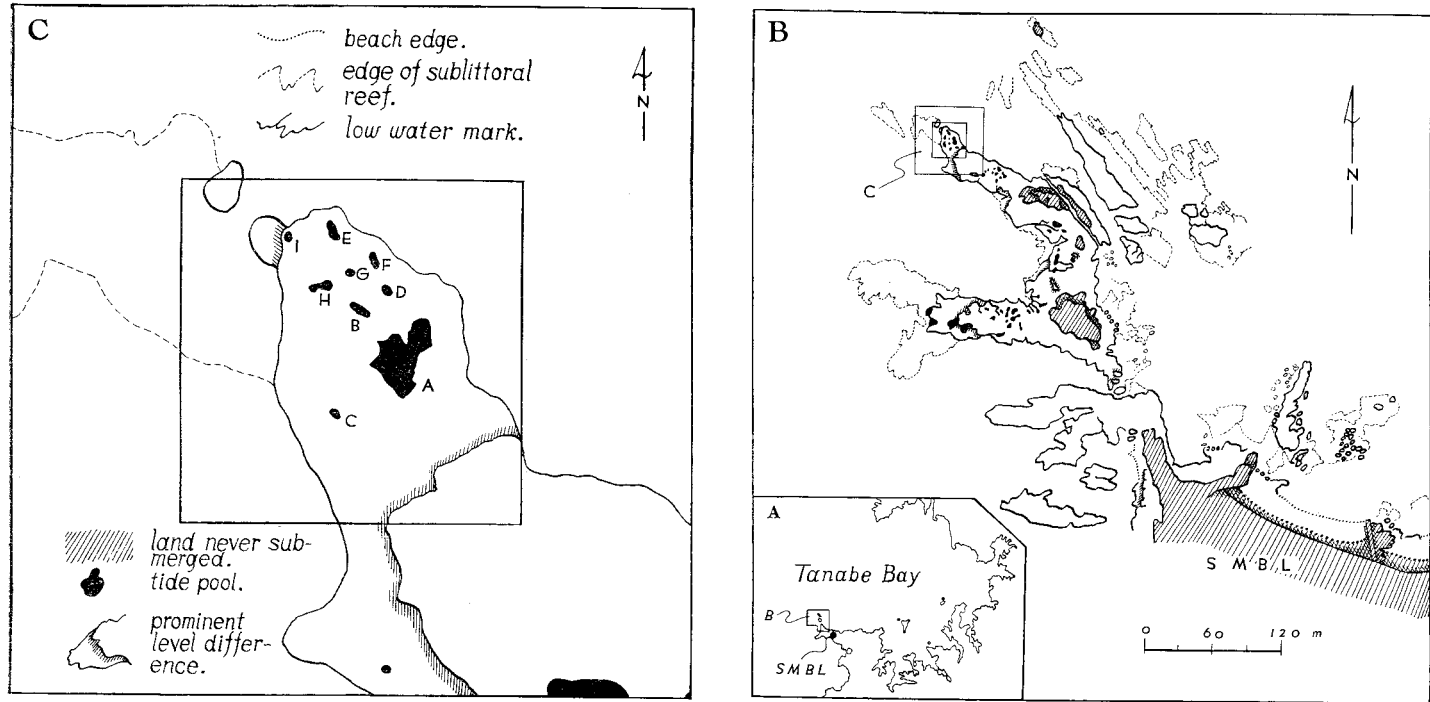**In addition, one individual of *Stomopneustes variolaris* (LAMARCK) was found,

Fig. 1. Maps showing the place of observations.

A: Site of Banshosaki Cape. B: Reef around Toshima Island (reproduced by FUSE from an air-photo).
C: The pool group surveyed.

in Table 1, which will show the general aspect of the distribution of sea urchins and the distribution patterns of respective species in the area studied.

Measurements of clinging power

Method: SHARP and GRAY (1962) measured the clinging power of sea urchins by applying some weights, but we thought of the use of a spring scale to measure the clinging power as a strength necessary to pull off the sea urchin from the substratum and to express it in kilogramme.   At first it was planned to make measurements in the natural environments, but at once many difficulties which would be met with in doing measurements actually in the field were noticed, besides the difficulty to unify the different conditons or factors of the substratum.   Thus, some devices for the indoor measurements in the laboratory using a certain uniform substratum were considered.

Then as to the choice between the measurement in an immersed state and that in an exposed state, the former was preferred to the latter without hesitation, as the former must be more natural.

Any damages on tube feet will bring about some decline of the clinging power. Thus the efforts were paid not to injure the tube feet as far as possible.   Whenever the sea urchins are pulled off from any substratum, inevitably some of tube feet will be damaged.   So it is very important to find how to eliminate the necessity of removing sea urchins during the treatment from collection to measurement.   First, it was thought of to place the sea urchin on a certain "measuring board" in order to keep the uniformity of the substratum, but this was given up, because for this the sea urchin had to be removed from the container in which they had been carried into the laboratory from the fileld onto that board.   Moreover it was found that some sea urchins needed a very long time to be set on that board.   Thus lastly, it was decided to make the measurement on sea urchins as they were attaching to the wall of the container in which they had been carried into the laboratory from the field.   Next problem to be solved was to have sea urchins set on the even surface of the container. A square container will afford five even substrata, but sea urchins will gather to corners and become unavailable for measurements.   Thus a round tub made of polyethylene was used as the container which afforded one even bottom surface and a wall surface with a gentle curvature.   Then arose another question,   which of the urchins attached to the floor or those set on the wall should be used for measurements.   This concerned the way to link the sea urchin to the spring scale.

The first idea was to spread a sheet of net over the floor of a tub to have any sea urchins which are extending tube feet through the net meshes to attach to the floor surface.   If this were successful, the net sheet enclosing a sea urchin within would be connected with a piece of string to a spring scale which would be then help up to pull off the urchin from the bottom surface.   Thus the clinging power of sea urchins in the dorso-ventral axis would be measured.   However, this was failed as sea urchins

attached to the network itself instead of extending tube feet to the floor through meshes.

The final manual thought of was to catch the sea urchins on the side wall of the tub by a small spoon net and to link the net to a spring scale with a piece of string. In this way, the clinging power of the sea urchin in the axis perpendicular to the dorso-ventral axis was measured. This measurements seemed more natural than the measurement of the clinging power in the dorso-ventral axis, as in the natural environment the clinging power of sea urchins will stand the wave action seemingly most effective on the side of the animal. The round tub used was about 60 cm in diameter. Theoretically, the larger the tub is, the more individuals can be kept alive and the less significant the curvature of the side wall is. A spring scale for 4000 grammes was used. The tub was supplied with running sea water; overflowing may be allowed in another small vessel as shown in Fig. 2b in order to prevent the escape of urchins out of the tub. The clinging power on the even and smooth polyethylene substratum was thus measured.
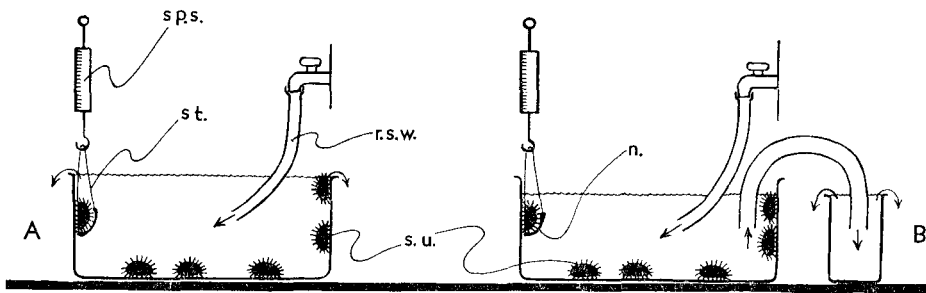

Fig. 2. Way of measuring the clinging power of sea urchins.
n.—net, r.s.w.—running sea water, sp.s.—spring scale, st.—string, s.u.—sea urchins.

It is natural that the clinging power on other substrata will differ significantly from that measured on the above-mentioned substratum. Strictly saying, in *Echinometra mathaei* the clinging power will differ considerably between the measurements in the major and minor axes, and some simular differences, though less pronounced, may appear in other sea urchins of a regular roundish shape, because they can be situated with an ambulacral zone or an interambulacral zone aobve. All such possible differences were neglected in the present measurements. The weight of the spoon net and the piece of string was too small to require any correction of the clining power measured; it was neglected, too. A single urchin was used only once, because many tube feet were found damaged by one measurement.

Results of measurement: Besides the clinging power (CP), the height (H), diameter (D, major and minor axes in *Echinometra mathaei*), and body weight (BW) were measured on 65 *A. crassispina*, 25 *Echinostrephus aciculatus*, 17 *E. mathaei*, 8 *Tripneustes gratilla*, 5

Toxopneustes pileolus nd 2 *M. globulus.* Then, correlations between these values were examined so that their biological significance was discussed.

Correlation between CP and H in each of examined species is given in Fig. 3, which will show clearly that CP differs considerably from species to species and that it is markedly less in *E. aciculatus* than in *A. crassispina* and *E. mathaei*.

As to *A. crassispina* and *E. aciculatus*, correlation is given between CP/D and H in Fig. 4, between CP/D.H and BW in Fig. 5, and bwtween CP/BW andD in Fig. 6. And in *A. crassispina* correlation between CP and H is compared with that between
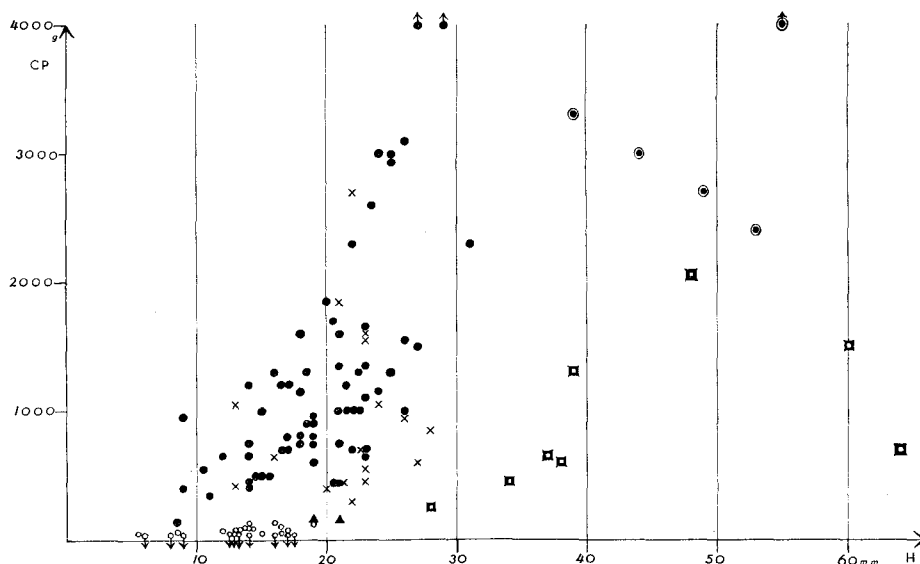
Fig. 3. Correlation between H (heihgt) and CP (clinging power) measured in six species of sea urshins. Larger solid circle: *Anthocidaris crassispina* smaller empty circle: *Echinostrephus aciculatus*, cross: *Echinometra mathaei*, square: *Tripneustes gratilla*, double circles: *Toxopneustes pileolus*, and solid triangle: *Mespilia globulus*. Upward arrow shows that the value marked with it was beyond the maximum of the spring scale used, 400 g, and downward arrow indicates that the value was below the minimum of the scale, 40g.

CP and D in Fig. 7; this comparison conforms exactly to the linear relation between D and H throughout males and females: D=k.H as, is clearly given in the table given by MORTENSEN (1943, p. 329).

Observations on colonial stability

Method: TOKIOKA (1969), having made some observations on the echinid colonies on Hatakezima Island in Tanabe Bay, seems to hope to examine the composition of certain sea urchin colonies in relation to the long-term succession of the shore fauna

of that island. For this, it is essential that the composition observed on a certain day will represent that which is maintained unchanged for a term of a considerable length. Thus, he gave two compositions observed in the summer of 1969 at an interval of one month, and emphasized the similarity found between them. However, to confirm the stability of such colonies, it is very desirable that some specimens are
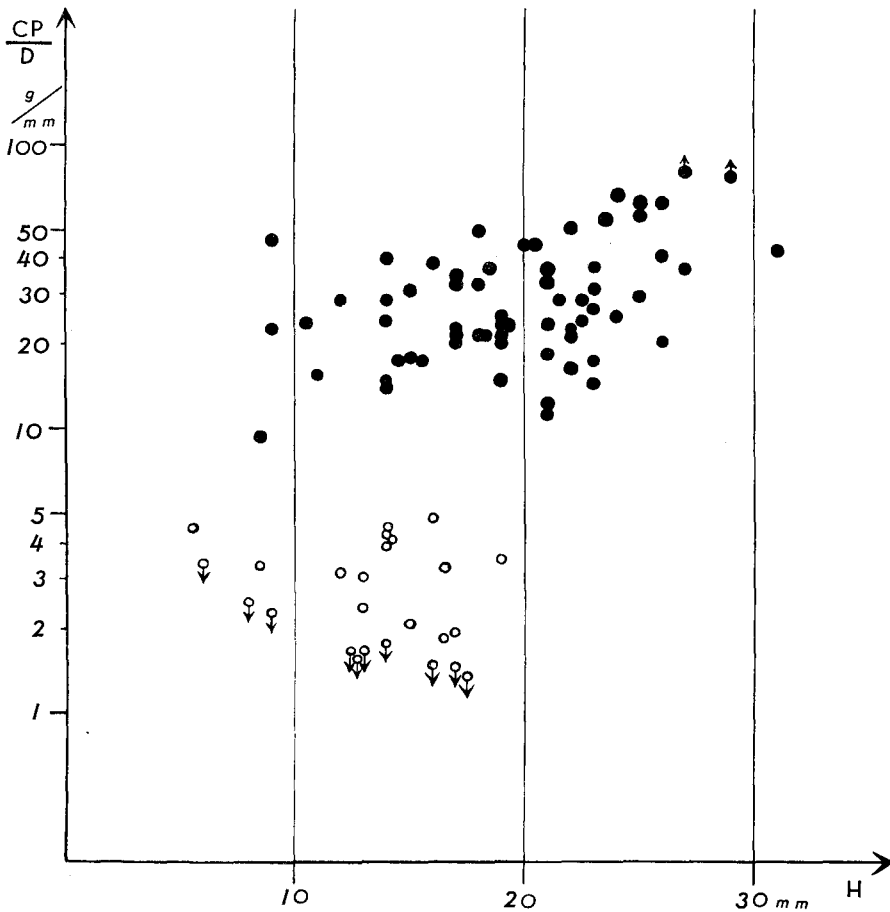
Fig. 4. Correlation between (clinging power) CP/D (diameter) and H (height) in *Anthocidaris crassispina* (larger solid circle) and *Echinostrephus aciculatutus* (smaller empty circle). For arrows, see Fig. 3.

traced individually. This is essential, too, from the view point of confirmation of a positive relation between the composition and the wave action and further that between the latter and the clinging power of sea urchins.

Firstly the tagging of individual sea urchin is necessary for the tracing. This was done by putting small pieces of vinyl tubes of different colours and lengthes on

some spines of sea urchins. Red, green, and white tubes were respectively cut into 5, 8, 11, 15 and 20mm long pieces. The use of one or two of such pieces was enough to mark a considerable number of urchins.

Three observations were made on tagged individuals: (1) the first observation was to tag some members of a certain colony as they were distributed at the time of tagging and to trace them for several days, (2) the second was to remove some urchins from a certain colony and to see whether or not vacant niches thus prepared are occupied by any other tagged urchins in the same colony, and (3) the last was to trace some tagged urchins brought into a certain colony from other colonies to see how the seemingly available excavations are occupied by them.

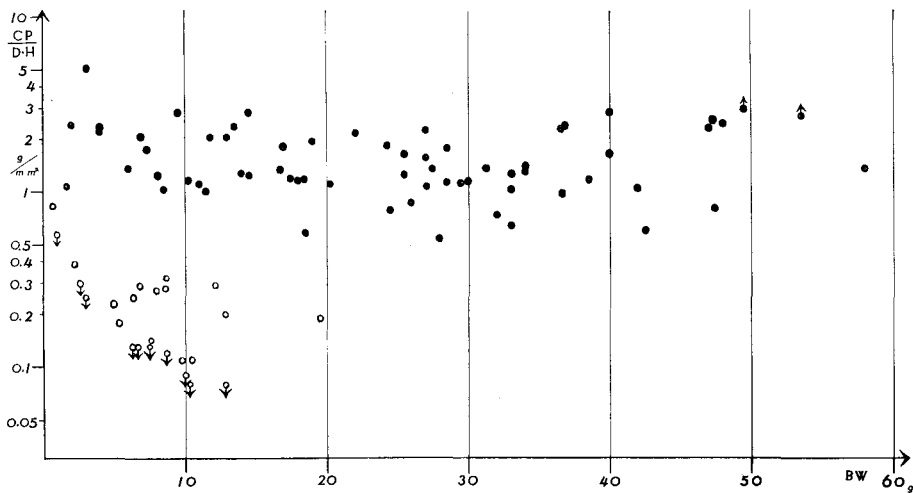*Results of observations*: (1) The first observation was made during the morning ebb

Fig. 5. Correlation between (clinging power) CP/(diameter) D. H (height) and BW (body weight) in *Anthocidaris crassispina* ('larger solid circle) and *Echinostrephus aciculatus* (smaller empty circle). For arrows, see Fig. 3.

tide in the tide pool A in five days from July 27 to 31. Three quadrates, 60 cm × 70 cm, were set in shallow places to cover in all 50 *A. crassispina*, 98 *Echinostrephus aciculatus*, and 4 *Echinometra mathaei*. All individuals of *A. crassispina* and *E. mathaei* and some of *E. aciculatus* were tagged as mentioned previously on July 27 and continuent examinations of the distribution of those tagged urchins were made on July 28,29 and 31. During the observation, all of *E. aciculatus* and 20% of *A. crassispina* lost their tags. However, at least it was sure that 40 (80% of) *A. crassispina* and 4 (all of) *E. mathaei* never changed their niches in four days. The taggs put on all *E. aciculatus* and 10 (20% of) *A. crassispina* had seemingly been washed away by strong wave action or lost together with spines by a kind of autotomical reaction of the sea urchins themselves, as many fragments of spines and some detached pieces of vinyl tubes were found on

the floor of the same tide pool. Furthermore, sea urchins around the quadrates had been tagged differently, but none of them was found moved into any quadrates during the period of observation. Thus, it may be concluded safely that the populations of urchins in the quadrates were maintained stable during the observations. (2) From a quadrate, 40 cm $\times$ 60 cm in extent and set in the tide pool C to cover 18 *A. crassispina*, 15 *E. aciculatus* and 2 *E. mathaei*, 8 individuals of *A. crassispina* were removed on July 27 to make ready for vacant excavations. Those eight excavations remained vacant on July 28 and 29.
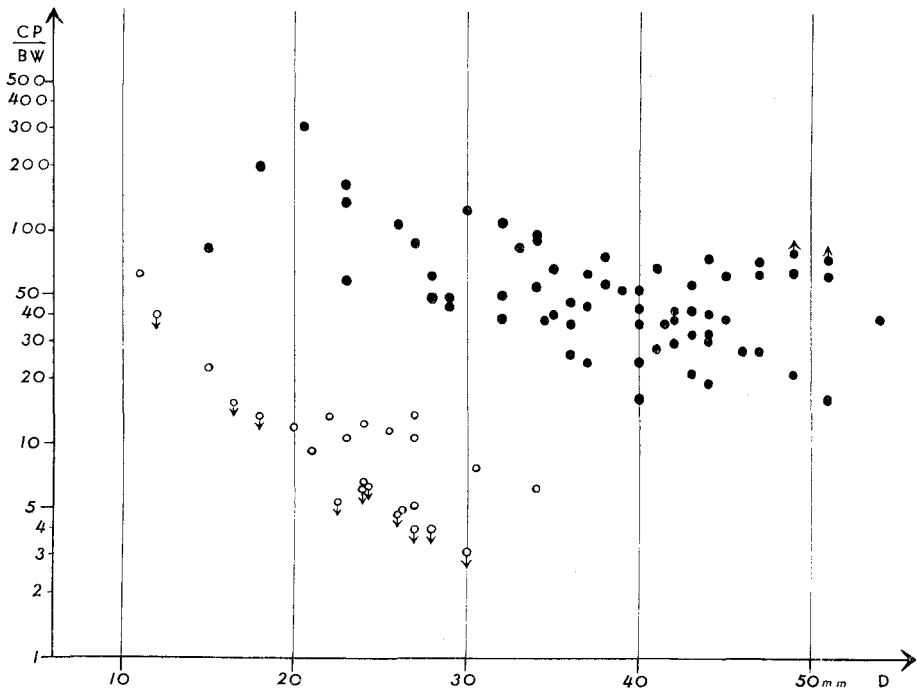

Fig. 6. Correlation between (clinging power) CP/BW (body weight) and D (diameter) in *Anthocidaris crassispina* (larger solid circle) and *Echinostrephus aciculatus* (smaller empty circle). For arrows, see Fig. 3.

(3) Three *A. crassispina* and one *E. mathaei* were introduced on July 29 into the above-mentioned quadrate in the tide pool C. The former occupied respectively a vacant excavation sited nearest after a hovering for a while, but the latter continued to crawl around till July 31, when it was found settled in a peripheral depression in the tide pool C. On that day, the three *A. crassispina* introduced there two days before were found steadily keeping respectively the same niche, other urchins either never changed their sites during the observation, and five vacant excavations were still left unoccupied.

All examinations mentioned above were made during the ebb tide in the day-

time. Then some observations were made complementarily in the flood tide at night during the period of observations. So far as our examinations were concerned, the distributions of sea urchins in the night flood tide in tide pools A and C were quite the same as those in the daytime ebb tide.

On the results given above, it may be concluded safely that sea urchins will scarcely go out from or come into the colonies in tide pools in a short time-span as several days in the summer season.
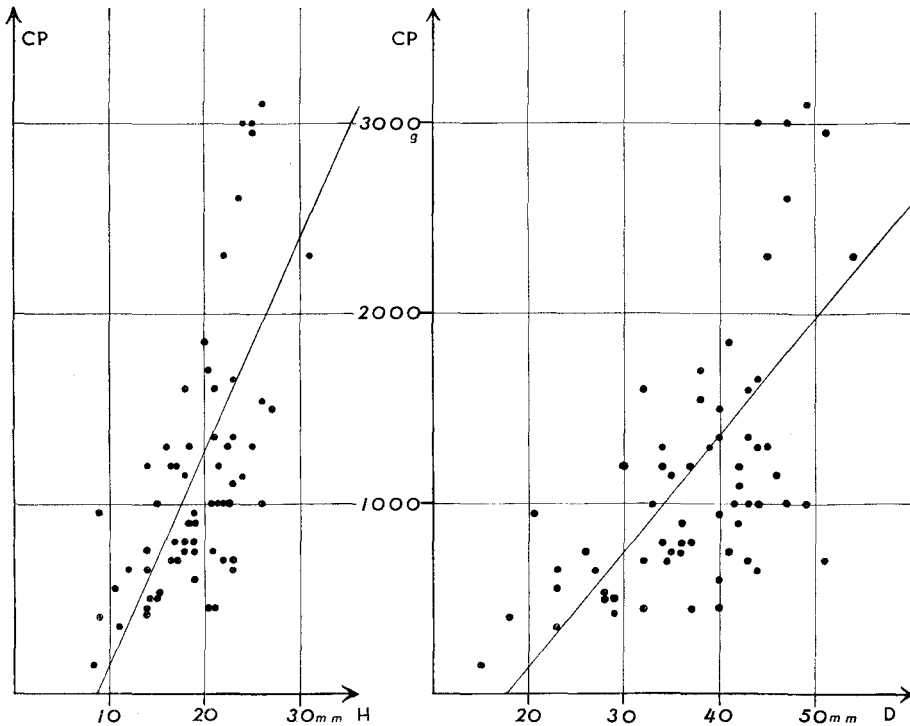

Fig. 7. Correlation between (clinging power) CP and H (height) against that between CP and D (diameter) in *Anthocidaris crassispina*.

Stomach contents of littoral sea urchins

The stability of the sea urchin colonies seems to depend upon the inactivity of sea urchins in tide pools. Then, it is a matter of interest to know how they take enough nourishment without moving around actively. For this reason, some *A. crassispina* and *Echinostrephus aciculatus* were collected from the tide pool A for the examination of stomach contents; the latter were never taken out of the pit without breaking some parts of the rocky substratum by using chisel and hammer. The stomach contents of these sea urchins consisted chiefly of algae; especially it was note-

worthy that a small amount of spine fragments and some other materials were found mingled with algal substances in the stomach contents of *E. aciculatus*. Then fine pieces of the green alga, *Ulva conglobata* Kjellman were scattered on the dorsal side of sea urchins in tide pools. *A. crassispina* and *Echinometra mathaei* did not react to this, but *E. aciculatus* immediately responded to this by active movement of spines which seemed to catch and carry the algal pieces towards the oral side to ingest them.

Discussions

The CP difference between *A. crassispina* and *Echinostrephus aciculatus* is very remarkable; CP of the latter is only about one tenth of that of the former of the same body size (diameter) (Figs. 3, 4, 5, 6.) The weak CP of *E. aciculatus* is apparently related with its pit-dwelling habit and its distribution avoiding the sites exposed to violent wave action. Thus the CP of this urchin does not seem to fit the further crucial analyses of CP in relation to the wave action. On the contrary, *A. crassispina* may be taken as one of the sea urchins which are generally living exposed to wave action, though strictly its habitats are usually semi-sheltered—this may be seen in the asymmetrical development of spines in this pecies.

Clinging power in A. crassispina: The clinging power to the substratum may be effectual mainly to maintain the situations of sea urchins against the water movements mostly caused by wave action, though partly correlated with the locomotion, the crawling behaviour. The power is considered to be a function of the clinging power of the sucking disc of repsective tube feet, the number of tube feet on the oral side and the distributional pattern of feet on that side, when the physiological factors can be put aside. And the effectiveness of CP against the wave action will be affected much by the size of the animal and slightly by the friction between the substratum and the spines on the oral side.

Because the water movement caused by wave action works seemingly on the side of the sea urchin mainly to wash off the animal from the substratum, CP may be expressed as $CP = k.D.H.$ or $CP.(D.H)^{-1} = k$. This seems to be supported as is shown in Fig. 5. Then $CP.D^{-1} = k.H$; this shows that $CP.D^{-1}$ increases with the height, as it is seen in Fig. 4. Further, $CP.BW^{-1} = CP.(\alpha.D^2.H)^{-1} = (CP.D^{-1}).(\alpha.D.H)^{-1} = (k.H).(\alpha.D.H)^{-1} = k'.D^{-1}$; this shows that $CP.BW^{-1}$ decreases with the increase of D, as seen in Fig. 6. Going back from these results, the formula $CP = k.D.H$ seems to be very probable, though the graphs wil lnever always accord strictly with the formula, because of such other factors as the form or the degree of development of spines.

Correlations between CP and D, and between CP and H in *A. crassispina* are given together in Fig. 7; correlation coefficient (r) is 0.621 in the former and 0.656 in the latter. The correlation between CP and H seems superficially slightly higher than that between CP and D. But the existence of any significant difference between

two coefficients evidently contradicts theoretically the constant relation between H and and D, D = k.H. Moreover, such a slight difference can not be regarded as significant even at the level of 50%, as only 65 specimens were dealt with. Anyhow, taking what are seen in Figures 4–6 into consideration, it is supposed that the regression curve of the correlation between CP and H or D will be a quadratic curve or one close to it.

On the other hand, checking closely respective measurements shown in Figures 3–7, it is revealed that different individuals of the same size and of the same species will never always show the similar CP, but rather the difference found in CP shown by these individuals may sometimes be considerably remarkable. The differences seem to be beyond the range of individual variation. It is evident that the differences are partly attributable to the injury of tube feet, inevitably occurring at the collection of sea urchnins, but much more significant may be what part of the full CP of sea urchins is expressed at the measurement. Thus, the potential clinging power (PCP), that is the maximum CP unique to respective individuals, is suggested against the measured clinging power (MCP) which are here discussed. PCP must be equal to or larger than MCP. It is urged to learn when and how the PCP is expressed, and to find any way to make a diagnosis of a physiological condition of sea urchins and any manual to let urchins express MCP close to PCP at measurements. Then, it might become possible that PCP can be calculated from MCP and that the biological significance of CP can be discussed on PCP.

Clinging power in Echinostrephus aciculatus: The correlation between CP, D and H, namely CP.D^{-1}=k.H, observed in *A. crassispina* is not applicable to *E. aciculatus.* Contrary to the case in *A. crassispina*, CP. $(D.H)^{-1}$ is never constant, but decreases with the growth of this sea urchin, as seen in Fig. 5. CP.D^{-1} increases in *A. crassispina*, but decreases in *E. aciculatus* with the growth as seen in Fig. 4. The difference of CP between *A. crassispina* and *E. aciculatus* is fairly prominent even in young individuals and becomes larger with the growth. Such a feature of CP in *E. aciculatus* is related evidently with the pit-dwelling habit of this urchin and its CP seems to have been reduced with its acquisition of this habit in evolution.

Stability of colonies: Situations of respective individuals of *A. crassispina* in tide pools examined were never altered throughout the observations. First, it was thought that *A. crassispina* would go out of the niche in the night flood tide and return to be found in the same excavation in the daytime ebb tide. But this is not likely, because *A. crassispina* did not seem to have any homing ability and moreover the distribution of this sea urchin in the night flood tide was found in some observation quite the same as that in the dyatime ebb tide. Thus it may be concluded safely that no individual of *A. crassispina* went out of the niche at least during the period of obervations.

Echinometra mathaei seemed to remain immobile as *A. crassispina*, though observations were limited to a small number of individuals.

Echinostrephus aciculatus, though they could not be tagged successfully, did not seem either to change the niche during the observations. This was deducible from the following three points:

(1) The distributions of the three kinds of sea urchins were maintained strictly unaltered during the observations. (2) CP of this sea urchin is too small even to stand the weak wave action outside the pit. And (3) this sea urchin seems to feed in its site in the pit, as seen in an experiment with some algal pieces scattered on the dorsal side of the animal. A similar mode of life has been known in *Strongylocentrotus purpuratus* (Stimpson) having an adaptation to "the pounding surf" on the California coast of North America. It is mentioned that "an urchin will be found that has imprisoned itself for life, having, as it were, gouged out a cavity larger than the entrance hole made when it was young" (Ricketts and Calvin 1968, pp. 202-203). The feeding in the pit seems very probable.

There remain, however, some questions essential in the biology of some shore animals. Are they obtaining enough nutriments in tide pools to bring themselves to maturity? Do urchins of the same species living in the subtidal zone free from surf stay immobile, too? *A. crassispina* and *E. mathaei* did not react to algal pieces scattered on them. Then, when and how are they feeding?

Lastly, it is indispensable, to complete the study about the stability of echinid colonies, to clear the life-span of urchins in pools and the way of recruitment. The least size of urchins in the tide pool A was about 10 mm in diameter; this seems to be of the young urchins within a year after settling (Tokioka 1966, p. 12). And it was very strange that such small urchins were very scarce as compared with larger ones. Then, the population in tide pools must be recruited from the zone upper or lower than the level of pools. The only thing about this to be noted during our observations was that about 20 small individuals of *A. crassispina*, 5–20 mm in diameter, were found adhering to a kind of brown algae growing about 1 m below the low-water mark.

Summary

(1) The echinid fauna in tide pools on the rocky shore around Tôshima Islet near the Seto Marine Biological Laboratory was studied. *Anthocidaris crassispina* (A. Agassiz) is distributed abundatly in pools exposed to strong wave action, but *Echinostrephus aciculatus* A. Agassiz tends to be distributed more abundantly in pools more sheltered.

(2) The clinging power (CP) of *E. aciculatus* is remarkably less than that of *A. crassispina* of the same body size, only about one tenth of that of the latter. The difference of CP between these two urchins increases with the growth.

(3) CP in *A. crassispina* seems to stand enough the wave action effected on the side of urchins, thus the correlation between CP, H (height) and D (diameter)—CP=k.D.H,

is established.

(4) Lesser CP in *E. aciculatus* is evidently related with its pit-dwelling habit and distribution in somewhat sheltered pools.

(5) Sea urchins of colonies in examined tide pools in the studied area seemed to remain immobile at least during the observations from July 27 to 31, 1970.

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