SHELL DIMENSION-LIVE WEIGHT RELATIONSHIPS,
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ATOLL RESEARCH BULLETIN

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Atoll Research Bulletin No. 604 ♦ 23 July 2014

Smithsonian Institution
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Published by SMITHSONIAN INSTITUTION SCHOLARLY PRESS
P.O. Box 37012, MRC 957
Washington, D.C. 20013-7012
www.scholarlypress.si.edu

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ISSN: 0077-5630 (online)

SHELL DIMENSION–LIVE WEIGHT RELATIONSHIPS, GROWTH AND SURVIVAL OF *HIPPOPUS PORCELLANUS* IN TUBBATAHA REEFS NATURAL PARK, PHILIPPINES

ROGER G. DOLOROSA¹, SEGUNDO F. CONALES², and NOEL A. BUNDAL²

ABSTRACT

Hippopus porcellanus is a rare and heavily exploited giant clam species with limited distribution range in the Indo-West Pacific Region. Overharvesting has resulted in the localized extinction of *H. porcellanus* in the Philippines, but its populations appeared to have recovered in Tubbataha Reefs Natural Park (TRNP) after more than 20 years of protection. As one of the least studied giant clam species, the shell dimension-live weight relationships were determined. In addition, the growth parameters of *H. porcellanus* in TRNP were monitored with the mark–recapture method. All three shell dimensions of *H. porcellanus* were good estimators of live weight. The von Bertalanffy growth parameters K (0.29) and L_{∞} (29.24 cm) were determined on the basis of 80 marked individuals recaptured twice within 2.5 years. Nearly 90% of marked clams survived at the end of the study. Studies on aspects of biology of other giant clams species at the park is suggested.

Keywords: Giant clam, growth, *Hippopus porcellanus*, mark–recapture, survival, Tubbataha Reefs Natural Park

INTRODUCTION

Giant clams (Cardiidae: Tridacninae), with only 11 extant species (Othman et al., 2010; Su et al., 2014) worldwide, are the largest living bivalves that for centuries have been utilized as food and their shells as ornaments. However, excessive harvesting of these clams for external trade has led to local extinctions of several species in the Philippines, Micronesia, Singapore and Indonesia (see Tan and Zulfigar, 2003; Gomez and Mingoa-Licuanan, 2006; Othman et al., 2010; Neo and Todd, 2013). All giant clams are listed in Appendix II of the Convention on International Trade in Enganged Species of Wild Fauna and Flora (CITES, 2014).

Hippopus porcellanus and the newly discovered three giant clam species *Tridacna costata*, *Tridacna rosewateri* and *Tridacna teveroa* have the most restricted geographical ranges (Othman et al., 2010), making them more vulnerable to harvesting. In the Philippines, *H. porcellanus* has been reported only in the southern parts of Mindanao (Othman et al., 2010, Poutiers 1998b) and the Palawan group of islands (Villanoy et al., 1988). In 1993, only empty shells of *H. porcellanus*, *H. hippopus* and *Tridacna derasa* were encountered by Estacion et al. (1993) in Tubbataha Reefs Natural Park (TRNP). In the same year, Calumpong and Cadiz (1993) found a few individuals of *H. porcellanus*, suggesting that the species is rarely present or has been overexploited in the reefs of Tubbataha.

Efforts to conserve and restore the natural populations of giant clams have led to the study of their biology, propagation and restocking (Basker, 1991; Foyle et al., 1997; Gomez and Mingoa-Licuanan, 2006; Hart et al., 1998). However, the rare occurrence of *H. porcellanus* have made it difficult to understand its biology in captivity and in the wild. Juinio et al. (1989) reported that *H. porcellanus* were

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so rare that they failed to find breeders for propagation and restocking projects. Information obtained from studies involving bivalve growth, survival and shell dimensions–live weight relationships are important in resource management and in monitoring changes in environmental conditions (see Gimin et al., 2004; Watson et al., 2012). With the recovery of *H. porcellanus* populations in TRNP (Dolorosa and Jontila, 2012) after more than two decades of protection, this study sought to investigate some aspects of its biology such as shell dimension–live weight relationships, growth and survival.

MATERIALS AND METHODS

The Study Site

The study site was at the southern tip of the North Atoll of TRNP, Philippines (Figure 1), no more than 1 km away from the Ranger Station. It formed part of the shallow subtidal reef along the edge of the lagoon.

Figure 1. Dive map of Tubbataha Reefs Natural Park and the study site (white triangle) at the southern tip of the North Atoll. Map credit: Tubbataha Management Office.

The area was up to about 1 m deep at low tide with patches of massive and branching corals. Massive corals which dot the area were exposed during extreme low tides. Its sandy substrate shifts seasonally and poses hazards to the clams along the lowtide water margin. The area is also close to one of the translocation studies for the reef gastropod *Trochus niloticus* (Dolorosa et al., 2013).

Tagging and Sampling

Naturally occurring giant clams in the area were collected on 29 December 2009 and brought to the Ranger Station for cleaning, measurement and tagging. In total, 100 clams of varied sizes (Range: 8.2–31.3 cm; Mean: 21.98 cm; sd: 5.27 cm) were tagged. Tagging was done by first removing the marine growths on the shell with the aid of a steel brass before a prenumbered dymo tag was glued on the shell with marine epoxy (Figure 2 left photo). The clams were temporarily kept under the Ranger Station to protect them from exteme sunlight while allowing the tag to harden for a few hours. To avoid stress the clams were returned to their original habitat before sundown.

Figure 2. The newly marked *Hippopus porcellanus* ready to be returned in their natural habitat (left) and in situ shell length measurement (right).

During initial measurements, shell dimensions such as length, height and inflation of each clam were determined to the nearest 0.1 cm with calipers. The live weight of each clam was measured with a spring balance. On two succeeding events, only the shell lengths were measured (Figure 2, right photo). No measurements were taken from dead individuals and those with unrecognized and damaged tags.

Analysis

Shell dimensions (length, height and inflation) and live weight measurements obtained in December 2009 were subjected to regression analysis to derive shell dimension – live weight relationships.

Increase in size of giant clams at every measurement event was computed based on a total of 80 clams with complete records of shell lengths in all three events. Mean sizes of the clams were compared using analysis of variance and Scheffé post hoc tests with the use of R version 2.12.0 (R, 2011). Growth parameters such as the average maximum attainable shell length (cm; L_{∞}) and the Brody growth coefficient (K) for *H. porcellanus* were obtained using the formula of Fabens (Ogle, 2010):

$$L_r = L_m + (L_{\infty} - L_m)(1 - e^{-k\delta t})$$

where Lm stands for the size of clams at the time of marking; Lr represents the recorded size at the time of recapture; and δt stands for the difference in size between recapture and time at marking or between the second and first recaptures. The time intervals (days) between sampling were converted into years by dividing the data by 365 days. To determine the size of giant clams at a particular age, the estimated growth parameters (K and $L\infty$) were then substituted into the von Bertalanffy growth formula (VBGF) (Ogle, 2010),

$$Lt = L\infty(1 - e^{-k(t-t_0)})$$

where Lt is the size at time t and t_0 is the theoretical age at size zero. Unknown parameters were determined with the use of FSA package (Ogle, 2010) in R version 2.12.0 (R, 2011).

RESULTS

Shell Dimension–Live Weight Relationships

The relationships between the different shell dimensions and live weight of *H. porcellanus* were best expressed by the equation $W = aL^b$, where W stands for live weight and L for any of the three shell dimensions. The variable a represents the y -axis value when the x -axis is zero; b is the slope of the regression equation. The derived equations suggest that 93.3–96.7% of the changes in the live weight of *H. porcellanus* is influenced by the change in shell dimensions (Figure 3).

Figure 3. Relationships between shell dimensions (length, height, inflation) and live shell weight of *Hippopus porcellanus* in TRNP.

Growth and Survival

On average, the shell length of *H. porcellanus* increased by 3 cm in 2.5 years, or about 1.2 cm per year. The mean shell lengths at three measurement events were significantly different as suggested by ANOVA tests ($P < 0.01$), but Scheffe post hoc tests found no significant difference ($P > 0.05$) between means in the second and third measurement events (Table 1). The predicted average maximum length $L_{\infty} = 29.24$ cm and growth constant $K = 0.24$ when substituted to the VBGF suggested a rapid growth in the first five years, reaching about 22.30 cm or 76.27% of its L_{∞} . Annual growth rate declined by about 25%, suggesting that L_{∞} would be attained in approximately 20 years (Figure 4).

Table 1. Mean increase in size of marked *Hippopus porcellanus* with complete shell length (SL) records (n=80) for the duration of the study. Similar superscripts are not significantly different.

Sampling	Date	Number of days from tagging	No. of ind.	Mean SL (cm)	sd	Min. SL (cm)	Max. SL (cm)
Initial	29 Dec 09	0	80	22.92 ^a	4.52	8.2	31.3
Second	21 Dec 10	357	80	24.52 ^b	3.79	14.2	31.8
Third	13 Jun 12	897	80	25.92 ^b	3.14	17.5	32.2

Figure 4. Predicted size at age and yearly growth rates of *H. porcellanus* in Tubbataha Reefs Natural Park obtained by substituting the L_{∞} and K values in the von Bertalanffy Growth Formula.

In total, 88 of the clams were recovered alive at the end of the study period. Three empty shells were recovered and nine missing clams were assumed dead, thus total mortality was 12 individuals in 2.5 years (Table 2). This suggests 4.8% mortality per year and a life span of more than 20 years. This life span estimate coincides with the projected number of years at which the L_{∞} could be attained (Figure 4).

Table 2. Number of marked *Hippopus porcellanus* that survived during the study period. A dash (–) indicates no data.

Sampling	Date	No. of days	No. of live clams recovered with tag	No. of live clams with lost tag	No. of live clams	No. of missing clams	No. of dead clams
Initial	29 Dec 2009	0	–	–	100	–	–
Second	21 Dec 2010	357	94	2	96	4	–
Third	13 Jun 2012	897	81	7	88	9	3

DISCUSSION

Studies on shell dimension–live weight relationships have been reported for many bivalve species (Gaspar et al., 2001; Gimin et al., 2004) but not for live giant clams, possibly because of their large size, limited population and rock-burrowing habits of some species. Villanoy et al. (1988) only reported the relationships between shell lengths and empty shell weights for *H. porcellanus* and other giant clam species (Table 3). The established shell length–weight relationships are important for monitoring the growth in the natural population (Gimin et al. 2004). They also allow life history and morphological comparison between species and between populations of the same species from different habitats and localities, and can be used to estimate live weight and/or the biomass of the stock (see Gaspar et al., 2001).

Table 3. Estimated values of a and b in the length–shell weight relationships of different giant clam species of genera *Hippopus* and *Tridacna* in the Philippines. An asterisk (*) indicates measurements obtained from empty shells.

Species	a	b	n	r	Source
<i>H. porcellanus</i>	0.0000630	2.75741	80	0.97	This study
<i>H. porcellanus</i> *	0.0000318	3.37959	69	0.98	Villanoy et al., 1988
<i>H. hippopus</i> *	0.0002900	2.78961	100	0.98	Villanoy et al., 1988
<i>T. squamosa</i> *	0.0000379	3.50340	140	0.97	Villanoy et al., 1988
<i>T. gigas</i> *	0.0000954	3.17109	160	0.96	Villanoy et al., 1988

The average ($\pm$ sd) shell length of *H. porcellanus* at marking was 21.98 ± 5.27 cm with a range of 8.2–31.3 cm. The L_{∞} (29.24 cm) is 10 cm less than the reported maximum size the clams can attain, but the average length in this study is similar to the reported common length in its distribution range (Poutiers, 1998a). The growth rate of *H. porcellanus* in this study is comparable to that of *Tridacna derasa* in village farms in the Solomon Islands; these reached an average SL of 15 cm in 2 years from an initial size range of 2–3 cm (Hart et al., 1998). It is also comparable with the growth rate (5 – 8 cm per

year) of *Tridacna gigas* in Eniwetok Atoll (see Yamaguchi, 1977). A little slower were the growth rates of *T. maxima* and *T. crocea* from the Solomon Islands. From an initial size range of 2–3 cm, *T. maxima* attained an average shell length of 7.8 cm in 19 months, while *T. crocea* reached an average of 5 cm after 22 months (Hart et al., 1998). Variations in growth within and among species (Table 4) could be attributed to various environmental conditions (Hart et al., 1998; Watson et al., 2012) and biological attributes of each species (Beckvar, 1981; Griffiths and Klumpp, 1996).

Table 4. The growth parameters for *Hippopus porcellanus* and other tridacnid species from other localities with comparable L_{∞} .

Species	Country	L_{∞} (cm)	K	Author
<i>H. porcellanus</i>	Philippines	29.24	0.270	This study
<i>H. porcellanus</i>	Philippines	43.60	0.130	Villanoy et al., 1988
<i>H. hippopus</i>	Philippines	43.70	0.130	Villanoy et al., 1988
<i>H. hippopus</i>	Papua New Guinea	40.00	0.213	Munro and Heslinga, 1983
<i>H. hippopus</i>	Palau	40.00	0.100	Munro and Heslinga, 1983
<i>T. maxima</i>	Papua New Guinea	30.50	0.112	Munro and Heslinga, 1983
<i>T. squamosa</i>	Philippines	30.00	0.230	Villanoy et al., 1988

Size at sexual maturity for *H. pocellanus* is not known, although Alcazar et al. (1987) had successfully induced a 16 cm clam to release sperm and a 31 cm clam to release eggs. If *H. porcellanus* become sexually mature at 16 cm, such size is attainable within 3 years based on the predicted growth rates at TRNP. In Palau, spawning was successfully carried out on *H. hippopus* measuring 25 cm shell length (Jameson, 1976). Sexual maturity for *T. maxima* is attained upon reaching a shell length of 11–13 cm, nearly 50% of its maximum shell length (Jameson, 1976).

Information on the life span of *H. porcellanus* in other countries is lacking. The estimated life span obtained in this study is comparable with age estimates for other giant clam species. Growth ring analysis on the shells of *T. squamosa* has shown that a 43 cm clam could be 22 years old (Basker, 1991). Estimates of life spans of other giant clam species are much longer. For example, a 24 cm *T. maxima* could be 40 years old, and the very large (140 cm) *T. gigas* could be 200 years old (Isamu, 2008). However, isotopic records on *T. maxima* (~20 cm) suggest a life span of 28 years (Romanek et al., 1987). Watanabe et al. (2004) reported a 60 year isotopic record from the shell of a 93 cm long *T. gigas*. Long-lived repeat breeding species like the giant clams are critical subjects for research because of their importance in the ecosystem (Cabaitan et al. 2008), in the economy (Andrefouet et al., 2005; Clarke et al., 2003; Gomez and Mingoa-Licuanan, 2006; Hart et al., 1998) and in providing useful information on past environmental settings (Aubert et al., 2009; Duprey et al., 2014). As growth rates among clams could vary between regions or among reefs, studies on aspects of the biology of other giant clam species in TRNP and in other parts of Palawan is suggested.

ACKNOWLEDGEMENTS

This study was made possible through the help of the composite team of Rangers assigned at TRNP from December 2009 through January 2010. Dr. Lota A. Creencia provided constructive comments and suggestions on the early draft of the manuscript.

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