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Original paper

PRODUCTIVITY OF TROPICAL LIMPET *Cellana testudinaria* (Linnaeus, 1758) LIVING ON THE ROCKY SHORE OF OHOIWAIT, SOUTHEAST MOLUCCAS, INDONESIA

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ABSTRACT

Study on the productivity of tropical limpet C. testudinaria has been carried out at approximately monthly intervals from October 2001 to September 2002. A total of 2404 limpets of 8.2 – 31.8 mm in size were obtained in 12 month collections. The size structure of population presented 6 cohorts with accounting for 48% of the second cohort of the total population. The mean annual population biomass was estimated to be 1013 ± 748 mg AFDW.m^{-2} or 21.8 kJ.m^{-2}, hence the annual population production estimated by the mass specific growth rate method to be 2.81 gr.m^{-2} or 60.7 KJ.m^{-2}.yr^{-1}. The annual biomass turnover ratio (production to biomass ratio, P/B) was 2.77 yr^{-1}. This value of the P/B ratio is higher than those obtained for other limpet species living 2 to 5 years reported by other researchers due to the different featuring of growth parameters such as K = 1.4 yr^{-1} and L_∞ = 33.08 mm resulted for C. testudinaria.

Key words: Productivity, *Cellana testudinaria*, mass specific growth rate method, turnover ratio

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INTRODUCTION

The production of an animal or group of animals (e.g., a population) is the quantity of matter or energy, which is potentially available as food for the next trophic level, i.e. for natural predators or, regarding exploited stocks, for man. Hence, it is that part of an energy budget both the ecologist and the fishery biologist are most interested in.

Production and productivity of a steady-state population are defined by two processes: individual growth and mortality. In terms of the general energy budget production P is defined as that part of the assimilated matter that is turned into body mass (mass per individual per time). In terms of energy flow, it is the change in biomass B with time (mass per area per time). If we relate production P to the biomass B already present, we get an estimate of productivity. Traditionally, benthic ecologist use the production-to-biomass ratio (P/B; per time), which relates production P to the average biomass B present during the period of investigation.

While there is a wealth of information about production and productivity of temperate and polar benthos species, including patellid gastropods (Sutherland, 1972; Picken, 1980; Wright & Hartnoll, 1981; Workman, 1983; Blankley & Branch, 1985), only little is known about tropical limpets. Here, this research provides the first data on production and productivity of *C. testudinaria*.

MATERIALS AND METHODS

Study site

The study was carried out monthly 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**) from October 2001 to September 2002. The intertidal region investigated is about 0.25 km^2 (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 of about 90% of covering substrate. 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.

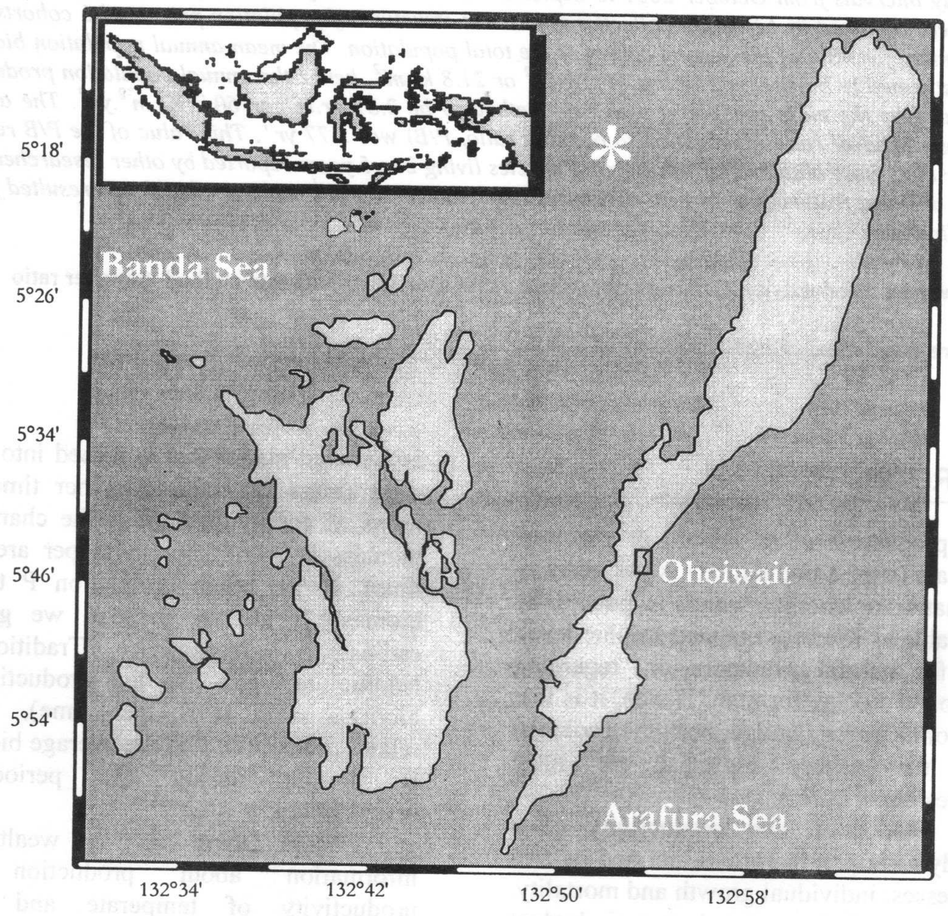

Fig. 1. Study site of Kai Island, Southeast, Mollucas, Indonesia

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Sampling

As pure random sampling was not feasible due to pronounced environmental heterogeneity within the shore, a systematic sampling design was chosen. A total of 36 permanent quadrates were placed between the extreme high water spring tide (EHWST) and the water edge, the first square being randomly defined. Heights of quadrates above extreme low water spring tide (ELWST) and the distances between quadrates were calculated from the profile obtained.

In each quadrate, specimens were collected by hand picking or dug out with a spade, and the shells were cleaned from the material covered. Samples were then counted and measured for their shell length using vernier caliper to the nearest 0.1 mm, while their total body wet weight were weighed using an analytical balance to the nearest 0.01 g, as this allowed limpets to be measured *in situ* on the shore. In some cases, the juvenile limpets could not be dug out because of their soft and brittle shell.

Investigations of the smallest juvenile limpets during recruitment process should consider the relative roles of initial settlement pattern and differential post-settlement size. In some cases, the larger initial size of 8 mm in length of recruits and conspicuous animals was considered, which may be attached or stationary on the substratum (Thorson, 1950; Mileikovsky, 1975). Consequently, more precise information on the limpet size of smaller animals than 8 mm was difficult to be had. These were done by searching regularly and intensively for the presence of juveniles smaller than 8 mm.

Analyses

The Mass Specific Growth Rate Method (MSGRM) was used to estimate the production and productivity of *C. testudinaria* (Brey, 2003). From the definition of the (instantaneous) Mass Specific Growth Rate of an individual, $G_{M.t} = (1/M_t) * dM/dt$, it is obvious that there can compute its production as $P_{ind.t} = dM/dt = G_{M.t} * M_t$. To apply this principle to a population, the following data are required:

(1) *A size-frequency sample of the population (N_j).* It should represent the true size distribution, i.e. the individuals should be taken randomly from the population and the overall number taken should be sufficiently high; therefore, it is usually obtained by pooling several samples taken at different times during the observation period.

(2) *The average body mass (M_j) per size class j.* Provided by applying the size-mass relation: $M_j = a * L_j^{\ b} = 0.03236 * L^{2.7703}$ (see Khouw, 2002).

(3) *The mass specific growth rate ($G_{M.j}$) per size class j.* Computed by combining the 1st derivative of the von Bertalanffy length growth function (featuring the parameter $K = 1.4\ yr^{-1}$ and $L_\infty = 33.08$ mm; see Khouw, 2002) and the parameter *b* (= 2.7703) of the size-mass relation: $G_{M.j} = b * K * [(L_\infty/L_j) - 1]$.

The individual production in size class j is computed by $P_{ind.j} = G_{M.j} * M_j$, and the production of a size class j is computed by $P = \Sigma P_j$; $j = (1, 2, 3, \ldots m)$ for m size classes. The production-to-biomass ratio (*P/B*) is computed by dividing production *P* by the corresponding average biomass *B* of the observation period.

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RESULTS AND DISCUSSION

1. Results

The 2402 collected specimens ranged in length from 8.2 to 31.8 mm with an average of 16.22 ± 5.26 mm. Their total body wet weight varied between 0.11 and 4.93 g with an average of 0.55 ± 0.70 g. The size class structure of the population was studied through the analysis of percentage size frequency distribution (**Fig. 2**). The overall specimen sizes represented 6 cohorts. The first cohort consists of juvenile limpets with an average length of < 10.5 mm, representing 13 % of the total population. The second cohort encompasses the limpets with lengths of 10.5 – 15.5 mm, accounting for 48 % of the total population. This sub-population generally presents the group of limpets with the highest growth rates (Russell, 1909). The remaining cohorts consist of limpets with an average length of 15.5 – 20.5 mm, 20.5 – 25.5 mm, 25.5 – 30.5 mm, and > 30.5 mm, accounting for 22 %, 9 %, 7 %, and 1 % of the total population, respectively. Specimens > 25.5 mm are considered to be mature. This is the common length of *Cellana* sp. (Balaparameswara Rao, 1973). The power regression equation of the relationship between shell length and total body wet weight for the whole period of study was $W = 0.0002343 \; L^{2.6601}$ hence the relationship equation between ash-free body weight (mg AFDW) and total body wet weight (mg WW) was $M_j = 0.03236 * L^{2.7703}$ (see also Khouw, 2002).

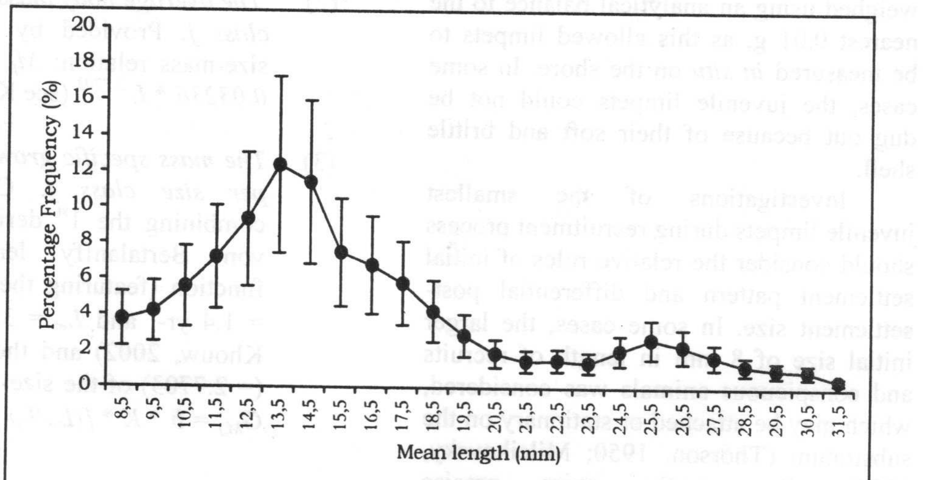

Fig. 2. Mean percentage frequency distribution of each size class category of *Cellana testudinaria*. Vertical lines represent standard deviation (SD).

Mean annual density (*D*), mean annual standing crop or population biomass (*B*) and annual production (*P*) were calculated to be 11.12 ind.m^{-2}, 1.01 g AFDW.m^{-2} (21.8 kJ.m^{-2}), and 2.81 g AFDW.m^{-2}.yr^{-1} (60.7 kJ.m^{-2}.yr^{-1}), respectively (Table 1). Thus, the annual biomass turnover ratio (production to biomass *P/B*) was 2.77. Overall, distinct peaks of annual production and mean annual biomass were identified for limpets with shell lengths of 13.5 mm and 25.5 mm (**Fig. 3**).

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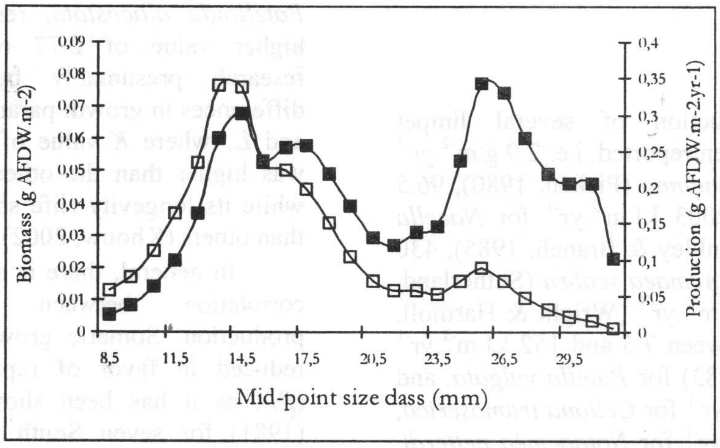

Fig. 3. Mean annual biomass (■) and annua population production of *Cellana testudinaria* (□) of each size class.

Table 1. Calculation of annual production of *Cellana testudinaria* by the mass specific growth rate method. Annual production based on sets of samples from October '01 to September '02, where N_j abundance per size class (ind.m^{-2}); M_j the average body mass per size class j (in g AFDW); $G_{M,j}$ the mass specific growth rate per size class j (in yr^{-1}); Bj standing crop or population biomass per size class j (in g AFDW.m^{-2}); P annual production (in g AFDW.m^{-2}.yr^{-1}).

Mid-class interval	N_j	M_j	$G_{M,j}$	B_j $(N_j * M_j)$	P $(B_j * G_j)$
8.5	0.42	0.012	11.215	0.005	0.0573
9.5	0.47	0.017	9.627	0.008	0.0749
10.5	0.62	0.022	8.340	0.014	0.1129
11.5	0.80	0.028	7.278	0.022	0.1635
12.5	1.04	0.035	6.385	0.037	0.2350
13.5	1.38	0.044	5.625	0.060	0.3400
14.5	1.27	0.053	4.970	0.068	0.3370
15.5	0.83	0.064	4.399	0.053	0.2345
16.5	0.75	0.076	3.897	0.057	0.2232
17.5	0.64	0.090	3.453	0.058	0.1986
18.5	0.47	0.105	3.057	0.049	0.1506
19.5	0.32	0.121	2.701	0.039	0.1048
20.5	0.21	0.139	2.380	0.029	0.0696
21.5	0.17	0.159	2.089	0.027	0.0565
22.5	0.17	0.180	1.824	0.031	0.0559
23.5	0.16	0.203	1.581	0.033	0.0515
24.5	0.23	0.228	1.358	0.053	0.0713
25.5	0.30	0.255	1.153	0.077	0.0882
26.5	0.26	0.284	0.963	0.074	0.0710
27.5	0.19	0.314	0.787	0.060	0.0470
28.5	0.14	0.347	0.623	0.049	0.0303
29.5	0.12	0.382	0.471	0.046	0.0216
30.5	0.11	0.419	0.328	0.046	0.0151
31.5	0.05	0.458	0.195	0.023	0.0045
Total	***11.12***			***1.013***	***2.8148***

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2. Discussion

Production

Annual production of several limpet species has been reported, i.e. 2.9 g.m^{-2}.yr^{-1} for *Nacella concinna* (Picken, 1980), 96.5 g.m^{-2}.yr^{-1} or 2003 kJ.m^{-2}.yr^{-1} for *Nacella delesserti* (Blankley & Branch, 1985), 430 kJ.m^{-2}.yr^{-1} for *Acmaea scabra* (Sutherland, 1972), 163 kJ.m^{-2}.yr^{-1} (Wright & Hartnoll, 1981) and between 7.5 and 152 kJ.m^{-2}.yr^{-1} (Workman, 1983) for *Patella vulgata*, and 1045.5 kJ.m^{-2}.yr^{-1} for *Cellana tramoserica*, 1514.1 kJ.m^{-2}.yr^{-1} for *Notoacmea petterdi*, and 196.7 kJ.m^{-2}.yr^{-1} for *Patelloida alticostata* (Parry, 1982). The considerably lower estimate of annual production obtained for *C. testudinarai* in the present study (2.81 g AFDW.m^{-2}.yr^{-1} or 60.7 kJ.m^{-2}.yr^{-1}) is a reflection of relatively low densities of this limpet species.

The P:B ratio of 2.77 of *C. testudinaria* is higher than those obtained for other limpet species living 2 to 5 years, e.g., those reported by Sutherland (1972) for *Acmae scabra* (1.58), Branch (1975) for *Patella oculus* (1.55), Robertson (1979) for *Siphonaria diemenensis* (1.23). For limpets with longevities of 6 to 15 years, Robertson (1979) obtained the P:B ratios of 0.83, 0.63 and 0.66 for *Cellana tramoserica*, *Notoacmea petterdi* and *Patelloida alticostata*, respectively. This higher value of 2.77 resulted in this research presumably because of the differences in growth parameters such as K and L_∞, where K value of *C. testudinaria* was higher than the other limpet species while its longevity (life span) was shorter than others (Khouw, 2002).

In general, there is a strong positive correlation between growth and production. Somatic growth (P_g) can be reduced in favor of reproductive effort (P_r), as it has been showed by Branch (1981) for seven South African *Patella* species. However, overall the growth rate was positively correlated with the reproductive effort. This implies that although energy may be diverted from P_g to P_r (or *vice versa*) when food is short, in general species have "strategies" of high or low turnover (Branch, 1981). This is reflected in the significant negative correlation of the productivity (P:B) and longevity (Robertson, 1979; Branch, 1981). Pattern of low or high turnover in different invertebrate species, and the position of *C. testudinaria* are shown in **Fig. 4**. It shows that *C. testudinaria* has a productivity that is substantially greater than that of other limpet species, which is primarily a function of its high growth rate (Robertson, 1979).

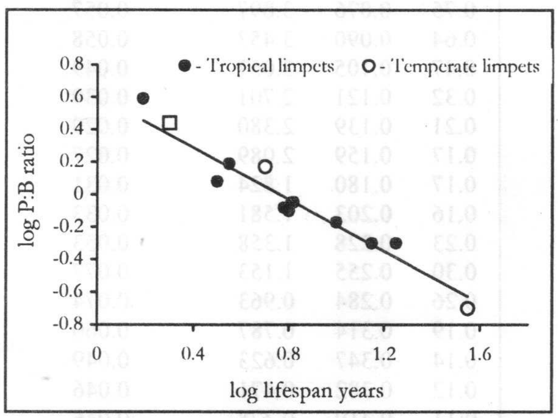

Fig. 4. Relationship between log (P:B) and log (lifespan) for 11 species of limpet including *Cellana testudinaria* (□) (after Branch, 1981). *A*, *Acmaea scabra* (Sutherland, 1972); *B*, *Patelloida alticostata* (Robertson, 1979).

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Energy content

The assessment of the energy content calculated for the limpet *C. testudinaria*, gives a value of 21.59 $kJ.g^{-1}$ AFDW. This value was considerably higher than that of many temperate limpet species, such as *Patella vulgata* (19.3 $kJ.g^{-1}$ AFDW) (Workman, 1983), and *Nacella delesserti* (20 $kJ.g^{-1}$) (Blankley & Branch, 1985), but eventually similar to the tropical limpet species such as *Cellana tramoserica* (22.59 $kJ.g^{-1}$), *Notoacmaea petterdi* (21.63 $kJ.g^{-1}$), *Patella peroni* (22.30 $kJ.g^{-1}$), and *Patelloida alticostata* (22.93 $kJ.g^{-1}$) (Parry, 1982). It is known that the quantity and quality of energy content of soft tissue differ among limpet species living at different shore levels (Paine, 1971), or at neighbouring sites (Hughes, 1971), or even in the same area according to seasonal variation in food availability (Blankley & Branch, 1985).

Seasonal changes in the calorific value of the soft tissues of *C. testudinaria* were probably due to changes in the proportion of lipids (energy storage). The relationship between somatic calorific value and gonad index (**Fig. 5**) suggests that lipid is stored in the soft tissues (somatic and gonadal tissues) during the gonad-resting phase and then transferred to the gonad during gametogenesis. In September, however, the maximum of the energy content in the limpets' soft tissues coincided with a decrease in the mean gonad condition index, suggesting a utilization of lipid stocks at times of spawning in August. The lower calorific values of soft tissue of immature limpets suggests that an energetic advantage is gained by building a growing individual initially out of "cheap" material until it is capable of making a genetic contribution to the population (Paine, 1971).

A variety of factors control the condition and its energy content of limpets. There are environmental factors (temperature, desiccation, waves) exerting physical stress, as well as biotic factors, such as sex, age and stage of maturity, stomach contents and others (Pauly, 1984; King, 1995). Wright & Hartnoll (1981) recorded that lower total soft-body dry weight of *Patella vulgata* in March each year are a result of both reduced feeding activity during winter and the release of gametes which comprise a greater proportion of the total soft-body weight with increasing overall size. Unfortunately, analyses of these factors were not included in this study because of the limited of equipments and time.

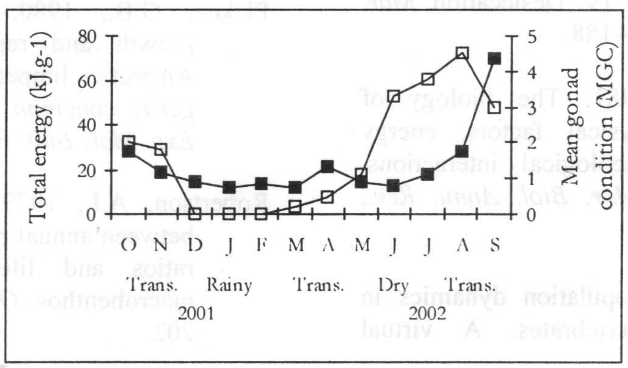

Fig. 5. The relationship between somatic calorific value and gonad index of *cellana testudinaria*.
Monthly total energy values (■)
and mean gonad condition (MGC) indices (□).

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