ECOLOGICAL STUDIES ON THE MORPHOLOGICAL VARIATION OF A SESSILE BARNACLE, CHTHAMALUS CHALLENGERI II. CONSTITUTIONAL CHARACTERS OF THE CHTHAMALUS POPULATION WITH SPECIAL REFERENCE TO THE STRATIFICATION OF THE CHTHAMALUS ZONE

著者	Kato Mutsuo, Hayasaka Kazuko, Matsuda Tatsuro
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ECOLOGICAL STUDIES ON THE MORPHOLOGICAL VARIATION OF A SESSILE BARNACLE, *CHTHAMALUS CHALLENGERI* II. CONSTITUTIONAL CHARACTERS OF THE *CHTHAMALUS* POPULATION WITH SPECIAL REFERENCE TO THE STRATIFICATION OF THE *CHTHAMALUS* ZONE[1,2]

By

MUTSUO KATÔ, KAZUKO HAYASAKA and TATSURÔ MATSUDA
加藤陸奥雄・早坂和子・松田達郎
Biological Institute, Tôhoku University, Sendai, Japan

INTRODUCTION

In the neighbourhood of the Marine Biological Station of Asamushi in Aomori Prefecture, the *Chthamalus* zone appears distinctly in the upper part of the intertidal community and the population density is dense nearby the high water level and becomes thin upwards and also downwards. It is also noted that the age distribution and the mortality change gradually from the upper part of the distributing zone to the lower part of it. Therefore, the growth form of the shell is considered to be characteristic to each level of the distributing zone.

In the previous paper (Katô et al. 1960), the writers have reported that owing to the density of the population the antagonistic relation is recognized between the shell elongation and the shell expansions, and the expression "$\log H + k \log A = K$" was given where H is the shell height, A is the size of the shell base (length$\times$ breadth) and k and K are constants. And it was advocated that k may be considered as "an index of the morphological heterogeneity of the constituents" of the barnacle population, and also as "the sparseness and denseness index".

In the present paper, using this index the comparison of the shell shapes in different levels of the *Chthamalus* zone was investigated with special reference to the age and the growth.

MATERIAL AND METHOD

The distributing zone of *Chthamalus challengeri* was divided into five strata at Hadaka-island near by the Marine Biological Station, namely from the uppermost portion to the lowermost one, Sts. A, B, C, D and E were set, here St. A

1) This paper is dedicated to Professor Tadao Jimbo for his 63rd birthday.
2) Contributions from the Marine Biological Station of Asamushi, Aomori Ken, No. 259.

is above the high tide mark and St. E below the low tide mark (Fig. 1).

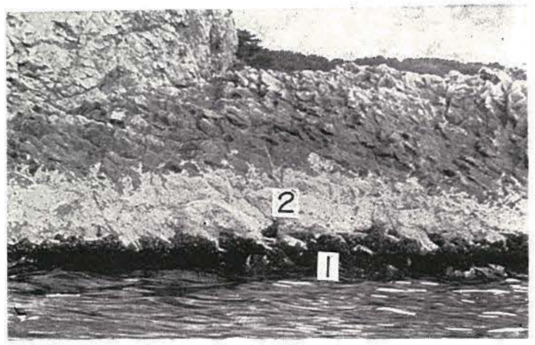

Fig. 1. The tidal zone at Hadaka-island near by the Marine Biological Station of Asamushi. 1 : *Mytilus* zone, 2 : *Chthamalus* zone.

All individuals attaching to rock surface at each station were collected. The age of each individual is easily known from the number of striae running parallel with the shell base, but as this striated feature of the shell surface becomes eliminated with the advance of the age, it was difficult to conclude the age of the large shell older than six years. All shells examined were divided into six classes, which correspond respectively with each age except for the sixth class which contains all shells older than six years.

As the dimensional characters of the shell, the length and the breadth of the opercular portion and of the shell base and the shell height were measured.

RESULTS AND DISCUSSIONS

1. *The Age Distribution of the Barnacle Population.*

The age distribution of shells in each stratum is shown in Fig. 2. In Sts.

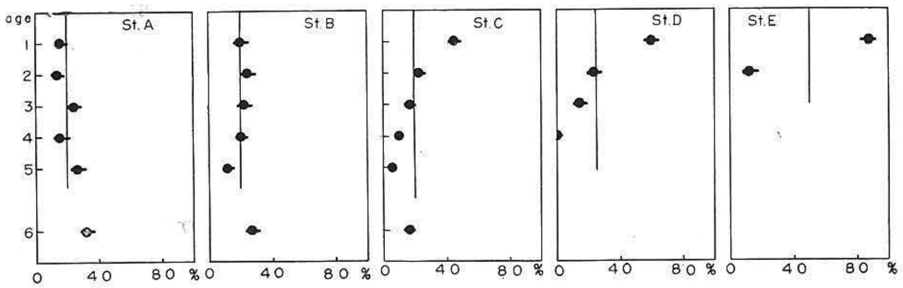

Fig. 2. The age distribution in each station. The percentage is shown with the confidence interval in 90 per cent reliability.

A and B the percentage of individual number of each class to the total number shown by the confidence interval in 90 per cent reliability, is equal or approximately equal to the theoretical mean value, 20 per cent, which is given if individuals of each class are considered to have appeared by the same occurrence probability. Therefore, it may be said that the individuals of each age distribute equally in number at these two strata.

In Sts. C and D the age distribution is heterogeneous, namely individuals of the first year stage are relatively numerous, but large shells are reversely small in number. In St. D indiviuals older than five years disappear and only the first and second classes are found in St. E where the first year stage barnacles are remarkably numerous and only a few of the second year stage ones appear.

It may be concluded from the above that younger animals become relatively more numerous downwards to the lower strata, but reversely the old ones disappear.

This may be due to the difference of the mortality in each stratum which happens in the course of the growing, the mortality of the young animals being higher in the lower strata. To clarify this problem at an adjacent place of the rock, other stations were selected from the supra-tidal zone down to the sub-tidal zone, namely St. 1 was set above the high tide mark, St. 4 below the low tide mark and the other two, Sts. 2 and 3 at the middle part of the distributing zone, the former is under but near the high tide mark and the latter above but near the low tide mark. At these stations the mortality of the barnacle was examined and the results were as follows (Fig. 3) :

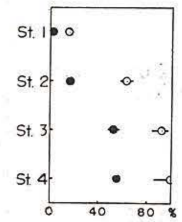

Fig. 3. The mortality of the first year barnacle (solid circle) and of the barnacle older than two years (open circle), with the confidence interval in 60 per cent reliability.

At St. 1 the mortality of the first year barnacles was only about three per cent of the attached first year individuals, but at St 4. it was remarkably large being 56 per cent. As for the barnacles older than two years, though at St. 1 the mortality is still low having the value of about 16 per cent, at St. 4 it is very high attaining to 100 per cent of the attached animals.

From the above the mortality is low at the upper half of the distributing zone, but increases downwards to 100 per cent at the sub-tidal zone, and here it is noteworthy that the mortality increases suddenly near the low tide mark.

It may be conclusively said that the vertical change of the age distribution in the barnacle zone should depend upon the difference of the environmental conditions which have influences on the growing of the barnacle.

2. *The Density Effect to the Individual Shell Growth.*

In the present observation it was ascertained that the population density changes from the supra-tidal zone downwards to the sub-tidal zone being high at the middle part, but low at the lower part.

Table 1
Changes of the dimensional characters of *Chthamalus challengeri* in relation to time and space

Contact-density	St. A	1<2=3=4=5=6	1st year stage	A<B<C>D>E
	B	1=2<3=4=5=6	2nd	A<B<C>D>E
	C	1≦2=3=4=5=6	3rd	A<B<C>D
	D	1<2=3	4th	A<B<C
	E	1=2	5th	A<B<C
			6th	A<B<C
Length of opercular portion	St. A	1<2<3<4=5<6	1st year stage	A<B>C>D>E
	B	1<2<3=4=5<6	2nd	A<B=C>D>E
	C	1<2<3<4<5<6	3rd	A<B>C=D
	D	1<2<3	4th	A=B>C
	E	1<2	5th	A=B>C
			6th	A=B>C
Breadth of opercular portion	St. A	1≦2<3<4=5<6	1st year stage	A>B>C=D=E
	B	1<2<3<4=5<6	2nd	A<B>C>D>E
	C	1<2<3<4<5=6	3rd	A<B>C>D
	D	1<2<3	4th	A<B>C
	E	1<2	5th	A<B>C
			6th	A<B>C
Size of opercular portion	St. A	1<2<3<4=5<6	1st year stage	A>B>C=D>E
	B	1<2<3<4≦5=6	2nd	A=B=C>D>E
	C	1<2<3=4=5=6	3rd	A=B>C=D
	D	1<2<3	4th	A=B>C
	E	1<2	5th	A=B>C
			6th	A=B>C
Length of shell base	St. A	1<2<3=4<5<6	1st year stage	A>B>C=D<E
	B	1<2<3=4=5=6	2nd	A=B>C<D=E
	C	1<2=3=4>5>6	3rd	A=B>C<D
	D	1<2<3	4th	A=B>C
	E	1<2	5th	A>B>C
			6th	A>B>C
Breadth of shell base	St. A	1<2<3<4=5=6	1st year stage	A>B=C<D<E
	B	1<2<3=4=5=6	2nd	A>B>C<D<E
	C	1<2=3=4=5=6	3rd	A>B>C<D
	D	1<2=3	4th	A>B>C
	E	1<2	5th	A>B>C
			6th	A>B>C
Size of shell base	St. A	1<2<3<4<5=6	1st year stage	A>B>C<D<E
	B	1<2<3<4=5=6	2nd	A>B>C<D<E
	C	1<2=3=4>5>6	3rd	A>B>C<D
	D	1<2<3	4th	A>B>C
	E	1<2	5th	A>B>C
			6th	A>B>C
Shell height	St. A	1<2=3=4=5=6	1st year stage	A>B≦C=D>E
	B	1<2<3<4<5<6	2nd	A<B<C>D>E
	C	1<2<3<4<5<6	3rd	A<B<C>D
	D	1<2<3	4th	A<B<C
	E	1<2	5th	A<B<C
			6th	A<B<C

Arabic numerals in the 3rd column represent respectively the shell age, alphabetical letters in the 5th column represent symbols of five stations.

As is obvious in the previous reports done by many authors (Utinomi 1943, Barnes and Powell 1950, Katô et al. 1960) the shell shape changes from the conical form among the sparsely distributed population to the cylindrical form among the densely aggregated one.

Now, the density effect to the individual shell growth should appear in such a stratum as the population density is high but the mortality is low, and moreover this effect may be strengthened with the advance of the shell age.

Taking the above mentioned phenomena into consideration the population dynamics of the barnacle was investigated with regard to the morphological variation occurring in each stratum of the distributing zone.

The contact-density, which was named in the previous paper for the number of shells being in contact with the examined shell (Katô et al. 1960), was first studied. Then the dimensional characters were measured using the individuals obtained from each stratum and also from each stage, namely the population dynamics relating to space and time were analysed statistically. The results are arranged in Table 1.

(1) The contact density.

At Sts. A, B and C the contact-density does not increase with the advance of the age, but between the first and the second year stages a significant difference is recognized, being higher in the second than the first year stage. The fact is the same in St. D, but no barnacle older than the fourth year stage appears. At St. E, first and second year stages are not different in their contact-densities.

On the other hand, the contact-density is always highest at St. C and decreases upwards attaining to the lowest at St. A, the uppermost strata, and also downwards to the lowermost strata.

(2) The dimensional character in the shell growth.

Judging from the previous work (Katô et al. 1960), the above mentioned contact-density should be in close connection with the morphological variation of the shell in space and time.

In Table 1 the growth gradient and also the spacial gradient with regard to the shell age are schematically shown.

It is generally said that the opercular portion of the shell grows with the advance of the age in each station, but at the lower part of the distributing zone the growing tends to stop in the earlier stage than that at the upper part.

With regard to the distributing stratum, the opercular portion is always small in size at the lowermost stratum and the size difference of the opercular portion are inclined to decrease with the advance of the age.

The growth form of the shell base differs from that of the opercular portion. In each station the shell base is smallest in size in the first year stage. Though the base size continues to grow till the sixth year stage in Sts. A and B, in St. C the growing is not so remarkably and soon stops, and reversely in the fifth and sixth year stage the size becomes small. On the other hand, in every stage, the size is small at St. C.

The shell height increases with its age, but its growth rate decreases from the lower stratum to the upper one, being remarkably large in St. C.

It is here also noted that the shell is highest at St. C throughout all stages and therefore the spacial gradient of the shell height is recognized being the highest center at St. C.

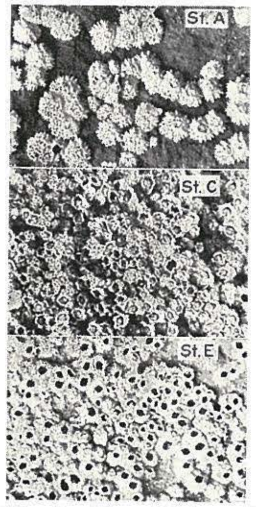

Fig. 4. The settled condition of barnacles in each of examined stations.

As is understood from the above, it is noticeable that the spacial gradient recognized in the size of the shell base is antagonistic to it in the shell height and that this fact should be introduced by the already mentioned spacial gradient in the contact-density.

3. *Constitutional Characters of the Stratification in the Distributing Zone.*

It has been alluded to that the constitutional characters of a given population may be defined by the so-called heterogeneity index or the denseness and sparseness index.

In the following the statistical treatment using this index was done with regard to the second, fourth and sixth year stages and to Sts. A, C and E (Fig. 4).

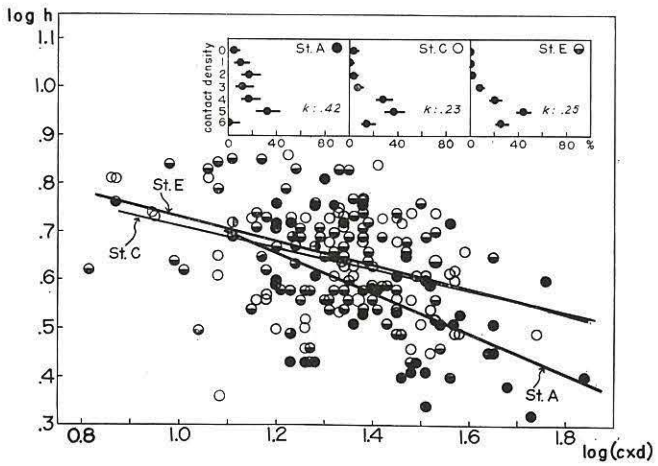

Fig. 5. Relation between the shell height (h) and the size of the shell base (c×d) in the case of the second year stage.

If the logarithmic value of the shell height is plotted against the logarithmic value of the size of the shell base, the expression, log H+k log A=K, is obtained, and thus the population dynamics may be analysed by the value of constant k.

(1) The second year stage (Fig. 5).

The so-called contact-density is the highest in St. C and lowest in St. A (Table 1). and judging from the frequency distribution of the contact-density it is found that the shell distributes 'rather uniformly and densely in Sts. C and E, but heterogeneously and thinly in St. A where the heterogeneity index is 0.42, while it is low in St. C or E, being respectively 0.23 or 0.25.

From the above mentioned fact that the size of the shell base is generally larger in St. A than C or E and the relation in the case of the shell height is the reverse (Table 1), it is recognized that the modification of the shell shape and size introduced by the density occurs uniformly and stronlgy in Sts. C and E, but heterogeneously and weakly in St. A.

(2) The fourth year stage of the barnacle (Fig. 6).

The contact-density is not different statistically from the second year stage (Table 1 and Fig. 6). In St. E the mortality of young animals is very high and thus no fourth year stage barnacle appears.

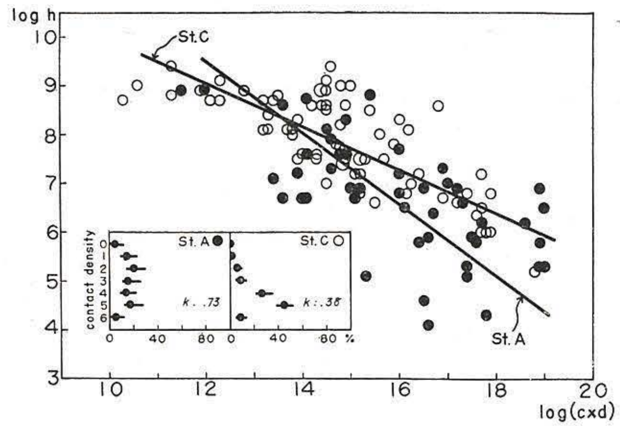

Fig. 6. Relation between the shell height (h) and the size of the shell base (c×d) in the case of the fourth year stage.

The heterogeneity index is larger than that of the second year stage in both of Sts. A and C, being 0.73 in the former and 0.38 in the latter.

It is very interesting that, though the contact-density in Sts. A and C is respectively similar to that in the second year stage, the heterogeneity index increases distinctly, especially in St. A.

It may be said that this phenomenon is caused by the increasing of the inter-relation among individual shells with the advance of age, namely with the growth of shells, and therefore the modification of shell size and shape is strengthened in the densely colonized portion of the examined population, while it is not so strong in other portions.

That the modification of shell size and shape is remarkable, especially in St. A, is easily known from the frequency distribution of the contact-density which differs distinctly from it in St. C.

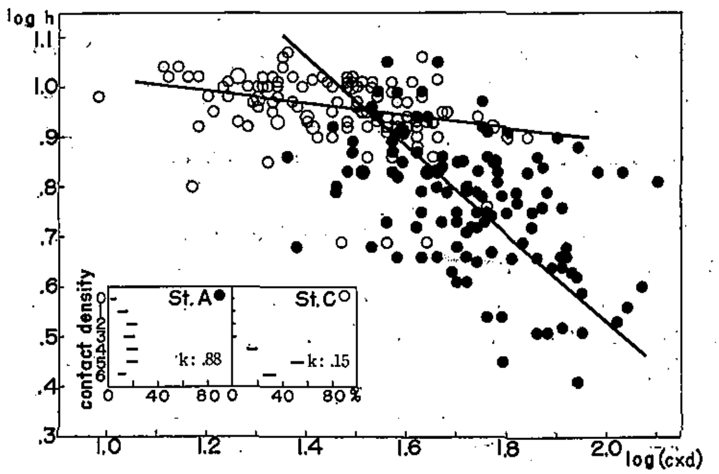

Fig. 7. Relation between the shell height (h) and the size of the shell base (c×d) in the case of the sixth year stage.

(3) The sixth year stage of the barnacle (Fig. 7).

The contact-density is not still significantly different from the former second and fourth year old stages. But it is recognized remarkably that the heterogeneity index is very large in St. A, while it becomes small in St. C, being 0.88 in St. A and 0.15 in St. C. The present fact may happened from the following phenomenon. Namely, in the colonized portion of St. A the individual growth is influenced markedly by the contact of other shells, but in the sparsely sessiled portion the individual barnacles grow typically being independent of other individuals. On the contrary, in St. C, as the initial population density is high comparing with St. A, the division of densely distributed portion and sparsely populated portion becomes eliminated with the progress of individual growth, and the result may be that all of the individuals become to grow under similar interrelationship and therefore the population consisting of equally grown individuals should be formed.

It should be therefore obvious that the conical and cylindrical shells distribute heterogeneously at St. A, but in St. C the shell shape is all uniformly cylindrical owing to the remarkable inter-relationship because the shells are closely in contact with each other.

From the above it may be concluded that the characteristic appearance of *Chthamalus* shell size and shape found in each stratum of the distributing zone should depend upon the characters of each stratum with regard to the initially sessiled population density, the degree of the mortality during the course of the shell growth and the dynamics of the inter-relation among the individuals which are in contact with each other.

SUMMARY

1. In the present paper, the constitutional characters of the *Chthamalus* population was analysed with special reference to the vertically stratified distributing zone.

2. The initial density of sessiled barnacles and the mortality in each stage of barnacle are characteristic to each stratum of the distributing zone and therefore the characteristic age distribution appears respectively.

3. The growth form, that is the morphological variation of the shell shape and size occurring with the advance of the age, is also characteristic to each stratum being introduced by the population density.

4. From the view-point of the pouplation ecology the constitutional characters of each stratum was analysed with regard to space and time using the expression, log H+k log A=K, advocated by the present writers.

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