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Rhythmic Activity of the Seaside Barnacle, *Tetrachita squamosa japonica* PILSBRY

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Introduction

Peculiar mode of life of barnacles has attracted attentions of many investigators and a lot of works have hitherto been published. Among them, the pedal rhythm was noticed by such investigators as W. H. COLE and his colleagues (1928, 1929, 1930, 1932, 1934 and 1935), V. WALDES (1939), D. E. MINNICH (1940), R. SATO (1941), A. J. SOUTHWARD (1955, 1957) and K. OTA (1957). Some authors treated this problem from purely physiological standpoint, showing the interest on the effect of chemical substances on the mode of the pedal rhythm or on the shadow reactions or so on. As for the rhythmic behavior exhibited in the natural life we can find rather fragmental descriptions except few, which will be cited below.

It is agreed with some authors that the pedal activity is induced or accelerated by the current of water caused by the waves and is not controlled by light (although sudden change induces shadow reflex) (COLE, 1928, for *Balanus balanoides*; SATO, 1941, for *Chthamalus challengeri*; OTA, 1957, for *Balanus amphitrite albicostatus*, *B. amph. communis* and *B. amph. hawaiiensis*). COLE (1932) submerged *Balanus tintinabulum* and *B. balanoides* in running water as long as 38 days, but no abnormalities in the frequency of the pedal rhythm or in other points were observed. On the other hand, OTA (1957) has succeeded in culture of *B. amph. hawaiiensis* in standing waters in the laboratory. He stated that the pedal movement could be evoked when fresh planktons were supplyed in the aquarium, notwithstanding the water was maintained quiet.

These works do not almost pay regard to the rhythmic life in nature, except SATO's which insisting that the chief factor controlling the rhythmic behavior is the tide, being more active at the time of ebb and flow and rather quiescent at the flood, and generally no daily march of rhythmic activity can be observable.

The present report concerns the rhythmic behavior of the seaside barnacle, *Tetrachita squamosa japonica* PILSBRY, which inhabiting at the intertidal zone of rocky seashore exposed to the open sea. The observation and experiments were all performed at the Seto Marine Biological Laboratory during the summers of 1956 and 1957.

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Observations at the Natural Habitat

During my stay at the Laboratory I had often observed that the active protrusion and contraction of the cirri were taken place during only at night. On the contrary, I had scarcely observed the pedal movement in the daytime. At the time of low water in the nighttime, if the water was splashed repeatedly over the animals, they used to protrude their feet vigorously; whereas in the daytime they never protruded their feet against the same treatment. These facts seemed to contradict the statements given by the other investigators mentioned above, saying that the rhythmic activities of the barnacles were not related to light. So, more precise observations were attempted.

Two plots were selected on a rock near the Laboratory, the numbers of the barnacle inhabited there were 62 and 90 individuals respectively. The observation was performed from 8.30 of July 23 to 15.30 of the next day. The conditions of activity were observed at adequate intervals, sorting into three states:—scuta and terga closed tightly (inactive state) or scuta and terga slightly opened but not protruding feet (intermediate state) or protruding feet vigorously (active state). Water temperature, surface temperature of the exposed rock, depths of water where the animals inhabited, were measured simultaneously.

Results obtained at the plot No. 1 are illustrated in Fig. 1.

It can be concluded from this figure and other observations that:

a) When submerged, the animals more or less open their scuta and terga; and if it is at night some protrude their feet vigorously, whereas if it is in the daytime they never protrude the feet.

b) When emerged, the animals more or less close their scuta and terga. Degrees of closeness are related to degrees of dryness of the habitat, so that they are closed most tightly after the noon.

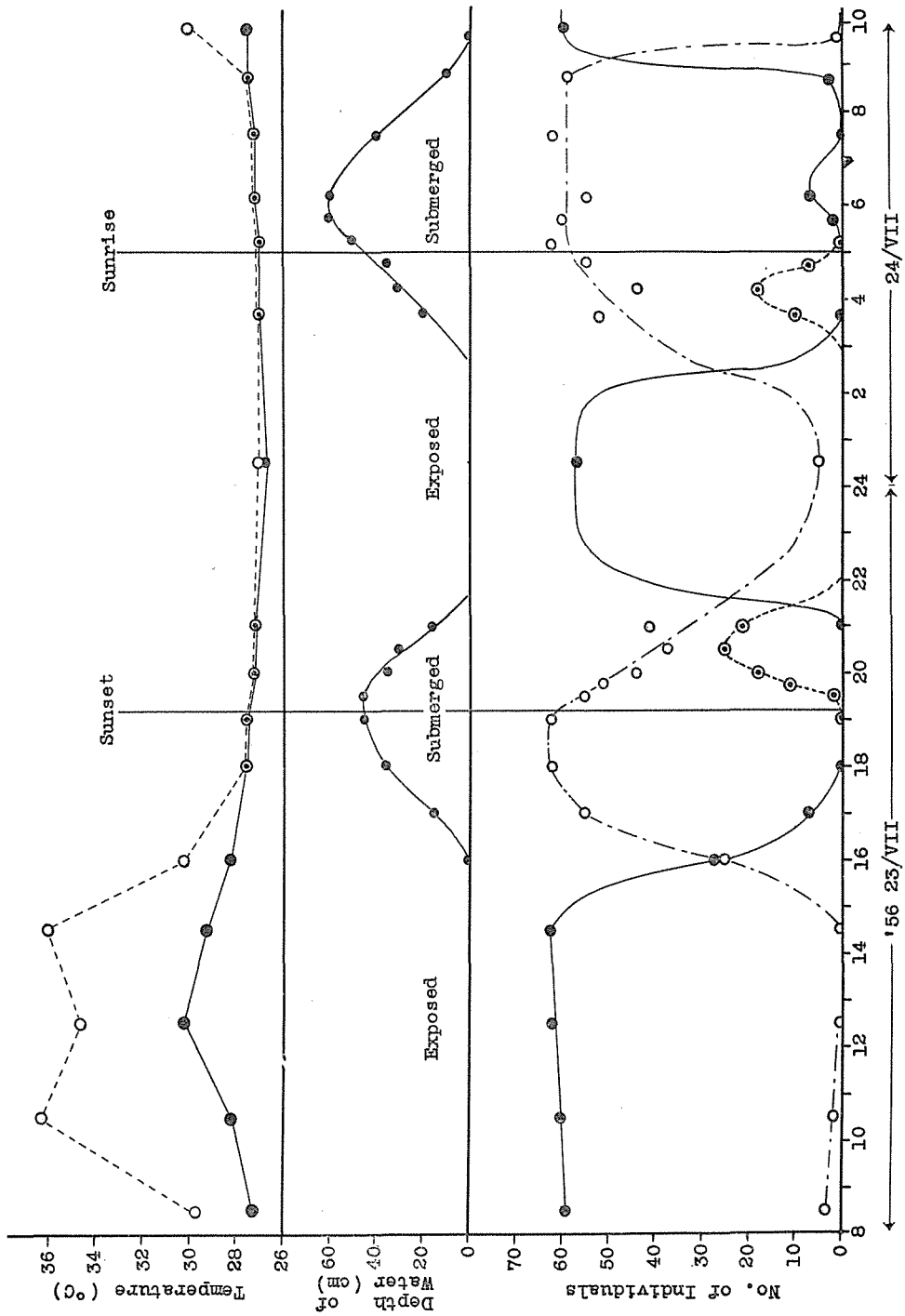
As the existence of the daily rhythm was clear from above field observations, some experiments concerning with the role of light and, if any, of internal factors were desired to be performed at the next step. At the third step, some biotic relations such as food relation had to be reflected upon the experiments.

Fig. 1. Daily march of the activity of the barnacle, with changes of the physical environments.

Upper figure: Change of water temperature (●—●) and temperature of the surface of rock where the barnacles inhabited (○—○).

Middle figure: Change of depth of water and periods when the barancles were submerged.

Lower figure: Change of activity (●—● numbers at inactive state, ○—·—○ at intermediate state, ◉···◉ at active state).


Temperature (°C)
Depth of Water (cm)
No. of Individuals
Sunrise
Sunset
Exposed
Submerged
Exposed
Submerged
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Activities under Laboratory Conditions

1. *Relation between the activity and light*

Broken pieces of rock with the attached barnacles were brought into the laboratory. At first, it seemed to be very difficult to make protrude the feet in the laboratory, but soonafter two methods were found out.

When the water was splashed repeatedly over the animals placed on the experimental desk, they were generally made to open the shells and to protrude the feet. Usually more than 30 times of splashing were necessary to induce the protrusion and after 60 or 70 times the full protrusion was observed[1].

Another method is based on the principle that, when the animals are subjected to strong current suddenly, the feet can easily be made to protrude. The barnacles, carefully collected with pieces of rock, were placed in the glass aquarium. The water was flowed quietly and constantly, and under this condition they never protruded the feet. At adequate intervals they were suddenly subjected to the strong current, which was generated by the water running out from a rubber water-pipe. Some of them protruded the feet against the current.

These two methods were succeeded only at night and no method could induce the protrusion of the feet in the daytime.

Fig. 2 shows one of the results obtained by the former splashing experiment. It was executed from 15.00 of Sept. 4 of 1956 to 21.00 of the next day. The pieces of rock, inhabited by 30 individuals of the barnacle, were collected in the beforenoon of Sept. 4.

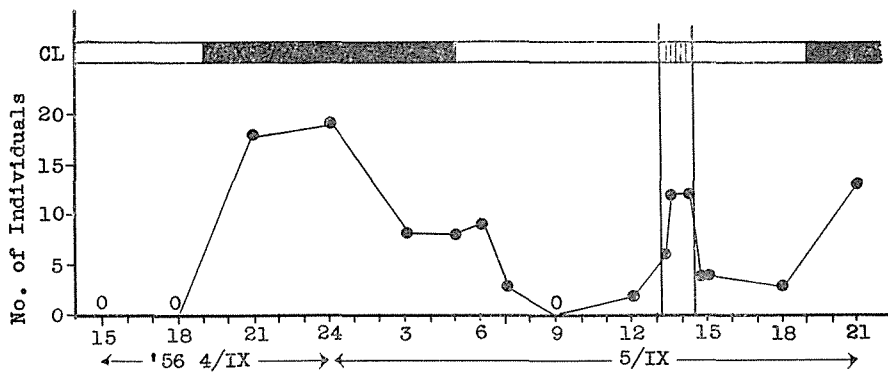

Fig. 2. Daily change of the protruding response of the barnacles against splashed water. During from 13.10 to 14.20 of Sept. 5 the room was darkened.
Ordinates: Number of individuals protruded the feet when water was splashed over.
CL: Change of the environmental light conditions.
□ Normal daylight, ▩ Night, ▥ Period when the room was darkened artificially.
Water temperature varied between 27.8–28.8°C.

1) This method was first discovered by Mr. A. MIYAKE of the Osaka City University.

It is clear that the activity was evoked during only at night or in the darkness. This was ascertained again by the second series of the experiment, one of the results of which is indicated in Fig. 3. This experiment was performed during from 13.20 of Sep. 6 of 1956 to 3.00 of the next day, using 79 individuals attached to the pieces of rock, which were collected on Sept. 4.

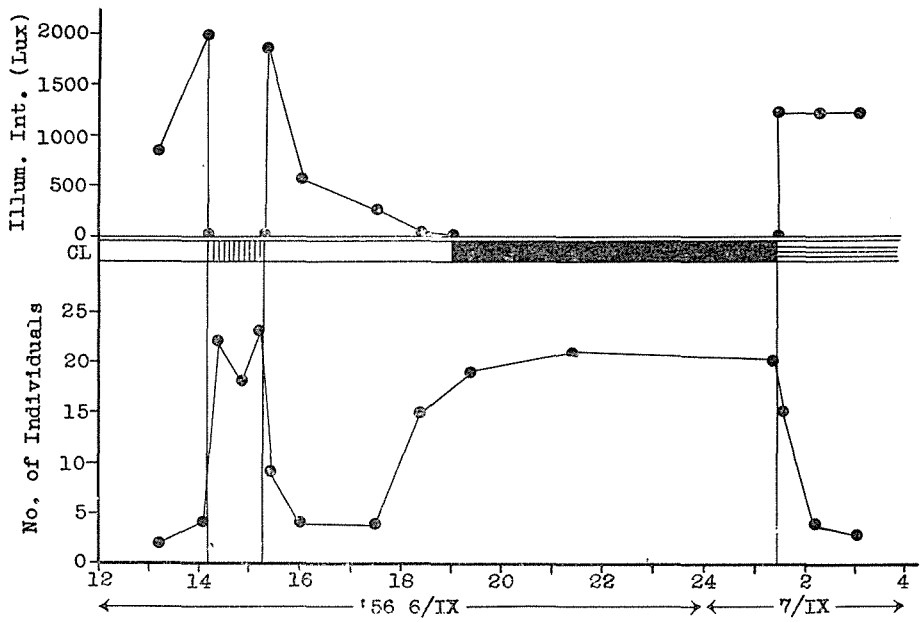

Fig. 3. Change in the protruding activity of the barnacles submerged in the water when subjected suddenly to the strong current.
Upper figure: March in the illumination intensity in the process of the experiment. CL column shows schematically the change of light or darkness— ▭ diffused daylight, ▬ natural night darkness, ▥ period when the room was artificially darkned, ▤ period when the room was artificially lighted (1220 Lux). Water temperature varied between 28.0–29.0°C.
Lower figure: Number of individuals protruded the feet when subjected suddenly to the strong current.

From this figure it may be concluded that ;

a) The activity of protruding feet cannot be evoked in the constantly, weakly flowing water. It is needed to be subjected suddenly to strong current.

b) This induction of activity is generally possible only at night or in the darkness.

2. *Relation between the activity and the planktons*

As has been quoted, OTA (1957) has the opinion that the activity of *Balanus amphitrite hawaiiensis* can easily be evoked by supplying planktons irrespective of light or current conditions. To ascertain whether it is true or not in the present

material, a good quantity of fresh planktons was offered to *B. squamosa japonica* in the glass aquarium. The result of the experiment performed in the daytime is indicated in Table 1 and those at night in Tables 2 and 3.

Table 1. Effect of planktons on evoking the pedal activity in the daylight. Pieces of rock attached with 56 individuals were collected on July 13 (1957) and reared in the glass aquarium with overflowing water. The experiment was done on July 15.

Time		6.25	6.30	7.00	7.30	9.00	9.01
Treatments	Water	W*	S*	Q*	Q	Q	S
	Planktons	N*	N	P*	P	P	N**
No. of individuals protruded the feet rhythmically		0	5	—	0	0	8

* W : constantly and quietly flowing.
S : subjected to strong current suddenly at the time of the observation.
Q : standing, no current.
N : nearly no planktons.
P : supplyed with a good quantity of planktons.
** Removed the planktons by exchanging water.

Table 2. Effect of planktons on evoking the pedal activity at night. Pieces of rock inhabited by 58 individuals were collected at 14.00 of July 15 (1957) and the experiment was commenced 2 hours later. Other explanations see Table 1.

Day & Night		Daytime				Nighttime							
Time		15.50	16.00	18.00	21.00	21.01	21.10	21.30	22.00	22.01	22.20	22.55	23.00
Treatments	Water	W	S	S	S	Q	Q	Q	Q	Q	Q	Q	S
	Planktons	N	N	N	N	P	P	P	P	N	N	N	N
No. of individuals protruded the feet rhythmically		0	4	5	25	—	8	10	6	—	3	4	24

Table 3. Effect of planktons on evoking the pedal activity at night. Pieces of rock inhabited by 70 individuals were collected at 14.50 of July 16 (1957) and 40 minutes later the experiment was commenced.

Day & Night		Daytime				Nighttime									
Time		15.30	15.33	17.00	17.03	20.15	20.20	20.23	20.30	20.45	21.00	21.30	21.32	1.00	1.03
Treatments	Water	Q	S	Q	S	Q	S	Q	Q	Q	Q	Q	S	Q	S
	Planktons	N	N	N	N	N	N	N	P	P	P	P	N	N	N
No. of individuals protruded the feet rhythmically		0	4	0	8	2	28	1	0	0	1	0	37	0	25

From these tables it may be concluded that;

a) Planktons do not influence the activity in the daytime.

b) They somewhat influence (viz. slightly induce) the activity (Table 2) or play no effect (as in the daytime) (Table 3) at night. In general, the effect due to the planktons, even when it is surmised, is far insignificant when compared with the effect due to the light or the strong current.

Discussions and Conclusions

From above observations and experiments, the existence of the daily rhythmic activity in the barnacles is ascertained, which has never been stated clearly by other investigators. As the activities of crustaceans are generally known to be daily rhythmic, being usually active at night, it is rather a strange matter that the sure existence of the daily rhythm has never been noticed in the barnacles. Indeed, A. J. SOUTHWARD (1955), although he could not find out any signs of diurnal variations in behaviors of *Chthamalus stellatus*, *Elminius modestus* and *Balanus balanoides*, had already pointed out that "the possibility of their existence can not be discount". The present seaside barnacle, *Tetrachita squamosa japonica* PILSBRY, protrudes its feet and collects foods usually only at night and stay quiscent in the daytime even when it is submerged.

The conditions of the environments under which the said activity took place were explored by the natural observations and the laboratory experiments. Absence of light is necessary for evoking the vigorous pedal activity, by which the nocturnal rhythm of activity appears. Furthermore, exposure to strong current caused by the dashing waves is indispensable. In standing waters they scarcely show the normal rhythmic protrusion of the feet.

Any endogenous rhythmic factors seem not to be partaken in; at least the role of the rhythmic physical environments is so powerful when compared with the role of the endogenous rhythmic factors that the daily march of the rhythmic activity is practically controlled by the marches of the physical environments.

Whether there are any concealed rhythms which can only be recognizable by statistical treatments as being insisted in various organisms by F. A. BROWN, Jr. and his colleagues (1955 a, b, c; 1957 a, b) or not, is not clear.

As for biotic environments, the presence of food (planktons) has been found by OTA (1957) to be effective for releasing and maintaining this activity in *Balanus amphitrite hawaiiensis*. However, for *Tetrachita squamosa japonica*, the supply of planktons has scarcely any effect on the induction of the activity under consideration.

After all, it may be said that the modes of rhythmic activities of the barnacles are considerably different as the species differ and consequently the factors concerned are varied. The pressent seaside barnacles, *Tetrachita squamosa japonica*, protrude their feet rhythmically when the water of the environment moves arround

them with dashing waves in the nighttime, irrespective of the water contains planktons or not.

Literatures

BROWN, F. A., Jr., WEBB, H. M. & BENNETT, M. F., 1955a. Proof for an endogenous component in persistent solar and lunar rhythmicity in organisms. Proc. Nat. Ac. Sci., **41**: 93–100.

———, FREELAND, R. O. & RALPH, C. L., 1955b. Persistent rhythms of O_2-consumption in potatoes, carrots and the seaweed, *Fucus*. Plant physiol., **30**: 280–292.

——— 1957a. Response of a living organism, under "constant conditions" including pressure, to a barometric-pressure-correlated, cyclic, external variable. Biol. Bull., **112**: 228–304.

———, SHRINER, J. & WEBB, H. M., 1957b. Similarities between daily fluctuations in background radiation and O_2-consumption in the living organism. Ibid., **113**: 103–111.

———, WEBB, H. M. & MACEY, E. J., 1957c. Lag-lead correlations of barometric pressure and biological activity. Ibid., **113**: 112–119.

COLE, W. H., 1928. The pedal rhythm of the rock barnacle. Anat. Rec., **41**: 36.

——— 1929. The relation between temperature and pedal rhythm of *Balanus*. J. gen. Physiol., **12**: 599–608.

——— & ALLISON, J. B., 1930. Chemical stimulation by alcohols in the barnacle, the frog and planaria. Ibid., **14**: 71–86.

——— 1932. The sensitivity of the cirri and the variability of their movements in the barnacles *Balanus tintinabulum* and *B. balanoides*. J. exptl. Zool., **63**: 143–153.

——— & SIZER, J. W., 1934. Note on the behavior of the barnacle. Bull. M. Desert Island, Biol. Lab., 1934.

MINNICH, D. E., 1940. A preliminary study of the light reaction of the rock barnacle, *Balanus balanoides*. Ibid., 1940, 24.

OTA, K., 1957. Notes on the ecology of *Balanus amphitrite hawaiensis* BROCH. Physiol. and Ecol., **7**: 127–130.

SATO, R., 1941. Cirri movement of a barnacle, *Chthamalus challengeri* HOEK, and its environments in summer. Ecol. Rev., **7**: 236–240.

SOUTHWARD, A. J., 1955. On the behaviour of barnacles. II. The influence of habitat and tide-level on cirral activity. J. Mar. Biol. Ass. U. K., **34**: 423–433.

WALDES, V., 1939. Ueber die chemische Beeinflussung des Rhythmus und der Reaktionsdauer der Cirren von *Balanus perforatus*. Z. vergl. Physiol., **26**: 347–361.