Estimation on Mortality of Tropical Limpet *Cellana testudinaria* (Class: Gastropoda, Family : Patellidae) Living on the Rocky Shore of Ohoiwait, Southeast Moluccas, Indonesia

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Abstrak

Sebanyak 2402 ekor limpet diperoleh dari 12 bulan pengambilan sampel yakni dari Oktober 2001 sampai September 2002. Rata-rata mortalitas limpet C. testudinaria diestimasi dengan mempergunakan tiga metoda yang berbeda dengan hasil adalah sebesar 94% per tahun (Z = 2.81). Mortalitas terbesar yang dilakukan dengan menggunakan pendekatan metoda Ault-Ehrhardt dijumpai pada bulan Oktober 2001 dan April 2002, dimana terjadi kekeringan dan hempasan gelombang yang terbesar. Akan tetapi tidak ada korelasi yang jelas antara mortalitas dan faktor-faktor lingkungan.

Kata kunci: *Limpet daerah tropik, Cellana testudinaria, mortalitas*

Abstract

A total of 2402 limpets were obtained in 12 monthly collections (from October 2001 to September 2002). The mean mortality of C. testudinaria was estimated, using three different methods; reduction in the survival of individual size frequency cohorts through time, monthly calculation of the Ault and Ehrhardt moment estimation, and length-converted catch curves, to be 94% per year (Z = 2.81). Highest monthly mortality rates, determined with the Ault-Ehrhardt approach, were observed in October 2001 and April 2002, when desiccation stress (temperature of the rocky surface was about 40°C) and wave action (was about 3 m), respectively, were highest. However, there was no significant linear correlation between mortality and environmental variables.

Key words: *Tropical limpet, Cellana testudinaria, mortality*

Introduction

The determination of the mortality of a species is a fundamental requirement for any analysis of the structure and dynamics of biological communities (Ebert, 1973; Van Sickle, 1977; Underwood, 1979; Creese, 1981; den Boer, 1981; Fletcher, 1984; Takada, 1997). For many years, ecologists believed that it is impossible to have a better understanding of population dynamic of species without knowing a theoretical mortality model for a population (Underwood, 1975; Van Sickle, 1977; Fletcher, 1987). Admittedly only after some years, it became evident that mortality is a vital parameter in analysing the community structures of population.

Many studies have investigated the mortality rate of limpet species, often under different environmental conditions, relating any variations found to differences in their respective regimes of selection. Many authors mention the presence of mortality caused by natural influences, such as heavy storms, strong wave action, and extreme high or low temperatures; these effects are sometimes observed in limpets during their life stage as planktonic larva, juvenile, and adult individuals (Lewis & Bowman, 1975; Blankley & Branch, 1985; Fletcher, 1987). Catastrophic limpet mortality due to temperature extremes in relation to desiccation has been noted in the high intertidal on particularly stressful days (Orton, 1933; Frank, 1965; Sutherland, 1970; Wolcott, 1973). Little mortality is found at high levels on the shore, although occasional "catastrophic" mortality may occur (Creese, 1980b). In addition, sublethal levels of desiccation may be responsible for making limpets more susceptible to predation because of the decreasing of their tenacity (Lewis, 1954; Frank, 1965; Breen, 1972). Such studies on intertidal limpets, have also found that marked inter- and intraspecific variations in the population communities strongly influence mortality rate of species (Sutherland, 1970; Lewis & Bowman, 1975; Choat, 1977; Thompson, 1980; Creese, 1980a, Workman, 1983; Fletcher, 1984). The importance of the spreading of the risk of

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extinction species over differently fluctuating subpopulations is demonstrated by analysing the density of population in which mortality influences upon them (den Boer, 1981). Workman (1983) investigated two populations of Patella vulgata and found that the rates of mortality between the two populations differed although the reproductive effort of the two populations was similar. He concluded that the influences of the environment on the time of fecundity of individuals from different two places must have been different.

In order to establish a basis for the later more extensive mortality analysis, the general variation of limpet's density of C. testudinaria throughout the sampling period was studied. Therefore in some cases the environmental variables influencing the mortality should also be included. In this study three different methods in estimating mortality rate were carried out.

Materials and Methods

Study site

The study was carried out on the intertidal rocky shore of Ohoiwait (latitude 5°45'15" S, longitude 132°57'20" E), Big Kai Island, Southeast Mollucas, Indonesia (Fig. 1). The intertidal region investigated is about 0.25 km2 (1 km long and 0.25 km wide). Thus, it is small enough that atmospheric conditions may be assumed, for most purposes, to be uniform over the whole area. The shore consisted of shingles, pebbles, medium and big boulders. The physical conditions in the tidal zones are quite different; the higher shore is wetted almost exclusively by tidal sea level rise, but the lower shore receives considerable wave action.

Sampling

As pure random sampling was not feasible due to pronounced environmental heterogeneity within the shore levels, a systematic sampling design was chosen. At each shore level, 6 sampling squares (1 m^2), 25 m apart, were installed along a line parallel to the shoreline. Hence, a total of 18 permanent quadrates were placed between the EHWST (Extreme High Water Spring Tide) and the water edge, the first square being randomly defined. Heights of the quadrates above ELWST (Extreme Low Water Spring Tide) and the distances between quadrates were calculated from the profiles obtained.

In each quadrate, adults (> 25 mm), juveniles (> 10 mm and < 25 mm), and recruits (< 10 mm) were collected by hand picking or dug out with a spade. Sampled specimens were counted. Most of C. testudinaria live attached to the surface of the substratum, although some of them were also found hiding below the boulders, pebbles, and shingles. Rocks lying within the quadrates, which were movable, were turned over and removed down to bedrock, and the undersides of rocks were searched as far as possible, so that concealed limpets were included in the count. Loose small gravel, a habitat sometimes favoured by small individuals, was also carefully searched. Sampling on juveniles and adults was conducted monthly during low tide and continued until the samples represent the most complete series of data, which were about 1 year, so that all settled individuals are represented in accordance with their relative frequency in the population.

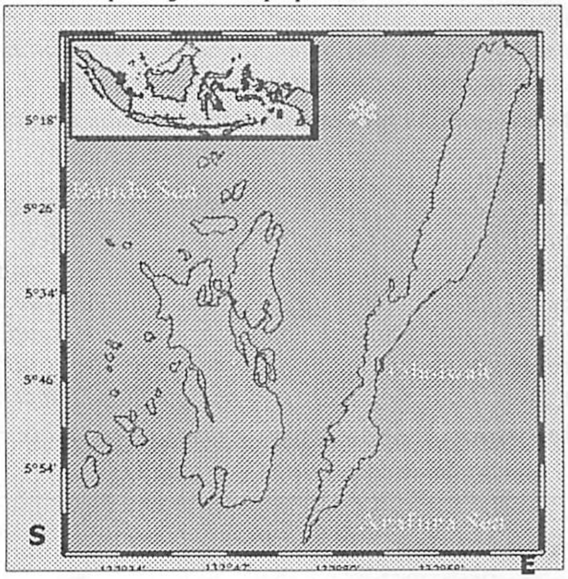

Figure 1. Map of study site of Ohoiwait located at the Big Kai Island.

Analysis

Simulating the fluctuation pattern of population density, three different methods were applied to have direct estimating of mortality rates:

1. Reduction in the survival of individual size frequency cohorts through time. The estimate of mortality rates was based on the monthly survival number of individuals, derived from the size frequency of cohorts. This method helps to provide an optimal fit to a size-frequency histogram, and then survival curves of those organisms were estimated. The efficacy of this method is that if the recruitments occur several times along the year, then it is difficult to differentiate the mode of polymodal curves. The

survival curve of C. testudinaria was constructed by following the cohorts recruited during the period of sampling. The periods used to estimate the rates of mortality were deliberately chosen to correspond to periods when numbers in a particular cohort decreased in an approximately logarithmic way.

2. Monthly calculation of the Ault and Ehrhardt moment estimate of mortality (Ault & Ehrhardt, 1991). This model does not assume an infinite life span for the animal of the stock being analysed and thus is applicable to short-lived tropical species (Sparre & Venema, 1998). The formula is:

$$[(L_{\infty} - L_{max})/(L_x - L_c)]^{ZK} = [Z(L_c - L_x) + K(L_{\infty} - L_x)]/[Z(L_{max} - L_x) + K(L_{\infty} - L_x)]$$

where Z is the instantaneous rate of mortality, L_{∞} and K are growth parameters, L_{max} is the maximum length or the largest limpet in the sample, L_x is the mean length of limpet in a sample representing a steady-state population, L_c is the cut-off length or the lower limit of the smallest length class included in the computation (< 8.5 mm). This equation uses the fact that the size frequency distribution of a population is the result of previous growth, mortality, and recruitment (Ebert, 1973).

3. Length-converted catch curves. This method was developed by Sparre & Venema (1998) under the computer program FiSAT. The mortalities can be estimated directly from observed size-frequency curves in which individual growth rates are changing with body size, as discussed by Ricker (1958), and growth data without explicitly determining the population's age distribution (Van Sickle, 1977) with the assumptions that the population should fulfil the required stationary or steady-state and of time-invariance in growth and mortality rates (Smith, 1972).

Results and Discussion

Reduction in the survival of cohorts

Estimations of seasonal and annual mortalities for C. testudinaria populations were quantitatively calculated. Logarithms of survival individuals in each cohort (Log_{10} N) were plotted against time (month) to provide the survivorship curves. This produces a straight-line plot, which suggests that the probabilities of death numbers of limpets were evenly distributed throughout the sampling period. Mortality rates were determined from the slope of the regression line. Three different cohorts of cohorts-A, cohort-B, and cohort-C were chosen, which presumably represent the all cohorts from the 12 months of sampling period.

Cohort-A. Survival curve of this cohort is presented in Figure 2 and summarised in Table 1. Survival limpets decreased rapidly in the first 5 months. A slight increase in individual numbers was observed between December 2001 and January 2002 and from February to April 2002. No clear seasonal trends can be recorded in May 2002. Regression equation is: Log_{10}(individual numbers) = 1.1973 - 0.0699 * Julian date (months), r = 0.65, n = 8. From this equation the mortality rate was calculated to be 85 % per year (Z = 1.93).

Cohort-B. Survival curve of this cohort is presented in Figure 3 and summarised in Table 2. The numbers of survival decrease slightly and almost linear throughout the period of study, in which 209 individuals marked at the beginning of which only 2 individuals remained after 11 months of sampling. An increase of survival limpets between May and June 2002 was may be partly due to an extended period of recruitment. Regression equation is: Log_{10}[number of individuals] = 2.2755 - 0.1582 x Julian date (months), r = 0.88, n = 11. The mortality rate of this cohort is 98.7 % per year (Z = 4.37).

Cohort-C. Survival curve of this cohort is presented in Figure 4 and summarised in Table 3. This cohort has a much steeper survivorship curve. In the first four months and in the last three months of their life, no dying individuals of limpets were encountered. However, this cohort had relatively great mortality rate in the middle period of their life. The greatest decrease in numbers was found between February and June, in which 67 individuals die during this period. Regression equation is: Log10[number of individuals] = 1.9047 - 0.0816 x Julian date (months), r = 0.64, n = 10. The mortality rate of this cohort is 90 % per year (Z = 2.30).

Ault-Ehrhardt's method

Monthly mortality rates of limpet C. testudinaria are summarised in Table 4 and presented in Figure 5. An average rate of mortality for this species was 91 % per year (Z = 2.46 ± 0.55 of 95 % confidence level), which has been estimated from the mean length of 17.42 ± 1.99 mm and the mean maximum length of 30.32 ± 1.02 mm.

The greatest mortality rate was calculated for October 2001 and April 2002, while the lowest one was in September 2002. Monthly mean mortality rate of 7.7 % per month (Z = 2.58) during the rainy season was higher than 7.4 % per month (Z = 2.17) during the dry season. On the other hand, during the transition (September - November), the mean rate of mortality of 7.5 % per month (Z = 2.30) was lower than 7.8 % per month (Z = 2.8) during the transition (March - May).

Length converted catch curve

Another estimate of the mortality of the limpet C. testudinaria was made from the losses of individuals in the size-classes (Table 5). These animals were separated into size groups in the interval of 1-mm. The length converted catch curve was constructed by plotting relative age of samples (dt) against natural logarithm of individual numbers in each class (ln N/dt), which is presented in Figure 6. The linear regression equation was: $Y = -2.8143 \pm 0.3740 X + 9.5033 \pm 0.3886$. Analysis of variance on this relationship showed that there is a high correlation ($r = -0.96$) and highly significant on linear regression ($F = 243$, $P < 0.05$) (Table 5). The calculated mortality rate was 94 % per year ($Z = 2.81 \pm 0.37$ of 95 % confidence limit).

Despite the problems of data interpretation created by inadequate sampling in the present study, a general pattern of seasonal mortality occurrence of C. testudinaria is suggested for the intertidal rocky shore of Oholwait. Mortality in this limpet species may be divided into juvenile and adult phases as was pointed out by Lewis & Bowman (1975), whereby juvenile mortality is inextricably bound up with recruitment processes, and is complicated by differences between populations at the time of emergence, and also immigration and emigration. A general distinction, however, could not be differentiated since the numbers of juvenile limpets derived from the reduction in their cohort density in the stage of post-larval settlement were unlikely counted due to recruitment occurrence throughout most of the year, and the cause of these juvenile mortalities is not clear (Creese, 1981). Subject to these limitations, the three different methods were considerably used, so that all limpet sizes in their life stage are possible to be included to provide the right estimation.

Mortality rate of C. testudinaria population appeared to be positively related to their density as shown in the reduction of individual size frequency cohorts and length converted catch curve methods, but not to the growth rate (as suggested by Ebert, 1973 and Parry, 1982). This was similar to the most other intra-specific studies of limpets, which have also proved that mortality has a negative correlation with respect to the growth but positively related to the population density (Sutherland, 1970; Underwood, 1976; 1978; Creese, 1980b; Creese & Underwood, 1982; Fletcher, 1984). Similar results in the estimation of mortality rates using these three methods; an average of 91 %, 91 %, and 94 % loss of individuals per year, indicates that these results are realistic and the assumptions behind those methods have been matched. This consideration shows that size-frequency analyses is most applicable to short-lived species (< 5 years, say) with relatively restricted periods of recruitment and rapid enough growth so that age cohorts can be confidently distinguished over long periods of time preferably until they disappear from the population.

It has often been stated that rapid growth is directly related to high mortality rate (Ebert, 1973). Of the species studied here, C. testudinaria grows faster (K = 1.4) and mortality rate was higher (Z = 2.81), thus lives shorter (t_{max} = 2 years). Creese (1981) reported that *Siphonaria virgulata* is the fastest growing limpet that is suffering the greatest mortality, while *Notoacmea petterdi* grows slowest and lives longest (lower mortality).

Many earlier workers have concluded that most adult limpets die of old age, and that longevity is inversely related to the mortality rate (Moore, 1937; Lewis & Bowman, 1975; Thompson, 1980). These observations agree with Ault-Ehrhardt estimation of mortality in the present study; e.g. limpets with shorter maximum length (shorter longevity) have lower mortality than those with longer maximum length (see Table 4). An alternative estimation, therefore, can be gained from this method resulted an approximately maximum longevity of this limpet species of 2 years old.

Catastrophic mortality from either environmental or biological factors, or both, has been documented for several populations of intertidal limpets (Lewis, 1954; Hodgkin, 1960; Frank, 1965; Sutherland, 1970; Creese, 1981; Parry, 1982). I put forward the hypothesis that rate of mortality of C. *testudinaria* is enhanced by environmental conditions. In this study, even though, sources of mortality were not directly determined, it seems to be related to the harsh summer conditions.

Desiccation is generally considered to be an important environmental stress causing mortality of organisms (see review by Branch, 1981). Many tropical gastropods were found dying due to higher desiccation stress (Garrity, 1984), specifically related to limpet species (Evans, 1947; Southward & Orton, 1954; Lowell, 1984).

The mortality of limpets was also found to be higher in April 2002. This is presumably because of strongly breaking waves with an average of 3 m during this period, which may impose large forces on intertidal organisms. A wave breaking on the shore could exert very large impact pressure on the organisms present (Jones & Demetropoulos, 1968; Denny, 1982; 1985). Wave action may also affect a number of factors including desiccation, abrasion, crushing, and the danger of detachment (Branch, 1981; Grenon & Walker, 1981). No attempts have been made to simultaneously quantify the effects of wave actions on the mortality of limpets, but direct field observations found that many organisms have been dislodged from the substratum and sporadically breaking shell due to frequent large wave action along the shore on the period of transition (from March to May).

Mortality is greater at low levels because of increased intra-specific competition, which is a result of greater recruitment to these levels (Creese, 1980b), and overcrowding in a diminished food intake and restricted to a narrow range on the shore (Liu, 1994). In the present study, I could not point out the sources causing mortality on limpet species from the intra-specific competition view, since there were some problems in determining certain factors responsible for it, because lack of ecological parameter measurements.

It is apparent that the present work could good be described as pre-surveillance with an estimated mortality. Since it is impossible to provide really satisfactory results in estimating mortality from available data, summer heat; when air temperature reached an average of 29°C (Tual Meteorology and Geophysics), thus appear to be the major causes of death of limpets.

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Table 1. Summary of survival numbers (SN) of cohort-A together with ANOVA test on the relationship. *df*-degrees of freedom; *SS*-sum of squares; *MS*-mean square.

Time	*SN*
October '01	21
November '01	12
December '01	6
January '02	8
February '02	3
March '02	9
April '02	10
May '02	69
June '02	3
July '02	-
August '02	-
September '02	-

ANOVA				
Sources	*df*	*SS*	*MS*	*F*
Regression	1	0.24	0.24	4.32
Residual	6	0.34	0.06	
Total	7	0.58		

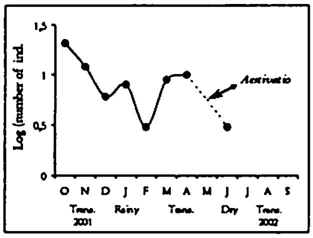

Figure 2. *Cellana testudinaria.* Survival curve of cohort-A. There were 21 individuals at the beginning of which 3 remained after 7 months.

Table 2. Summary of survival numbers (SN) of cohort-B together with ANOVA test on the relationship. *df*-degrees of freedom; *SS*-sum of squares; *MS*-mean square.

Time	*SN*
October '01	209
November '01	132
December '01	45
January '02	44
February '02	18
March '02	11
April '02	15
May '02	5
June '02	27
July '02	9
August '02	2
September '02	-

ANOVA				
Sources	*df*	*SS*	*MS*	*F*
Regression	1	2.75	2.75	32.01
Residual	9	0.77	0.09	
Total	10	3.53		

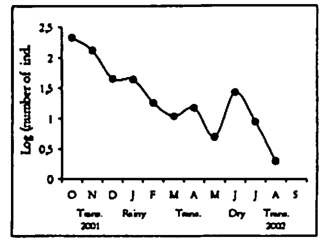

Figure 3. *Cellana testudinaria.* Survival curve of cohort-B. There were 209 individuals at the beginning of which 2 remained after 11 months.

Table 3. Summary of survival numbers (SN) of cohort-C together with ANOVA test on the relationship. *df*-degrees of freedom; *SS*-sum of squares; *MS*-mean square.

Time	*SN*
October '01	-
November '01	55
December '01	51
January '02	52
February '02	71
March '02	24
April '02	55
May '02	14
June '02	4
July '02	18
August '02	26
September '02	-

ANOVA				
Sources	*df*	*SS*	*MS*	*F*
Regression	1	0.55	0.55	5.67
Residual	8	0.77	0.09	
Total	9	1.32		

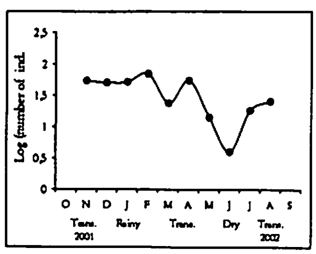

Figure 4. *Cellana testudinaria.* Survival curve of cohort-C. There were 55 individuals at the beginning of which 4 remained after 7 months.

Table 4. Monthly mortality rates of limpet *Cellana testudinaria* based on the Ault-Ehrhardt's equation. L_∞ = 33.08; K = 1.4; Ls = 8.5 mm; L-the mean length (mm); Lmax-the largest limpet in the sample (mm); Z-mortality rate.

Time	*L*	*Lmax*	*Z*
October '01	15.58	29.3	3.40
November '01	16.55	29.3	2.72
December '01	18.74	31.8	1.90
January '02	16.48	30.5	2.87
February '02	16.35	31.6	2.97
March '02	17.34	30.0	2.33
April '02	15.22	29.0	3.67
May '02	17.32	30.5	2.40
June '02	16.81	30.5	2.48
July '02	16.60	30.4	2.79
August '02	19.64	29.1	1.03
September '02	22.40	31.8	0.77

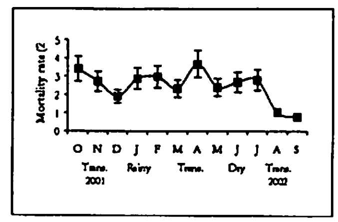

Figure 5. *Cellana testudinaria.* Monthly mortality rates calculated using the Ault-Ehrhardt equation within the population. Vertical lines represent standard deviation (± 1 SD).

Table 5. Calculation of mortality rate of limpet *Cellana testudinaria* based on the length converted catch curve method together with ANOVA on the relationship. N-number of individuals at size class; dt-relative age. *df*-degrees of freedom; *SS*-sum of squares; *MS*-mean square; *CL*-convidence levels.

MidSize	*N*	*dt*	*Ln(N/dt)*
8.50	90	0.302	8.038
9.50	101	0.332	8.112
10.50	134	0.363	8.351
11.50	173	0.395	8.561
12.50	224	0.429	8.772
13.50	297	0.465	9.004
14.50	274	0.502	8.871
15.50	180	0.542	8.396
16.50	163	0.583	8.238
17.50	139	0.628	8.017
18.50	102	0.675	7.641
19.50	70	0.726	7.193
20.50	46	0.781	6.697
21.50	36	0.840	6.369
22.50	37	0.904	6.306
23.50	34	0.975	6.122
24.50	50	1.054	6.397
25.50	65	1.142	6.535
26.50	56	1.243	6.244
27.50	42	1.361	5.791
28.50	30	1.502	5.255
29.50	25	1.678	4.824
30.50	23	1.912	4.407
31.50	11	2.263	3.157

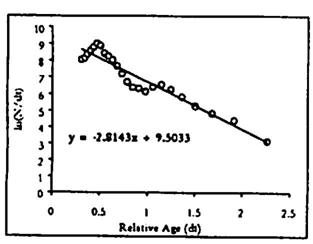

Figure 6. Length converted catch curve of C

ANOVA				
Sources	*df*	*SS*	*MS*	*F*
Regression	1	51.18	51.18	243.37
Residual	22	4.63	0.21	
Total	23	55.81		
Multiple R	-0.96		95 % CL	
Intercept (a)	9.5031		0.3826	
Variable (b)	-2.8140		0.3740	