Secretariat of the Pacific Community

ISSN 1025-7462

Issue 14 – July 2008

TROCHUS
and other marine molluscs
information bulletin

Contents

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Produced with financial assistance
from Australia, France and New Zealand

Editorial

A year after the last publication, we are proud to present issue #14 of the *SPC Trochus Information Bulletin*. With the help of excellent contributors from various fields, we have managed to put together a substantial and well-balanced issue, offering you an array of research results, reviews and reflections on topics related to the harvesting, aquaculture and management of marine molluscs in the Indo-Pacific.

For starters, two studies on the growth of trochus in Wallis Island and Viet Nam, contributed by Soazig Lemouellic and Claude Chauvet (University of New Caledonia) and by Do Huu Hoang and collaborators (Institute of Oceanography, Viet Nam), respectively. Then, Simon Foale (James Cook University, Australia) writes on the resilience of trochus and other nearshore artisanal fisheries in the Western Pacific, and Antoine Teitelbaum (SPC) and Sompert Rena (Vanuatu Fisheries Department) provide an update on marine gastropod and bivalve aquaculture in Vanuatu. Last but not least, Antoine Teitelbaum and Kim Friedman (SPC) outline the outcomes of the reintroduction of giant clams to the Indo-Pacific region. As usual, we have included for your perusal a list of pertinent abstracts published in different sources over the past 18 months.

As you can see, we continue to make progress in broadening the scope and increasing the appeal of the bulletin – sincere thanks to those of you who have shared in this adventure. Our dream for the next issue (#15) would be to receive an even larger selection of articles dealing with a diversity of marine molluscs from a wide range of geographical areas. We remind readers and potential contributors that while this publication will remain focused on species of commercial significance to Indo-Pacific communities, such as giant clam, conch and trochus, we are always looking for complementary information on other species (of marine gastropods and bivalves), regions (i.e. Caribbean, Mediterranean, etc.) and endeavours (e.g. regional surveys, emerging aquaculture or fisheries programmes, workshops and conferences, relevant biological data, aquarium trade information). All forms of contributions are welcome, as are suggestions from scientists, hobbyists, managers and stakeholders regarding possible topics of interest.

We are counting on you all to help us get the next issue ready for publication in a year or so – maybe even less. Seize this opportunity to make yourself and your work known and perhaps get feedback from others involved in this constantly evolving field of research and business. We cannot wait to hear about new projects and novel findings.

Meanwhile, enjoy issue #14 and please share it with your friends and colleagues.

Jean-François Hamel and Annie Mercier

Trochus niloticus (Linnae 1767) growth in Wallis Island

Soazig Lemouellic[1] and Claude Chauvet[1,2]

Abstract

A study of the Wallis Island *Trochus niloticus* stock was undertaken between 2004 and 2006. The growth of individuals was studied by tagging. Results are presented and compared with growth trends in other regions of the Pacific.

Introduction

Trochus niloticus (Linnae 1767) is a marine gastropod. It belongs to the Prosobranchia subclass, Archaeogastropoda order and Trochidae family (Hickman and McLean 1990). Wild populations of *T. niloticus* occur between longitudes 90° W (Andaman Islands, India) and 180° W, and latitudes 20° N and 25° S. The Wallis *T. niloticus* population is therefore on the edge of the species' area of natural occurrence (Fig. 1). During the last century, some populations were artificially transplanted to the east, north and southeast of the species' occurrence zone in the wild (Gillett 2002). Although there were some failures, as in the Loyalty Islands with New Caledonian juveniles, most of these populations settled successfully (Hoffschir et al. 1989; Chauvet et al. 1998).

T. niloticus inhabits the intertidal and shallow subtidal zones. Its preferred habitat is the moderately exposed coral reef shore (McGowan 1956; Gail 1957; Smith 1979). Its diet is herbivorous, and it forages on small green and red seaweeds (Cyanophycae and Phaeophycae), benthic diatoms and Foraminifera (Asano 1944). *Trochus* spp. are gonochoric, without any external sexual dimorphism. Females and juveniles, however, have green gonads, whereas males have white gonads (Amirthalingam 1932a, b). Spring tides mark the breeding period, with external fertilisation and nocturnal spawning. Female spawning is induced by the presence of sperm (Amirthalingam 1932c; Nash 1985). In Micronesia, Australia and the Andaman Islands, spawning occurs all year round (Rao 1936). In New Caledonia, *T. niloticus* spawns between October and

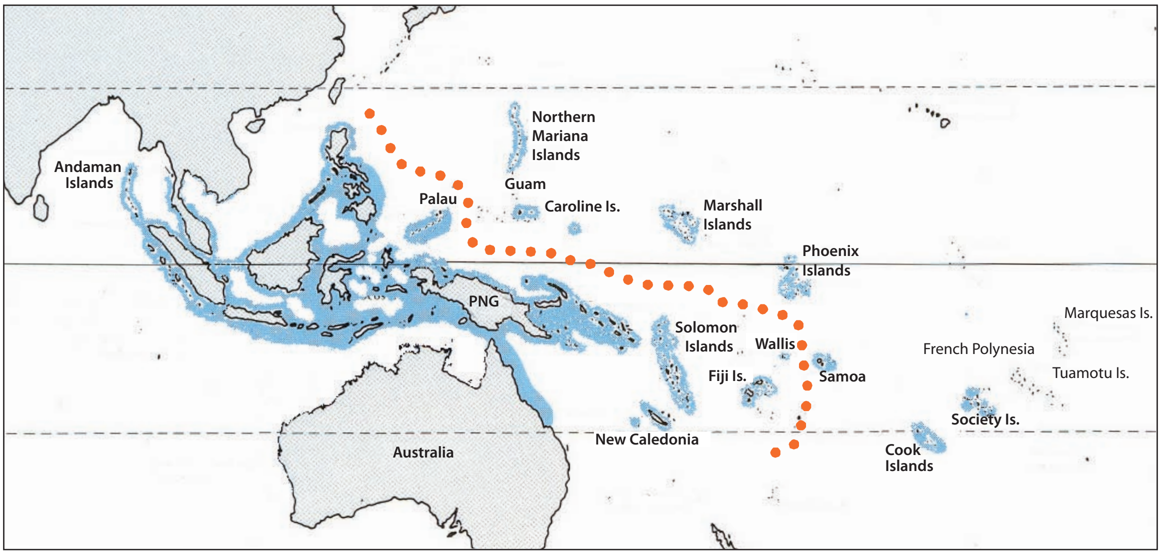

Figure 1. Distribution of *Trochus niloticus*. Natural stocks occur west of the dotted line. To the east, implanted populations of the Northern Mariana, Guam, Yap, Chuuk, Marshall and Phoenix Islands originated in Palau; the Society Islands population was implanted from Vanuatu and New Caledonia, whereas the Cook Islands population came from Fiji Islands.

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April (Bour 1989). Heslinga and Hillmann (1981) and Nash (1985) described the species' reproductive behaviour and larval development in Australia (Great Barrier Reef) and Palau, respectively. Fertilised eggs are covered by a thick chorion. The first division occurs between 30 and 60 minutes after fertilisation and the trochophore larva hatches after 12 hours. At the end of the first day, the larva becomes a veliger. Although the larva is teleplanic, its metamorphosis into a juvenile occurs classically during the third day of its life (Heslinga and Hillmann 1981; Nash 1985). Metamorphosis and settlement are stimulated by the presence of red algae or humic acids (Heslinga and Hillmann 1981).

The shells of *T. niloticus* are used as raw materials by the nacre button industry. The value of this natural material has increased steadily since the emergence of plastic materials. Artisanal jewellers put the shells to a variety of uses and designs, such as inlaying and incrustation. Commercial demand for these products has been on the rise for more than 30 years. It is therefore necessary to manage stocks carefully, particularly on small islands. Knowledge of growth rates is the basis of good management. Mean individual growths were studied in different islands of the Pacific Ocean and fitted to the Von Bertalanffy model, which has proven robust. Although similar, growth rates in different locations, such as Japan (Honma 1988), New Caledonia (Bour et al. 1982), the Great Barrier Reef in Australia (Nash 1985) and Vanuatu (Bour and Grandperrin 1985), differ sufficiently to suggest that they are specific to geographical units. In that case, management advice and practices should be adapted to each stock. The present study, designed as a follow-up to a short study of *T. niloticus* growth (Chauvet et al. 2004), aims to document the spring growth rates of tagged individuals.

Material and methods

T. niloticus inhabits the outer slope between the reef crest and 15 m depth (Chauvet et al. 2004). Individuals were therefore captured by snorkelling. Between 80 and 150 individuals were caught daily, totalling 477 individuals in a week. For the growth survey we developed a tagging method that enabled the easy spotting of marked individuals from the surface. Recaptures were done by scientists as well as by fishers. On recapture, the number of individuals and their size were recorded. All individuals were released at the site of capture. On the first capture, the shells were taken out and kept in an immersion net until tagging.

Tagging process

Trochus were tagged aboard the boat in batches of 10 individuals. Each individual was laid on its side horizontally on an openwork surface, facilitating the different steps of the tagging:

1. the shell is scratched clean with a knife on a 5 x 2 cm surface;
2. this surface is then polished with a sandpapering machine;
3. the surface is air-dried with a diving bottle;
4. the surface is cleaned with acetone to improve the resin's sticking power;
5. the first thin coat of epoxy is applied; the resin must remain tacky for ca. 7 minutes and must then be hardened in 2 minutes;
6. the number (Dymo tag) is placed; and
7. a second coat of resin is applied to cover the tag.

The specimens are then placed in an immersion net until they are individually released at the place of their capture. The best colours for tags are orange and yellow because they are easily discernible in shallow water. As concretions will cover up the mark in 4–6 months, it is advisable to double the tagging with an internal shell inscription made with a pencil.

The tagged specimens are then returned one by one to their natural habitat. Care should be taken during this step to ensure survival of the specimens and success of the tagging experiment. To prevent them from being turned over by waves or current, the specimens are repositioned so that they can quickly re-attach themselves to the substrate. When a *T. niloticus* is upside down it becomes vulnerable to predation and can be eaten by small fish, such as Labridae. Whenever possible, each trochus is released in an environment that matches the fouling of its shell, the best option being to take it back to the site where it was caught.

Recapture

Recapture is done by scientists as well as fishers. A reward is provided for trochus returned, enough to encourage fishers to send them back, but not too high to prevent the shells from being actively sought out.

Measurements

Two diameters were recorded: D1 and D2. Both pass over the ombilic (Fig. 2). D1 starts at the hollow of the crown basis; it is the most robust measurement. D2 is the longest possible diameter (D2 > D1). Measuring D2 can require several successive trials and the result may be imprecise. However, it is the measurement that most fishers use as fishing regulations almost always refer to the longest diameter. The following formula (Fig. 2) can best describe the relationship between D1 and D2 (r = 0.99):

$$D2 = 1.1915\ D1 - 2.0606\ (n = 720)$$

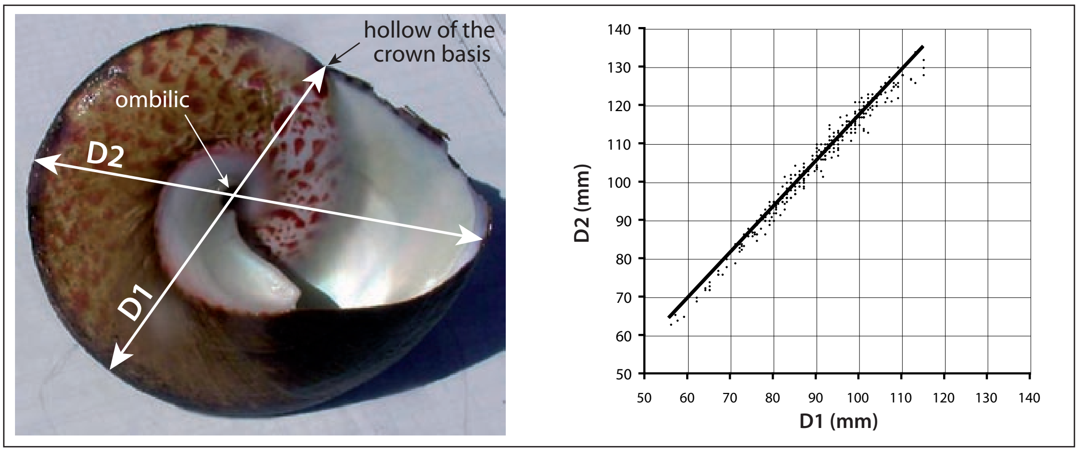


Figure 2. Regression of the two diameters (D1 and D2) of the basis of the shell.

Data treatment

Experimental results – shell size increments in relation to time at liberty – were used to calculate a Von Bertalanffy growth curve [$LF_t = LF_{inf} (1 - e^{-K(t-t0)})$] for all individuals measured. The length derived by the time (dLF/dt) is:

$$dLF/dt = LF_{inf.}\, K.e^{-K(t-t0)}$$

which, following the Von Bertalanffy curve, would give:

$$e^{-k(t-t0)} = 1 - LF_t/LF_{inf}$$

therefore:

$$dLF/dt = K\,(LF_{inf} - LF_t)$$

The Von Bertalanffy curve parameters are then obtained from this linear equation (where K is the slope, and KLF_{inf} is the y-intercept).

The confidence interval of r (Pearson product-moment correlation coefficient) is obtained by inverse tanh transformation (z-transformation in Dagnelie 1980):

$$z_1 = 1/2\ Log_e\ [(1+r)/(1-r)] - t_{a/2}\ /(n-3)^{0.5}$$
and
$$z_2 = 1/2\ Log_e\ [(1+r)/(1-r)] + t_{a/2}\ /(n-3)^{0.5}$$

Which gives:

$$r_1 = [\exp(2z_1) - 1]\ /\ [\exp(2z_1) + 1]$$
and
$$r_2 = [\exp(2z_2) - 1]\ /\ [\exp(2z_2) + 1]$$

Results

Trochus were recaptured over a period of one year, beginning in the first week after the onset of the tagging experiment. A total of 114 individuals were recaptured. The standard time unit was a day, and for LF_i the mean size increment of the shell during the time at liberty ($LF_i = [LF_{recapture} - LF_{capture}]\ /\ 2$). These data [$dLF/dt$; LF_t] provide the linear model that calculates K and $LF_{inf.}$ (Fig. 3). The confidence interval of r is – 0.744, which is between $r_1 = -0.666$ and $r_2 = -0.806$ for $P_{(1-a)} = 0.95$. The value of r is therefore significantly different from zero.

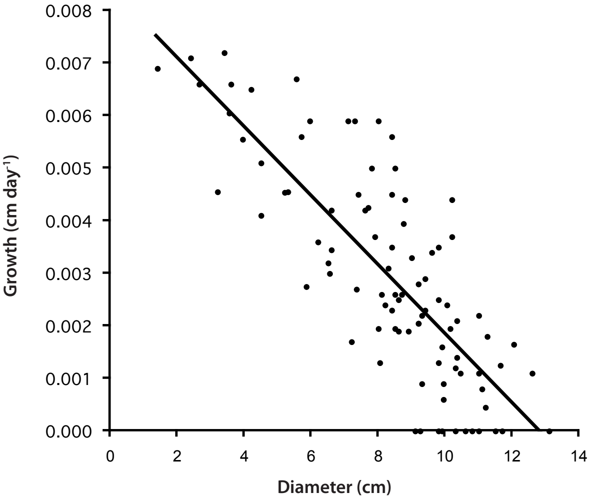


Figure 3. Tagged data fitted with: $dLF/dt = K\,(LF_{inf} - LF_t)$.

The slope (K) is in day^{-1} (K = 0.994) and could be transformed in yr^{-1} to obtain the classical expression of the Von Bertalanffy parameters: $K = 0.358\ yr^{-1}$ and $L_{inf} = 12.23$ cm (Fig. 4).

Discussion

These values are similar to those obtained by Chauvet et al. (2004) using statistical methods: $K = 0.35\ yr^{-1}$ and $L_{inf.} = 12.5$ cm. The growth curve of *T. niloticus* indicates that young trochus of Wallis Island grow quickly when compared to those of Vanuatu or New Caledonia (Fig. 5 and Table 1), which could explain why their shells

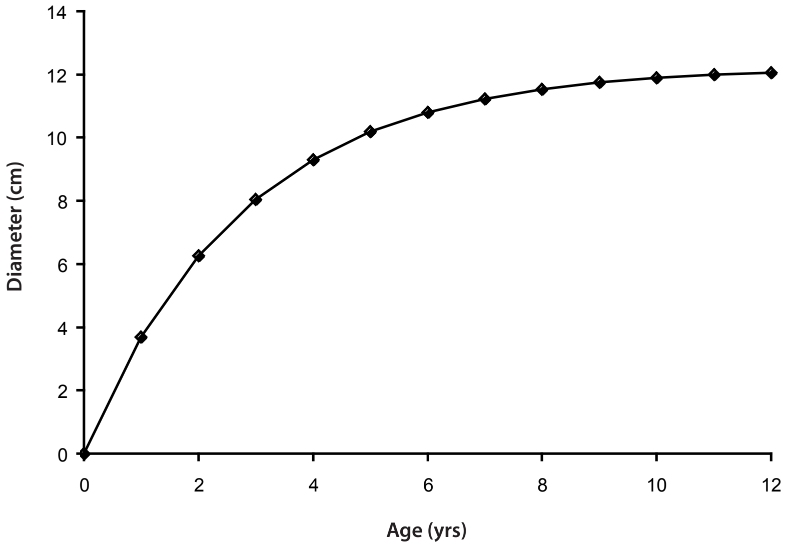
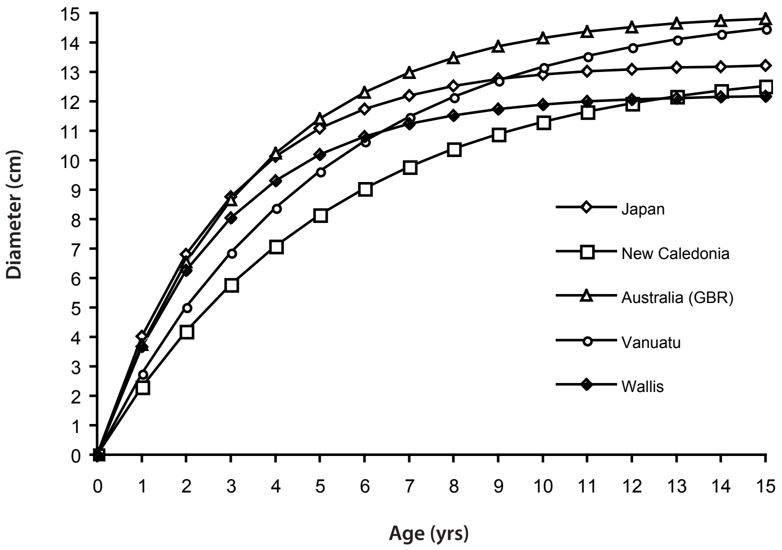


Figure 4. *T. niloticus* growth curve on Wallis Island.



Japan	(Honma 1988):	$L_t = 13.27\ (1 - e^{(-0.36\,t)})$
New Caledonia	(Bour et al. 1982; Bour 1989):	$L_t = 13.30\ (1 - e^{(-0.19\,t)})$
Australia (GBR)	(Nash 1985):	$L_t = 15.01\ (1 - e^{(-0.28\,t)})$
Vanuatu	(Bour et Grandperrin 1985):	$L_t = 15.23\ (1 - e^{(-0.20\,t)})$
Wallis	(present)	$L_t = 12.23\ (1 - e^{(-0.358\,t)})$

Figure 5. *T. niloticus* growth curves in different parts of the Pacific Ocean (Von Bertalanffy curves).

are thinner than trochus in other Pacific islands. Possibly correlated with weak shells, the maximum size observed was small, with few individuals reaching a diameter length of 13.5 cm. Gimin and Lee (1997) showed a correlation between growth, mortality and substrata. Sexual maturity was established at 6 cm (Chauvet et al. 2004); therefore, according to this growth curve (Fig. 5), trochus in Wallis become adults at two years of age.

Table 1. Estimated shell diameter of *T. niloticus* with age in different locations.

Age (years)	Shell diameter (cm)				
	Japan	New Caledonia	Australia (GBR)	Vanuatu	Wallis
0	0.00	0.00	0.00	0.00	0.00
1	4.00	2.30	3.63	2.76	4.40
2	6.80	4.20	6.38	5.02	7.36
3	8.76	5.78	8.47	6.87	9.34
4	10.12	7.08	10.05	8.39	10.66
5	11.07	8.16	11.25	9.63	11.55
6	11.74	9.05	12.16	10.64	12.15
7	12.20	9.78	12.85	11.47	12.55
8	12.53	10.39	13.38	12.16	12.81
9	12.75	10.89	13.78	12.71	
10	12.91	11.31	14.08	13.17	
11	13.02	11.65	14.30	13.54	
12	13.10	11.94	14.48	13.85	
13	13.15	12.18	14.61	14.10	
14	13.19	12.37	14.71	14.30	

The growth rate of the Wallis *T. niloticus* ($K = 0.358\ yr^{-1}$) is most similar to that recorded by Honma (1988) in Japan. Records from other regions in the Pacific Ocean – New Caledonia (Bour 1989), Australia (Nash 1985) and Vanuatu (Bour and Grandperrin 1985) – indicate a slower growth than what we obtained in Wallis. The asymptotic size recorded in Wallis (12.23 cm) was, however, the smallest reported in the literature. Wallis trochus reach nine-tenths of their maximal size at 6.5 years of age. Taking into account that less than 1 per cent of them reach sizes beyond 12.5 cm, we assume that 6.5 years is the life expectancy of trochus in Wallis Island.

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Growth rate of *Trochus niloticus* (L., 1767) fed different food types

Do Huu Hoang[1,2], Hua Thai Tuyen[1], Hoang Duc Lu[1]

Abstract

To better understand the growth rate of the top shell *Trochus niloticus* in captivity, a feeding experiment was conducted using F1 top shells measuring 11 mm. Trochus were fed on six different diets, including algae attached to rocks, algae in a coral tank, cultured algae *Navicula* sp., *Nitzschia* sp., dried algae (*Spirulina*), and equal proportions of *Navicula* and *Nitzschia*. Results showed that while all the trochus grew well when fed on all these diets, trochus that fed on algae living on rocks and in coral tanks showed the highest growth rate. Another experiment was conducted using top shells sized 27–28 mm and four types of feeds: dried algae + N1, dried algae + soya bean powder, dried algae + N1 + soya bean powder, and dried algae + N1 + soya bean + detritus. Result showed that trochus fed a mixture of dried algae + N1 + soya bean + detritus showed the highest growth rates, and trochus fed dried algae + N1 + soya bean grew the slowest.

Introduction

The trochus or top shell (*Trochus niloticus*) is a gastropod grazer found in the coral reefs of the Indo-Pacific region. It is a favourite seafood in the Asian and Pacific regions (Shokita et al. 1991).

The biology and ecology of trochus have been investigated in locations including Indonesia, Thailand, Japan, Micronesia and Australia, yielding data that are useful for applied studies (Bour 1988; Dobson and Lee 1996; Shokita et al. 1991). However, studies of trochus began only recently in Vietnam. Food items found in the stomach of trochus include 42 taxa belonging to Chrysophyta, Chlorophyta, Rhodophyta, Cyanophyta, Foraminifera, and suspended materials mixed with sand and detritus (Soekendarsi et al. 1998). Under laboratory conditions, trochus fed *Isochrysis galbana* grew faster than did three other groups fed *Tetraselmis* sp., *Chaetoceros gracilis* and *Nannochloropsis* sp. (Latama 1999). In the experiments by Soekendarsi et al. (1999) using individuals between 30 and 39.9 mm in size, a diet of *Ulva reticulata* produced the highest recorded growth rate, while groups fed *Caulerpa sertularioides, Ulva reticulata, Padina australis, Gracilaria salicornia* and *Eucheuma denticulatum* exhibited a much lower growth rate.

The shell is the most valuable part of the trochus. It is used for many purposes, but most commonly to make souvenirs and buttons. The shell is also used in cosmetics and paint (King 2001; Bouchet and Bour 1980; Nash 1993). The main producing countries are Indonesia, the Philippines and Thailand, while Japan, Hong Kong and Europe are the most important consumers. In Vietnam, *T. niloticus* has been exploited for human consumption, and shells are marketed as souvenirs (the current market price is about VND 40,000–70,000 per shell (USD 2.4–4.2 per shell) or VND 150,000 per kg (USD 9.03 per kg). Overexploitation of trochus due to high market demand has resulted in depletion of the resource in Vietnamese waters and *T. niloticus* is now listed as a protected species in Vietnam (Vietnam Red Data Book). Therefore, rehabilitation and enhancement of trochus stocks are necessary both locally and internationally. One of the solutions available is to replenish trochus resources through artificial breeding and release of larvae or juveniles in the wild (Ponia 2000; Amos 1992; Lee 2000). The aim of this experiment was to examine appropriate feeds for supporting mass seed production in hatcheries and for natural stock enhancement.

Materials and methods

Twenty broodstock top shells (*T. niloticus*) were collected from Khanh Hoa waters and cultured in a 6 m^3 tank in a hatchery at the Institute of Oceanography, Nha Trang, Viet Nam. The broodstock was induced to spawn as follows. They were first removed from the water and exposed to ambient air for approximately 30 minutes. They were then put in a tank with water that flowed through an 11 W ultraviolet light system with a flow rate of 7–8 litres per minute to stimulate spawning. The first spawning occurred within an hour.

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Experiment 1

When the basal shell diameter of the F1 generation had reached approximately 11.98 ± 0.08 mm (± S.E.) in size, their subsequent growth rate under six different diets was compared. The diets consisted of live algae found on natural rock, natural algae found on coral, *Navicula* sp, *Nitzschia* sp., an equal mixture of *Navicula* sp. and *Nitzschia* sp., and dried cells of *Spirulina* sp. The food supply was checked daily for abundance and replenished when required. The stocking density of the F1 was 20 individuals per 60 L tank and three replicate tanks were used for each treatment. The experiment lasted for 12 weeks.

Experiment 2

Another experiment was conducted using top shells with an initial diameter of 27–28 mm. This experiment was conducted for 10 weeks. Feeds used included dried algae + N1, dried algae + soya bean powder, dried algae + N1 + soya bean powder, and dried algae + N1 + soya bean + detritus (about 25% each). Dried algae refers to dried cells of *Spirulina* sp.; N1, a Japanese industrial feed for the prawn market (described as "mixed feed for *P. monodon*"), is used to feed postlarvae 15 or later stages; and detritus corresponds to organic matter on rocks collected from the wild. The density in the experimental tanks (n = 3 replicates) was 10 top shells per 60 L tank.

Husbandry, environmental checks and data collection

During the two experiments described above, the husbandry was similar. Monitoring, cleaning and other activities were undertaken daily. A continuous flow of sea water was used, corresponding to a volume replacement of 80% per day. Average daily temperatures varied between 26.5 and 31.5°C. The pH of the sea water was between 7.24 and 8.38 and the salinity was about 34. Basal shell diameter in millimetres and total weight in grams were measured every two weeks.

Data analysis

Data were tested for normality and analyses of variance were performed using SPSS (Version 10.0). Where data were not normally distributed, they were transformed to logarithms before analysis.

Results

I. Feeding experiment using top shells with an initial size of about 12 mm

Results showed that the weight (0.35 ± 0.05 g) and basal diameter (11.98 ± 0.07 mm) of the top shells used at the beginning of the experiment were not significantly different among the treatments (ANOVA, F = 1.035, p = 0.40).

During the first two weeks of the experiment, trochus sizes in most treatments showed little change (Figs 1 and 2), except for top shells fed live algae in coral tanks, which showed a slight gain in both weight and shell size. After the first two weeks, weights and shell sizes in all treatments increased dramatically and showed significant differences (ANOVA, F = 54.146, p <0.001) between treatments. By the end of the experiment the top shells had developed into two size groups.

The first group consisted of top shells fed natural algae on rocks and on coral. The top shells in these two treatments grew significantly faster than in the remaining treatments, and in these two treatments trochus fed algae on rock showed a significantly higher growth rate than those fed algae in the coral tank (ANOVA, p <0.02).

The second group, which had a slower growth rate than the first group, consisted of trochus fed *Navicula* sp., *Nitzschia* sp., dried algae, and a mix of *Navicula* sp. and *Nitzschia* sp. In this group, the trochus fed *Navicula* showed significantly higher growth rates than those fed on *Nitzschia* and *Navicula* + *Nitzschia* sp. (ANOVA, p <0.04). In addition, both treatments fed *Nitzschia* sp. and a mix of *Navicula* sp. + *Nitzschia* sp. showed a significantly slower growth rate when compared to other groups (ANOVA, p<0.001). However, there were no significant differences between these two treatments (*Nitzschia* sp. vs a mix of *Navicula* sp. + *Nitzschia* sp.) (ANOVA, p <0.01).

II. Feeding experiment on top shells with an initial size of 27–28 mm

In this experiment, the initial size of the top shells was larger (27–28 mm) than in experiment 1 (12 mm) (Fig. 3). There was no significant difference in initial size between the treatments at the beginning of the experiment (ANOVA, p >0.12).

In general, all the treatments showed good growth rates and by the end of the experiment, all the trochus had reached >33 mm in shell diameter. The trochus fed a mix of dry algae + N1 + soya bean + detritus reached the largest size in comparison to specimens in the other treatments (ANOVA, p <0.02). The specimens fed on a mix of dry algae + N1 + soya bean showed the slowest growth rate (ANOVA, p <0.001). Top shells fed a mix of dry algae + soya bean and a mix of dry algae + N1 exhibited intermediate growth rates without significant differences between each other (ANOVA, p >0.10). However, both of these conditions showed

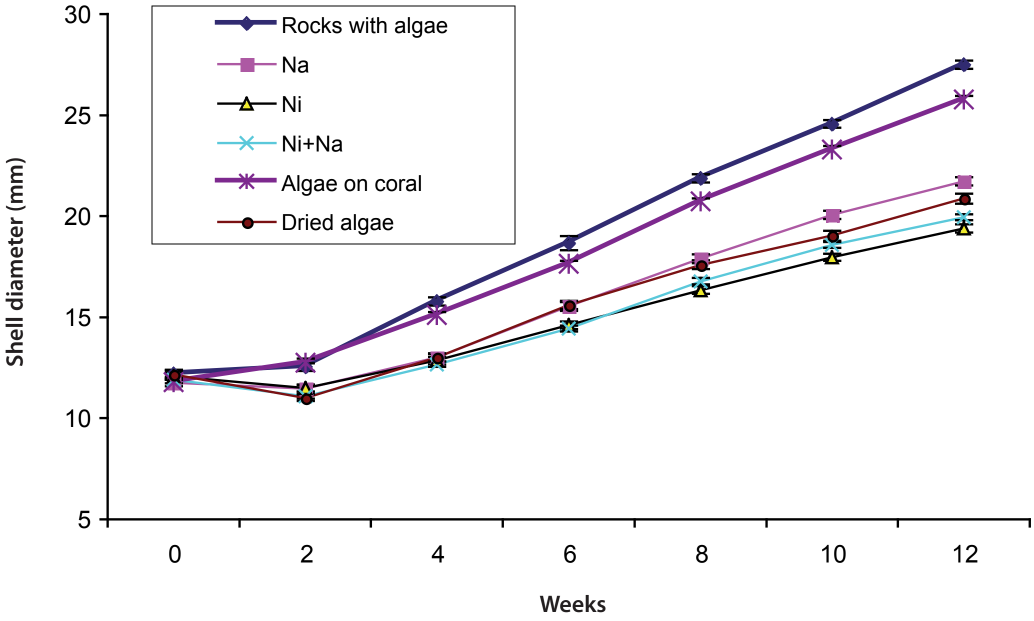

Figure 1. Mean shell basal diameter of *Trochus niloticus* fed on six different diets. Na: *Navicula* sp., Ni: *Nitzschia* sp., Ni + Na: 50% mix *Nitzschia* sp. and *Navicula*, dried algae: *Spirulina* sp.

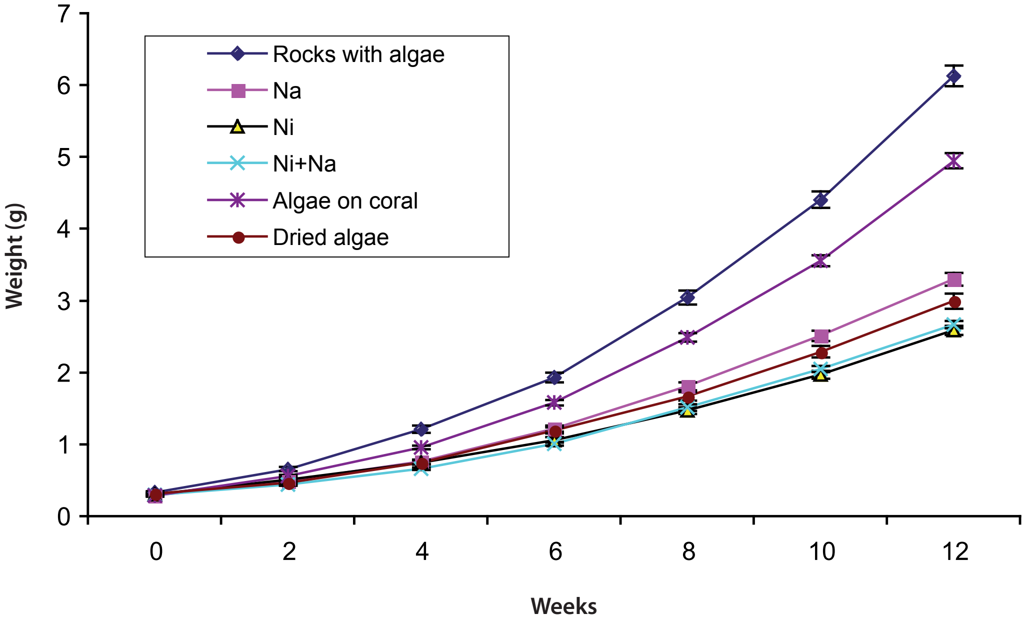

Figure 2. Mean weights of *Trochus niloticus* fed on six different diets. Na: *Navicula* sp., Ni: *Nitzschia* sp., Ni + Na: 50% mix *Nitzschia* sp. and *Navicula*, and dried algae: *Spirulina* sp.

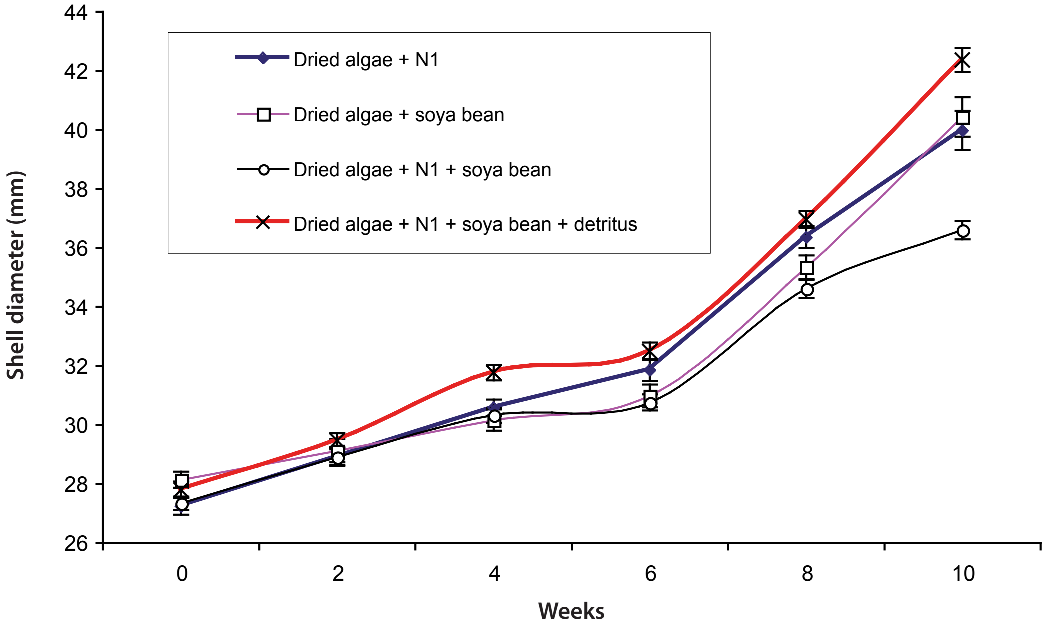

Figure 3. Growth of shell diameter (in mm) of top shells fed dry algae + N1; a mix of dry algae + soya bean; dry algae + N1 + soya bean; and mix of dry algae + N1 + soya bean + detritus.

significant differences in comparison to the mix of dry algae + N1 + soya bean + detritus (ANOVA, $p < 0.001$) (Fig. 3).

Discussion

According to Shokita et al. (1991), *T. niloticus* is a grazing mollusc and its natural diet consists of filamentous algae attached to rocks or detritus and sediments found on various substrata. However, this diet may change depending on the stage of development. The author also states that trochus juveniles feed on small-size seaweeds attached to the substratum, while adults eat small seaweeds and microalgae. Observations in captivity showed that both juveniles and adults ate microalgae, but adults also ate some seaweeds such as *Gracilaria*.

In both experiments, trochus fed on algae living on rocks and the walls of coral tanks showed better growth rates compared with other treatments. It is possible that the composition of food obtained from coral bases on rocks was similar to the usual diet of trochus in nature, which resulted in a shorter acclimation time and faster growth rate than in trochus fed other diets. For example, in experiment 1, during the first two weeks, trochus fed algae growing on the walls of coral tanks seemed to grow faster and did not show any delay in growth initially, while trochus in the other treatments grew more slowly – possibly while adapting to new food items. Another possibility is that the presence of detritus and sediment in the diet might be beneficial for trochus growth.

The trochus used in the experiments were initially cultured in tanks that had algae attached to their walls. These conditions were therefore similar to those in the experimental coral tanks. As a result, these trochus acclimated faster and had reasonable access to food, as shown by the good growth rates obtained.

The algae species composition on the natural rock included Rhodophyceae (*Ceramium mazatlanense, Centroceras clavulatum, Chondria repens*), Chlorophyceae (*Enteromorpha clathrata, Cladophora laetevirens, Chaetomorpha javanica*), Diatomophyceae (*Nitzschia* spp., *Navicula* spp., *Diploneis* cf. *bombus, Paralia sulcata, Achnanthes brevipes, Pleurosigma naviculaceum, Bacillaria paradoxa, Cylindrotheca closterium, Coscinodiscus* spp., *Oscillatoria* sp.), detritus, sand, and others (Final topshell report, 2005). This diet is close to the natural diet of trochus in the wild (Soekendarsi et al. 1998) and hence it yielded the best growth rate in captivity. The same results were found in a previous experiment conducted on *T. maculatus* bred in captivity. The result in that experiment, also performed in our laboratories, showed that trochus fed on algae on natural rocks exhibited the highest growth rate compared with those fed other diets (Do et al. 2003).

Despite the fact that the different types of feed used in the experiments resulted in different growth rates of trochus, all the diets could be selectively used to feed trochus in captivity, depending on practical conditions. In addition, although the results of the experiments showed that some diets produced higher growth rates in trochus in captivity, it is essential to conduct more experiments on numerous other diets, particularly using the industrial mixtures produced for other aquatic animals such as prawn.

There are some difficulties involved in trochus culture. Firstly, according to Nash (1993) trochus grow slowly, reaching a commercial size at 2–3 years of age. They are thus costly to culture in captivity. Algae attached to rock promote faster growth of trochus, but there are difficulties in collecting such rocks for mass production of trochus. For this reason, trochus should be cultured in natural conditions using methods such as sea ranching, or released into marine protected areas. Therefore, replacement feeds should be used only in the juvenile stages, until culturing them in the wild becomes possible.

Acknowledgements

We are grateful to the project leader, Dr Vo Si Tuan, for valuable help and advice, Huynh Minh Sang for comments on the report, and Ho Thi Hoa and Phan Kim Hong for supplying cultured algae. This work was funded by SUMA, Danida.

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Appraising the resilience of trochus and other nearshore artisanal fisheries in the Western Pacific

Simon Foale[1]

Introduction

Many coastal fisheries in the Indo-Pacific region are currently experiencing serious management problems with populations of a growing number of species showing steep declines. Trochus appears somewhat exceptional in this regard. It does not appear to be threatened with stock collapse in many places and, unlike some high-value invertebrates such as the green snail (*Turbo marmoratus*) and sea cucumbers (*Holothuria scabra* and *Holothuria nobilis*), appears to respond well to serial closures as commonly exemplified by the *tambu* or *tapu* system in many parts of Melanesia. In this short essay I wish to outline some of what I believe are plausible reasons for the relative resilience of trochus fisheries, and discuss what they imply for artisanal fishery management more broadly.

A number of extensive marine resource statistics, including diver surveys and surveys of landings, have been performed in Papua New Guinea (PNG), Solomon Islands and Vanuatu in the last five years or so (Amos 2007; Lincoln-Smith et al. 2006; National Fisheries Authority (Papua New Guinea) 2005, 2007a, b; Ramohia 2006; Skewes et al. 2002, 2003). These data collectively provide an alarming reminder of the severity of overexploitation of certain high value species across the region. However, trochus stocks, while they have reportedly declined in some locations such as Vanuatu, are far from collapsed. Amos (2007) reports significant declines in overall exports for trochus between 1996 and 2004, with 157.6 tonnes processed in 2003, down from a peak of 476.4 tonnes in 1998. The PNG National Fisheries Authority (2005) reported “mollusc” landings of just over 120 tonnes at Kavieng between December 2002 and April 2004, 99% of which was trochus, and 0.6% of which comprised green snail. In Milne Bay, no green snail was landed between December 2005 and December 2006 (National Fisheries Authority, Papua New Guinea 2007b), while around 18 tonnes of trochus were landed for the same period. During the country-wide diver survey of Solomon Islands performed by the Nature Conservancy in 2004, no green snails were sighted at all, while the overall density of trochus was calculated to be 10 per ha.

Several of the above-mentioned surveys also report sharp declines in other species, including the giant clams *Tridacna gigas* and *T. derasa*, and the sea cucumbers *Holothuria scabra* and *H. nobilis*, which will be discussed below in relation to the stock dynamics of the gastropod mollusc fisheries. First, however, I will outline an analytical framework for understanding the recent fates of the various commodity fisheries in the Western Pacific, why they have followed such different trajectories, and what this implies for management approaches in each case.

A framework for analysing pressure on, and resilience of, different commodity fisheries in the Pacific

A wide range of considerations must be taken into account when appraising the management challenges for different commodity fisheries in the Pacific. They include the following:

1. **Commodification**. Generally speaking, fishing pressure is much heavier for commodity fisheries than for subsistence fisheries. The divide between the two types of fisheries is much greater for countries with very low population densities, such as PNG, Solomon Islands and Vanuatu (Sabetian and Foale 2006).
2. **Market price** is a key determinant of the level of fishing effort applied to a fishery. As fisheries become depleted, the price frequently goes up. There are many examples of this, with perhaps one of the most spectacular being the Chinese bahaba fishery (Sadovy and Cheung 2003). The price of dried bahaba swim bladders increased from a few US dollars per kilo in the 1930s to between USD 20,000 and 64,000 in 2001, which made it more valuable than gold, even at today’s (2008) prices. This inverse relationship between abundance and price sets up a vicious cycle that often drives fisheries to collapse.

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3. **Ease of storage and transport**. Non-perishable and dried commodities such as shells, shark-fins and beche-de-mer are much easier to store and transport to market than fresh fish or live fish. Species that cannot be stored and economically transported to market will inevitably be subject to less fishing pressure than those that are.
4. **Life history**. Growth rate, age at maturity, longevity and fecundity all affect the way that populations of any given species respond to fishing pressure. As a general principle, species with higher rates of population turnover tend to be more resilient to fishing pressure (e.g. Dalzell 1993; Pauly et al. 1998). Exceptions to this principle should not be ruled out, however. There are other important and often complex life-history factors that affect resilience to fishing, particularly those relating to larval dispersal and settlement behaviour.
5. **Ease of capture**. Some species are more vulnerable to overfishing because they are easier to capture. Species with limited or no mobility and shallow depth distributions tend to be overharvested more rapidly than mobile, deep and/or cryptic species.

There are of course interactions and trade-offs among these factors for most fisheries.

Trochus occupies an interesting position with respect to the above rules. It is sedentary, and its shallow distribution (most animals live at depths of less than 15 m) means that reasonably fit divers can access most of the population without SCUBA or hookah. The shell can be stored indefinitely and transported at fairly low cost. In combination with a moderately lucrative price incentive, these factors render it vulnerable to overfishing. At the same time, it grows quickly and is sexually mature by about year two or three when it has a basal diameter of around 6 cm (Foale and Day 1997; Nash 1993). It also displays a level of cryptic behaviour (detailed below) that some researchers have noted (Nash 1993; Foale 1998a; Foale and Day 1997) and that has also been observed by Pacific subsistence and artisanal fishers (Foale 1998a, b; Foale 2006). This cryptic behaviour may be pivotal to the fact that trochus fisheries have not yet experienced widespread stock collapse, in contrast to green snail (*Turbo marmoratus*) and some of the other high value invertebrates mentioned above.

Throughout much of coastal Melanesia, trochus fisheries are "managed" with serial closures – the well-known *tambu* or *tapu* system. Some authors (e.g. Cinner et al. 2005; Hickey 2006; Johannes 2002) have argued that this "long-enduring" system (see Polunin 1984 for some important qualifications to this common assumption) constitutes a culturally appropriate and indeed "adaptive" form of fishery management for the Pacific. I would argue that the efficacy of this system is highly contingent on a host of other considerations, including all of those listed above. The *tambu/tapu* system has failed to prevent the commercial extinction or near-extinction of green snail, giant clam, sandfish and black teatfish throughout much of their range. But trochus populations, while they have clearly declined in some areas, appear not to have suffered quite the same level of depletion yet, in most places.

One of the shortcomings of the use of serial closures, particularly for commodity fisheries, is that when the closed area is opened to fishing, fishing effort can often be very intense and unrestrained – people usually harvest every last individual that they can find. In the case of trochus, it appears that a certain proportion of the population, perhaps up to a third, is hidden deep in reef crevices and out of reach of divers at any one time. Indirect evidence for this behaviour is provided by the observation that trochus populations tend to increase noticeably just after the full moon in summer months, when many animals apparently leave their hiding places and move to relatively exposed positions on the reef to spawn (Foale 1998a, b, 2000). A serial closure system means that those individuals that evade capture during a harvest (assuming all harvests are not timed to coincide with spawning) will then enjoy protection during the subsequent prohibition, and this may guarantee a level of population replacement sufficient to prevent stock collapse.

In contrast, green snail does not appear to enjoy such an ecological/behavioural refuge, and given the similar life history and depth range (Yamaguchi 1993),[2] it has experienced a very different fate throughout the same geographic range. White teat sea cucumbers (*Holothuria fuscogilva*) enjoy a different kind of refuge – depth. This species can be found as deep as 40 m (Skewes et al. 2002), putting a significant proportion of the population out of reach of free divers. Even using SCUBA or hookah, a diver cannot spend long at 40 m without risking decompression sickness. Consequently, white teat populations have not been depleted nearly as drastically over the past two decades as sandfish (*H. scabra*) or black teat (*H. whitmaei*) (National Fisheries Authority, Papua New Guinea, 2005, 2007a, b; Skewes et al. 2002).

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[2] The price offered to fishers for green snail in New Ireland Province, PNG (K 4.71 kg^{-1}) is slightly lower than for trochus (K 5.24 kg^{-1}) (National Fisheries Authority (Papua New Guinea) 2005), while in Vanuatu it is considerably higher (VUV 1,700–3000 kg^{-1} vs VUV 170–300 kg^{-1}) (Amos 2007).

There may well be other factors that have contributed to the differences in abundance patterns of trochus and other nearshore commodity fishery species. The minimum size limit of 8 cm basal shell diameter (9 cm in Vanuatu: Amos 2007) appears to have been reasonably well enforced in Solomon Islands since the late 1990s, and this measure ensures that each individual is sexually mature for about a year before it enters the fishery (Foale and Day 1997). Such a measure may have also contributed significantly to the prevention of stock collapse, along with the hypothesised ecological/behavioural refuge mentioned above.

Conclusions

Amos (2007) reports that there is now a 10-year ban on green snail in Vanuatu. The beche-de-mer fishery has also recently been closed there, as it has in Solomon Islands. These are drastic though obviously necessary measures, which make it clear that community-based management in the form of traditional serial closures has not been sufficient to prevent the collapse or near collapse of several high value species. What I have argued here is that by virtue of aspects of the behaviour, life-history and ecology of trochus, perhaps in combination with minimum size limits imposed by governments, stocks of this fishery have declined but not collapsed in PNG, Solomon Islands and Vanuatu. Probably the best managed trochus fishery in the Pacific is the Aitutaki fishery (Nash et al. 1995), which is run on a simple quota system, and is subject to regular stock assessments involving members of the local community. The management scheme at Aitutaki was developed over several years of collaboration between the Cook Islands Fishery Department and the Aitutaki community, which clearly enjoys a high level of social cohesion, making compliance with the regulations much less problematic than in many parts of Melanesia.

My research on trochus in the Nggela group in Solomon Islands in the 1990s showed that the *tambu* system was not a spectacularly successful system for managing trochus fisheries, and indeed yields there compared very poorly to yields at Aitutaki at the time (Foale 1998a; Foale and Day 1997). But a visit to Sandfly Island in mid-2007 made it clear to me that the trochus fishery at Nggela continues to deliver a modest but steady yield. While differences in reef type between Nggela (fringing reefs) and Aitutaki (an atoll) make it difficult to be too assertive about the differences in productivity of these fisheries, it does appear that trochus fisheries could perform much better with a quota-based management system in Melanesia. Setting up and enforcing such a system would probably be more challenging than it was in Aitutaki, however, given the high levels of social and political fragmentation in the Melanesian countries and the low levels of donor support to their Fisheries Departments.

The evidence at hand does not appear to support the argument that traditional serial closures are an "adaptive" form of management for nearshore fisheries in general in the Western Pacific. A closer examination of each fishery shows that some species, including trochus, have fared much better under this system than others, and that stock dynamics for the different fisheries are better explained using the framework outlined above. Serial closures do not appear to be likely to adapt to the inevitable increase in fishing effort that accompanies growing human populations and rising commodity prices driven by increased demand from China, along with the growing scarcity of many marine products. What is clearly needed across the region is greater support to governments to assist in establishing effective and transparent monitoring and regulatory measures to prevent further stock collapses and (if possible) rehabilitate severely depleted fisheries such as those discussed here.

Figure 1.
Wild male trochus spawning (Solomon Islands).

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Update on aquaculture of marine gastropods and bivalves in Vanuatu

Antoine Teitelbaum[1] and Sompert Rena[2]

Gastropods and bivalves, including giant clams, trochus and green snails, have been commercially exploited in Vanuatu for decades. The heavy fishing pressure on these organisms has led the Vanuatu Fisheries Department (VFD) to consider artificial propagation of some of these species to (i) replenish overfished stocks, (ii) substitute the export of wild-caught animals with farm-raised animals, and (iii) develop new and sustainable industries for the country.

Trochus, giant clams and green snails remain the species of major interest for mollusc aquaculture in Vanuatu. However, other species such as edible oysters and pearl oysters could generate some interest for further aquaculture diversification in Vanuatu.

Trochus

Trochus (*Trochus niloticus*) is primarily targeted for its shell, which is processed locally into blank buttons (Fig. 1) and exported to China and Hong Kong. Trochus shells are sold to button factories for VT 350–450 per kg (USD 3.7–4.7 per kg). In 2006, a total of 36 tonnes (t) of processed trochus shell was exported, contributing more than VT 35 million (±USD 325,000) in foreign exchange. In 2007, exports increased to about 55.2 t, harvested from five provinces. All shells were sold and processed by the sole licensed exporter in Port Vila.

Trochus have been produced at VFD's hatchery since the early 1980s to assess the potential of reseeding the reefs of Vanuatu to enhance the fishery. The Australian Centre for International Agricultural Research (ACIAR) has funded extensive research focusing on various aspects of trochus biology and aquaculture, including nutrition, seed production and community participation in stock management.

The annual production from the hatchery is around 20,000 seeds, most of which are supplied to communities for restocking purposes. The continuous involvement of Vanuatu in trochus research demonstrates the importance of this resource to the economic and social well-being of its rural communities.

One of the major challenges faced in producing trochus in Vanuatu was the deteriorating water quality of Port Vila harbour where the trochus hatchery is located. The hatchery was renovated in 2006 with financial assistance from the Japan International Cooperation Agency (JICA) (Figs 2 and 3). This work reduced the water-quality problems and should enhance the survival of seeds produced in the hatchery.

Figure 1. Processing buttons at Vanuatu 's only trochus shell factory. (Image: Antoine Teitelbaum)

Figure 2. Fibreglass raceways at VFD facilities (donated by JICA), used for producing marine molluscs. (Image: Antoine Teitelbaum)

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Figure 3. Header tank, pumping and filtration room at VFD aquaculture facility, donated by JICA. (Image: Antoine Teitelbaum)

Figure 4. *Tridacna maxima* being produced by a private exporting facility. (Image: Antoine Teitelbaum)

Figure 5. *Tridacna squamosa* spat being settled on concrete blocks at VFD aquaculture facility. (Image: Antoine Teitelbaum)

Giant clams

In 2001, the first batch of giant clams (*Tridacna crocea*) was successfully produced at the VFD land-based hatchery, with the aim of assessing the potential for restocking reefs as well as the commercial value of the clams on export markets. The work was prompted by concerns over the large quantity of wild giant clams being harvested for the aquarium trade. As a result, several hundred pieces, valued at over VT 100,000, were sold live to aquarium product exporters in Port Vila.

Vanuatu has four giant clam species (*Tridacna maxima*, *T. squamosa*, *T. crocea* and *Hippopus hippopus*). Four hundred pieces of the locally extinct *T. gigas*, the true giant clam, were introduced from Tonga by JICA and VFD in 2007. After acclimation, 200 specimens were established at Mangaliliu village and 200 at Mosso Island, North Efate. VFD expects that once they are mature, they will be taken back to the VFD hatchery for spawning. The juveniles produced will then be used to restock the reefs of Vanuatu.

High numbers of wild giant clams were harvested for the aquarium trade in 2000 and 2001, with exports worth VT 4–7 million. Soon after, harvests of *T. crocea* from the wild for export were banned throughout the whole archipelago and in October 2007, VFD decided to ban the export of all species of wild giant clams. Now, only cultured clams can be exported.

The main market for cultured giant clams is the live aquarium trade. Clams are sold for high retail prices in overseas markets (USD 20–300 per piece). In Port Vila, exporters of aquarium products sell them at an average of VT 500 (USD 4.50) per piece, starting at a size of 4–5 cm (Fig. 4). There is also a lucrative market for the adductor muscle of the larger species, but it takes a long time to grow.

There is potential to engage communities in giant clam farming. Although mass seed production of giant clams in the hatchery for grow-out targeting the aquarium industry is yet to be shown to be commercially viable in Vanuatu, VFD is currently working on producing seeds for grow-out in rural coastal areas (Fig. 5). Rural grow-out is currently being trialled in Mangaliliu village, North Efate, and on Lelepa Island.

Green snails

Green snail (*Turbo marmoratus*) seed production in VFD's hatchery began in 2003. The objective was to assess the potential for propagation and reseeding to enhance the wild fishery on the reefs, where stocks had been heavily depleted by overfishing. Further trials were undertaken in 2007 through the coastal resource management project funded by JICA, in which green snail was identified as a priority commodity (Figs 6 and 7).

The current project is aimed at identifying ways to produce green snail seeds more easily. The seeds will be available for restocking reefs at targeted sites in Vanuatu. In 2007, VFD carried out two green snail spawning runs – one in February with relatively low survival (996 pieces) and another in September that resulted in much higher survival (3624 pieces).

Some green snail spawner groups have been established on the reefs off Efate and are protected to ensure increased natural seed production. The broodstock were collected from Anetiyum Island, which still holds a healthy broodstock. Targeted coastal communities are being trained to manage the spawner groups in the protected area surrounding their villages.

Pearl oysters

The potential for culturing black pearl (*Pinctada margaritifera*) was investigated in 1996 at Peskarus in the Maskelyne Islands in a collaboration between VFD and a Tahitian pearl company. The study concluded that while stocks of blacklip pearl oysters are present in the area, the numbers were not sufficient to support a commercial farm and the pearl farming trials were abandoned. However, hatchery technology is now widely available for pearl oysters and there is good potential in Vanuatu for pearl farming based on hatchery-reared spat production.

Other molluscs and further potential

Further research on wild spat collection for pearl oyster species, scallops or edible coastal oysters could bring benefits to Vanuatu's growing aquaculture industry. VFD is building its capacity in aquaculture and is working hard to develop the country's full potential in this area.

Vanuatu's proximity to export markets (Australia, New Caledonia, New Zealand), its own domestic market (growing population of 200,000, with 20% living in Port Vila) and the rapid development of tourism (85,000 visitors in 2006) are all assets for the country's economic development. Vanuatu has great potential for aquaculture thanks to its huge diversity of sites, excellent water quality and supportive economic and social environment.

Further reading

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Vanuatu Fisheries Department (in press) Vanuatu Aquaculture Development Plan 2008–2013. A collaborative work by Vanuatu Fisheries Department, Ministry of Agriculture, Livestock, Quarantine, Forestry & Fisheries, and SPC Aquaculture Section. 35 p.

Figure 6. Second batch of green snails (4 months old) produced at VFD hatchery facility. (Image: Kenichi Kikutani)

Figure 7. Ten-month-old green snails ready for restocking. (Image: Antoine Teitelbaum)

Successes and failures in reintroducing giant clams in the Indo-Pacific region

Antoine Teitelbaum[1] and Kim Friedman[2]

Background

Giant clams (Tridacnidae) are the largest marine bivalves found in coastal areas of the Indo-Pacific region. Eight species of giant clam of varying size and habitat preference have been described (*Tridacna gigas, T. derasa, T. squamosa, T. maxima, T. crocea, T. tevora, Hippopus hippopus and H. porcellanus*). In addition to the colourful smaller boring clams, such as *T. maxima* and *T. crocea* that are found within limestone substrates, larger free-living species such as *T. squamosa, T. derasa and T. gigas* are usually recorded near reefs or over sand. Similarly, *Hippopus* spp. are often found on soft substrata, e.g. in seagrass beds. These bivalves are unusual in that they host symbiotic zooxanthellae within their mantle tissue and benefit from the products of photosynthesis, which provides part of their nutrition.

Giant clams are a highly prized food source, and both harvesting by subsistence fishers and exports of clam meat have been responsible for stock depletion across their range. The clams are also harvested for their shells and for live export for the marine aquarium trade. Although fishing by foreign vessels (for the adductor muscle) caused much of the depletion of the largest species, giant clams are now mostly under pressure from subsistence and semi-commercial (artisanal) fishers.

Giant clams have been depleted from coral reefs because they are slow growing, non cryptic and generally easily accessible to fishers. Habitat degradation is also responsible for declines in abundance, especially close to larger urban centres. Due to these pressures, and their depletion and slow recovery from overfishing, giant clams are listed under Annex II of CITES (1983), and are considered vulnerable under the IUCN red list of threatened species (1996).

Although there are examples of local extinctions (*T. gigas* in Guam, Mariana Islands, Federated States of Micronesia, New Caledonia, Taiwan, Ryukyu Islands and Vanuatu; *T. derasa* in Vanuatu; and *H. hippopus* in Fiji, Tonga, Samoa and American Samoa, Guam, Mariana Islands and Taiwan), in most cases giant clams are not eradicated through fishing and habitat change. In general, declines in abundance result in a pronounced constriction of their range and reduced spawning success as giant clams are sessile and cannot actively aggregate for sexual reproduction.

Programmes to re-establish or supplement depleted populations of giant clams have centred around two main activities: (1) protecting and aggregating remaining wild adults to facilitate spawning and fertilisation success and subsequent "downstream" recruitment, and (2) breeding and releasing hatchery-reared clams. In the early 1980s, several government and private institutions throughout the Indo-Pacific region agreed to a joint effort to propagate giant clams and restock the reefs of Pacific Island nations (Bell et al. 2005). The organisations involved in hatchery and early culture research were the Okinawa Prefectural Fisheries Experimental Station, University of Papua New Guinea, Micronesian Mariculture Demonstration Center, Australian Centre for International Agricultural Research, Marine Science Institute at the University of the Philippines, and WorldFish Center (formerly known as ICLARM). Re-establishment and reinforcement of stocks and increased awareness of the plight of giant clams stemmed from these initiatives.

Goals of restocking programmes

The various restocking programmes that took place throughout the region shared three main goals:

- To reinforce giant clam stocks at overfished sites in the Indo-Pacific region. This goal cannot succeed in isolation from improved general management of remaining stocks, which is not covered in this submission.
- To reintroduce giant clam species in places where they have been extinguished, with the aim of re-establishing populations capable of self-replenishment.

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3. A ninth member, *Tridacna rosewateri* has been proposed, although not established as a new species as yet. *T. rosewateri* has been recorded in Mauritius.

- To improve aquaculture technology and early grow-out systems to assist restocking projects that could be monitored and supported through the development of a successful long-term breeding programme.

Main stages in reintroducing giant clams: methods, implementation and post-release monitoring

Feasibility

In some areas of the Indo-Pacific, natural recruitment was thought to be almost impossible (other than through self-fertilisation) as large mature clams were so scattered they were considered to be beyond the threshold density required for successful cross-fertilisation (e.g. Tonga, see Chesher 1995). Trials were carried out to augment stocks through aggregating adult clams to increase the chance of successful external fertilisation and subsequent downstream recruitment. In theory, aggregation of adults in "clam circles" (Chesher 1995) overcomes Allee (Courchamp et al. 1999; Stephens et al. 1999) or depensatory (Liermann and Hilborn 2001) effects (i.e. when a population falls below a certain threshold, its population growth rate may decrease due to factors such as greater difficulty in finding a mate, or dependence on a mating strategy that requires larger numbers). Although there are few quantitative studies showing the success of clam circles, the simplicity and practicality of this low-cost system encouraged their establishment in many countries (Tonga, Fiji, Vanuatu and Solomon Islands). The practice of concentrating clams in "clam gardens" has long been documented in northern Papua New Guinea (Mitchell 1972).

The availability of spat for reintroduction projects generally relies on hatchery production and early grow-out technology as most Indo-Pacific countries do not have access to sufficient juveniles from the wild. An exception is French Polynesia, where "collectors" are used to settle *T. maxima* spat in atolls with exceptionally large clam populations (Gilbert et al. 2006). Manuals have been produced that document hatchery and culture methods for giant clams (see Fig. 1, Calumpong 1992; Ellis 1998).

Depending on the species and location, it takes between 8 and 14 days after fertilisation for giant clam larvae to settle on the bottom of tanks. They are then held in nursery grow-out facilities (generally land-based raceways) for around 3 to 6 months before first handling, and up to 12 months before being transferred to ocean nurseries.

Usually, simple mesh cages, kept off the bottom, are used to protect the giant clams against large predators such as turtles, rays, octopus and fish (Figs. 2 and 3). Growth rates vary greatly among species (Munro 1993a). Even in this protected environment, predatory gastropods such as *Cymatium* spp. (Fig. 4) and pyramidellid snails can settle into cages as larvae, making predation unpredictable until the giant clams reach a larger "refuge" size when they are less susceptible (Govan 1995). Site selection and juvenile management practices (Fig. 5) have proved to be critical factors in improving survival of cultured clams (Hart et al. 1998, 1999).

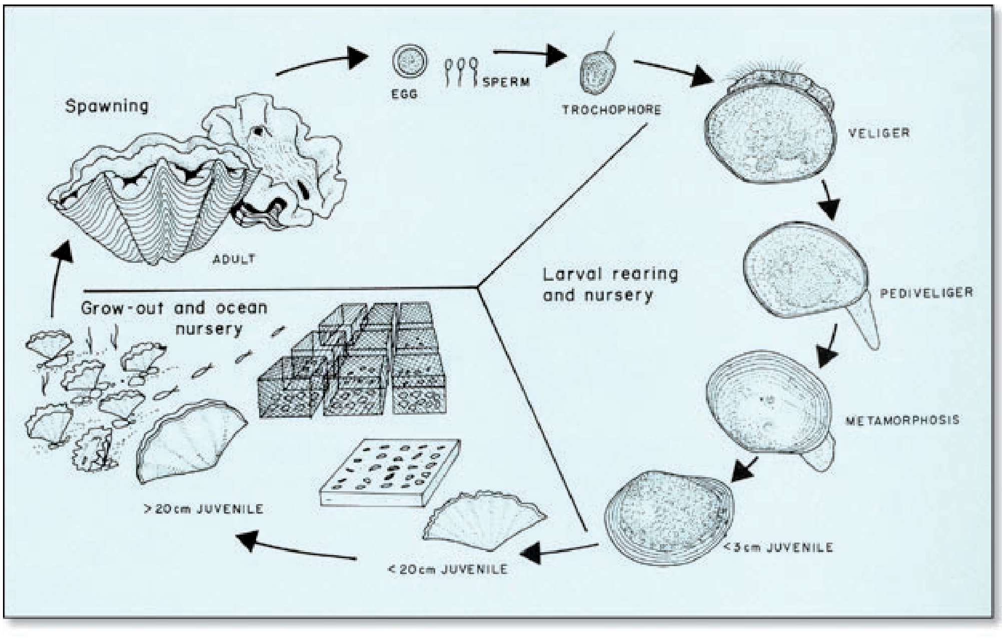

Figure 1. Four basic stages in clam culture, taken from Calumpong (1992).

Figure 2. Giant clam nursery cages near a coastal village in Solomon Islands. (Image: WorldFish Center)

Figure 3. Floating nursery cages used in Solomon Islands. (Image: WorldFish Center)

Figure 4. Predator (*Cymatium muricinum*) on juvenile *T. derasa* in Cook Islands. (Image: A. Teitelbaum)

Figure 5. In situ training on giant clam nursery practices in Solomon Islands. (Image: WorldFish Center)

A range of hatchery and nursery production systems are currently used in over 21 Indo-Pacific countries, but even low-tech operations still require trained personnel and specialised equipment. The process of maintaining large numbers of broodstock for hatchery production also requires holding adult specimens near hatchery sites (Fig. 6). These aggregations of broodstock, in more than 11 countries in the Pacific, also contribute to egg production and downstream settlement of clams.

Implementation

Clam restocking and stock enhancement projects have been carried out at various locations in the Indo-Pacific (Table 1).

Although programmes to aggregate adults have usually operated independently of commercial ventures, projects that rely on hatchery production have generally coupled re-establishment and reinforcement programmes with commercial clam farming activities.

Post-release monitoring

There has been little definitive proof of enhanced recruitment after the establishment of adult clams circles, although quantitative studies have detected increased settlement of *T. derasa* and *T. squamosa* on nearby reefs (Chesher 1995). For example, following establishment of clam circles at Falevai in Tonga's Vava'u Group, monitoring showed that the number of juvenile *T. derasa* (individuals per hour of searching) increased from 0 in 1987 to 1.48 in 1990. The increase was consistent over yearly assessments, and was even greater for the medium-sized clam, *T. squamosa*. There was no change in the average number of *T. maxima*, which were not aggregated. The real number of new recruits detected after the establishment of clam circles is low, but detection rates for juvenile clams are normally low, and this rate is higher than reported by other surveys of clam recruitment elsewhere in the Pacific (Braley 1988).

An interesting opportunity now exists to detect increased recruitment around *T. gigas* release sites on Australia's Great Barrier Reef. Concentrations of hatchery-reared *T. gigas* were relocated to reefs some distance away from the hatchery, and these clams have now had sufficient time to become egg-producing adults (giant clams mature first as males and later become functional hermaphrodites). It would be interesting to study whether additional recruitment is taking place downstream of these clam concentrations.

For clams returned to the wild at the end of nursery culture, high mortality is a major problem and further husbandry for up to three years is required to maximise survival (Bell et al. 2005). In the Philippines, where more than 75,000 clams have been restocked (Gomez and Mingoa-Licuanan 2006), 10,000 were placed in the Hundred Islands National Park. As many as 7531 remained after 2.5 years, with the last inventory showing that losses were predominantly among the juvenile size classes. Only 2% of sub-adults and 1% of broodstock were lost. Mortalities were attributed to typhoons, fouling, crowding, predation and poaching (Gomez and Mingoa-Licuanan 2006).

Figure 6. WorldFish Center *Tridacna gigas* broodstock at Nusatupe, Solomon Islands. (Image: WorldFish Center)

Table 1. Outline of Indo-Pacific giant clam restocking programmes*

Location	Organisation involved	Start	Species (translocated species in brackets)
American Samoa	Office of Marine and Wildlife Resources	1986	*(T. derasa), (T. gigas)*
Australia	James Cook University; ACIAR; Aquasearch (private company)	1984	*T. gigas, T. derasa*
Cook Islands	Ministry of Marine Resources	1986	*T. maxima, T. squamosa, (T. derasa), (T. gigas), (H. hippopus)*
Fiji	Fiji Fisheries Division	1985	*T. maxima, T. derasa, T. squamosa, (T. gigas), (T. tevoroa), (H. hippopus)*
French Polynesia	Service de la Pêche	2002	*T. maxima*
Federated States of Micronesia **	National Aquaculture Centre Marine and Environmental Research Institute of Pohnpei	1984	*(T. derasa), (T. gigas), (H. hippopus)*
Guam	Dept of Agriculture	1982	*(T. derasa), (T. gigas), (T. squamosa)*
Japan	Okinawa Prefectural Fisheries Experimental Station; Okinawa Kuruma-ebi Co., Ltd (private company)	1987	*T. crocea, T. squamosa, T. maxima, (T. derasa)*
Kiribati	Atoll Beauties (private company)	2000	*T. maxima, T. squamosa*
Marshall Islands	Marshall Islands Marine Resources Authority; Robert Reimers Enterprises & Mili Atoll (private companies)	1985	*(T. derasa), T. gigas, T. squamosa, H, hippopus*
New Caledonia	IFREMER	1993	*H. hippopus, T. derasa, T. maxima, T. crocea, T. squamosa*
Northern Mariana Islands	Dept of Lands and Natural Resources	1986	*(T. derasa), (T. gigas), (H. hippopus)*
Palau	Micronesia Mariculture Demonstration Center	Late 1970s	*T. derasa, T. gigas, T. squamosa, T. maxima, T. crocea, H. hippopus, H, porcellanus*
Papua New Guinea	UPNG – Motupore Island Research Centre	1983	*T. gigas, T. squamosa, T. crocea, H. hippopus*
Philippines	University of the Philippines Marine Science Institute	1987	*T. maxima T. squamosa, H. hippopus, (T. derasa), (T. gigas)*
Samoa	Samoan Fisheries Dept SPADP	1988	*T. maxima, T. squamosa, (H. hippopus), (T. derasa), (T. gigas), (T. squamosa)*
Solomon Islands	WorldFish Center	1989	*T. maxima, T. squamosa, T. derasa, H. hippopus, T. gigas*
Thailand	Department of Fisheries	1997	*T. squamosa*
Tonga	Ministry of Lands, Survey and Natural Resources; Japanese International Cooperation Agency (JICA); EarthWatch (private company)	1989	*T. maxima, T. squamosa, T. derasa, T. tevoroa, (T. gigas), (H. hippopus)*
Tuvalu	SPC/Tuvalu Fish	1989	*(T. derasa)*
USA (Hawaii)	Not available	1951	*(T. crocea), (T. squamosa), (T. gigas)*
Vanuatu	Vanuatu Fisheries Dept; JICA; Ringi Te Suh Marine Conservation Reserve, Malekula (Anon. 2000) (private companies)	1998	*T. maxima, T. squamosa, T. crocea, H. hippopus, (T. derasa), (T. gigas)*

* Also see Eldredge 1994 and Bell 1999.
** There are separate facilities in Yap, Chuuk, Kosrae and Pohnpei States.

T. gigas imported from Australia into the Philippines became female-phase mature as early as 1995, with second-generation clams being recorded at low density (R. Braley, pers. comm.). Yap is another example where re-establishment has occurred after translocation of hatchery-reared clams. Price (1998) argues that large clams were originally found on Yap but became extinct. The reintroduction of approximately 25,000 *T. derasa* to Yap from neighbouring Palau in 1984 resulted in only ≈8% survival of the introduced stock. However, these *T. derasa* matured, reproduced and re-established viable populations on nearby reefs (Lindsay 1995). Surveys conducted by the Secretariat of the Pacific Community (PROCFish/C–CoFish programmes) noted the continued presence of *T. derasa* in low numbers in mid-2006.

When smaller boring species (*T. crocea*) were restocked in Japan, survival of clams ranged from 0.3–56% three years after release. Survival was found to be higher when individual clams were settled into pits on *Porites* heads or on to artificial substrates and then released in situ, rather than releasing thenm directly on to limestone substrates (Masayoshi 1991; Murakoshi 1986). In Australia, predation of *T. gigas* was lower when clams were held in the intertidal zone (Lucas 1994), and in Solomon Islands, *H. hippopus* was held on the bottom but behind suspended cargo netting, to protect medium-sized, hatchery-reared clams from predation by large rays.

Major difficulties faced and lessons learnt

Difficulties

The range of difficulties encountered by various restocking programmes involve biological, technical and human factors.

When placed at sea, survival of juvenile giant clams (<25 mm shell length) is generally low even with protection and husbandry (Heslinga et al. 1984), and therefore clams require approximately nine months in land-based nurseries. Clams only reach a general refuge size at a shell length of around 150 mm. Even then, they are still vulnerable to rays, triggerfish and turtles (Heslinga et al. 1990).

Producing giant clam spat in hatcheries and holding them in early juvenile culture is relatively expensive. Estimates of the cost of raising juveniles till ready for transfer to sea range from USD 0.27 to 0.36 per individual (Hambrey and Gervis 1993; Tisdell et al. 1993). These estimates do not reflect the full capital cost of hatchery development. Furthermore, a variety of skills are needed for spawning giant clams and rearing spat until refuge size and these skills are not always available or funded for long periods, making some operations unsustainable.

Poaching of broodstock from clam circles, and clams from hatchery and restocking areas, has also been a problem. A very recent example of such a loss occurred in January 2008 in French Polynesia, where numerous clams restocked from the Tuamotu Islands to the Faaa site in Tahiti were poached just a few days after they were settled on a reef within a marine reserve (G. Remoissenet, pers. comm.).

From a biological standpoint, genetic diversity of hatchery-reared stock is likely to be lower, or in some cases different from that found in wild populations (Benzie 1993; Munro 1993b). Hatcheries also increase the potential for introduction of pathogens (Eldredge 1994). Although there have been no reports of mortality associated with viruses, *Chlamydia*, *Mycoplasma*, fungi, or neoplasms (Braley 1992), Rickettsia-like organisms have been noted in local and translocated giant clams. Furthermore, mass mortalities of *T. gigas* and *T. derasa* have been recorded on the Great Barrier Reef, although tests were not successful in identifying the pathogen involved (Alder and Braley 1989).

Lessons learnt

Many lessons have been learnt from these programmes over the years and most still apply.

The relatively high cost of producing giant clams suggests that managing wild stocks may be more cost efficient than investing in hatcheries to restock overfished giant clam populations (Bell et al. 2005).

Site selection and early stock husbandry are critical to the survival of giant clams, especially hatchery-reared juveniles. Selection of a site with suitable environmental conditions, and where there is social cohesion within the nearby community, assists the growth and general condition of stocks, while minimising losses to predation and/or poachers.

Stakeholder consultation is an essential part of successful restocking of giant clams. Reaching informed agreement between researchers, government workers and local villagers requires extended periods of awareness raising and information sharing. Special care should be taken to see that programmes respond appropriately to traditional reef tenure systems and encourage direct community and fisher participation in reintroduction and reinforcement programmes.

The original premise of the ICLARM/ACIAR Giant Clam Project initiated in 1984 was that the economic burden of producing large enough clams for restocking could be spread by coupling restocking programmes with commercial farming. This premise has been supported. The technology developed for clam production has in some cases been transferred to the private sector, and a number of people across the Pacific are employed to produce clams for the marine ornamental trade. A proportion of this production is also available for restocking.

Conclusion: limited success of giant clam restocking programmes

The success of reintroduction and reinforcement programmes aimed at placing clams in coastal environments has varied. Projects have been carried out in Australia (GBR), Asia (Philippines) and the Pacific (notably in Palau, Solomon Islands, Vanuatu, Tonga, Marshall Islands and Cook Islands). However, in general, after more than 20 years of work, most restocking projects can be considered to have been only partially successful. The reasons for these mixed results include:

- the high cost and length of time required to produce "seed" clams have limited the sustainability of many operations. The high mortality of juvenile clams has also lowered success rates.
- lack of social adhesion in communities participating in several of these projects. In some cases, projects were not well matched to the communities' needs or wants.
- lack of funding for monitoring and the absence of standard protocols for surveys have limited the reporting of successful results from some reintroduction and reinforcement programmes.

Rearing and growing clams have been learning processes for many of the participating countries. In the course of this activity, many countries now have greater knowledge of the clam life cycle and a more realistic awareness of the value of these resources. In some places, this has resulted in increased protection of giant clams at both national and community levels.

A further advantage is that the methods used to rear and grow clams have been adopted, refined and transferred between countries. The successful introduction of simple hatchery and early rearing processes has seen increased capacity development in countries, and local operators are now progressing from clams to more "difficult" species (Friedman and Tekanene 2005). Currently, simple hatchery technology is also being adopted by the private sector in a handful of Pacific Island countries and territories, and giant clam production is seeing another rise, this time to target the marine ornamental trade.

Acknowedgement

This article was taken from an IUCN submission on selected case studies in reintroductions for which SPC prepared the submission, "Re-introduction of giant clams in the Indo-Pacific". The IUCN book is due to be published in 2008.

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Abstracts & publications

Restocking and stock enhancement of coastal fisheries: potential, problems and progress

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Source: Fisheries Research 80(1):1–8. August 2006.

The demand for fish is expected to rise substantially by 2020. Although aquaculture must provide much of the additional fish, it remains to be seen whether restoration or enhanced production of various capture fisheries can also help fill the projected gap in supply. The key challenges for these capture fisheries involve reducing fishing effort, removing excess fishing capacity and building the institutional arrangements needed to restore spawning biomass to more productive levels, and to reverse degradation of the supporting habitats. Two interventions, based largely on hatchery technology, have the potential to reduce the time needed to rebuild some severely over-exploited fisheries, or improve the productivity of other "healthy" fisheries. These interventions are "restocking", which involves releasing cultured juveniles to restore spawning biomass to levels where the fishery can once again support regular harvests, and "stock enhancement", which involves release of cultured juveniles to overcome recruitment limitation. However, despite the potential of these interventions, few restocking and stock enhancement programmes have met expectations. The main problems have been a pre-occupation with bio-technical research at the expense of objective analysis of the need for the intervention, and integration of the technology within an appropriate management scheme that has the participation and understanding of the users. The papers presented at the Special Symposium on this subject at the 7th Asian Fisheries Forum provide a series of valuable lessons to guide objective assessment of the potential for restocking and stock enhancement, and how to implement these interventions responsibly and effectively where they are deemed to add value to other forms of management. Above all, these studies help demonstrate that restocking and stock enhancement programmes are applied in complex human-environment systems, involving dynamic interactions between the resource, the technical intervention and the people who use it.

Achievements and lessons learned in restocking giant clams in the Philippines

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Source: Fisheries Research 80(1):46–52. August 2006.

For almost 20 years, the Marine Science Institute (MSI), University of the Philippines, has been culturing giant clams to restore depleted populations of these large bivalves in the Philippines, and to promote giant clam farming as a sustainable livelihood. Restocking activities were done in collaboration with local groups by providing training in the culture and ocean rearing of giant clams, and by implementing a "user pays" approach. Initially, a variety of giant clam species were used but once F1 broodstock of *Tridacna gigas* were reared, restocking focused on this species due to its scarcity and fast rate of growth. About 20 000 *T. gigas* were placed on coral reefs with assistance from the Pew Foundation and the Philippine Tourism Authority. In addition, >50 000 clams (*T. gigas, T. squamosa, T. derasa, T. crocea, T. maxima* and *Hippopus hippopus*) were distributed through other means. Altogether, >40 sites throughout the Philippines received cultured giant clams. Grow-out trials to test the viability of supplying giant clams for the aquarium trade to create new sources of income were conducted successfully with a group of fishers in Bolinao, Pangasinan. However, this initiative encountered legal obstacles when the government regulatory agency prohibited the export of cultured clams, regarding this as a threat to the conservation of wild individuals. The long experience in culturing and restocking giant clams in the Philippines provides many lessons for other countries wishing to restore stocks of these large bivalves. Particular care needs to be given to selection of release sites, negotiations with participating groups to safeguard the released clams, adequate transfer of technology to collaborators, and transport of large clams from nursery areas to release sites.

Stock enhancement of the Japanese scallop *Patinopecten yessoensis* in Hokkaido

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Source: Fisheries Research 80(1): 62–66. August 2006.

Prior to the early 1940s, harvests of scallops from Japan fluctuated from ~10,000–80,000 tonnes per annum. However, the fishery collapsed in 1945 and production remained at chronically low levels (<100 tonnes p.a.) in key areas. A breakthrough in methods for catching juvenile scallops (spat) for grow-out in hanging culture paved the way for the restoration, and eventual stock enhancement, of the major scallop fisheries in Hokkaido Prefecture. Following this breakthrough, scallop fisheries were managed using a system based mainly on: (1) mass-release of cultured juveniles, (2) removal of predators, and (3) rotational fishing, i.e. partitioning fishing grounds into four areas, releasing one-year-old juveniles into one area each year, then harvesting them three years later. This management system was pioneered largely by the fisheries cooperative at Sarufutsu, Hokkaido, and catches there improved from <100 tonnes to consistent harvests of 40,000 tonnes p.a. Similar management systems have been adopted by neighbouring fisheries cooperatives, resulting in current total harvests of scallops from stock enhancement in Hokkaido of ~300,000 tonnes p.a. The success of scallop stock enhancement in Hokkaido is attributed to a good supply of larvae, development of simple and effective methods for catching and rearing spat, ideal habitat for growth of scallops, removal of predators, and devolution of management to fisheries cooperatives. The management system developed in Hokkaido should be transferable to other locations where there is a good natural supply of spat, low levels of predation, currents that retain larvae, and incentives for fishermen to invest in the capture, rearing and release of spat and the implementation of rotational fishing.

Abundance and distribution of queen conch (*Strombus gigas*, Linné 1758) veligers of Alacranes Reef, Yucatan, Mexico

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Source: Journal of Shellfish Research 26(1):59–63. April 2007.

Distribution and abundance of *Strombus gigas* (Linné 1758) larvae were studied in Alacranes reef to identify if this marine protected area could be a basin site for recruitment of this species. Duplicate samples were collected every month from November 1999 to October 2000. Plankton tows were made with a conical net of 302-µm mesh-size. During the sample period, 1,864 veligers were collected. Larvae were more abundant during June through August, with 1,288 larvae (69.10%), September through February with 367 larvae (19.69%), and 209 larvae were counted in March through May (11.21%). Larval density varied from 0.31 veligers 10 m^{-3} in March to 5.24 veligers 10 m^{-3} in June; 86.42% of larvae were less than 350 µm, and 2.35% were between 450 and 950 µm. A high abundance of small sizes suggests that Alacranes reef is a very important basin site for the recruitment of *Strombus gigas* larvae. Moreover surface marine current in Alacranes reef is northeast and crossing the lagoon reef, thus Alacranes could supply *S. gigas* larvae to Florida.

Isolation and characterization of eight polymorphic microsatellite markers from pink conch (*Strombus gigas*)

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Source: Molecular Ecology Notes 7(4):597–599. July 2007.

Many marine organisms have pelagic larvae, and these are often important agents of dispersal. The larval phase and the multiple paternity that occur in marine gastropods such as *Strombus gigas* are crucial for the success of this species throughout the Caribbean Sea. To analyse these factors, we developed eight microsatellite loci specific to *S. gigas*. On the same set of individuals, the microsatellite loci exhibited a greater level of polymorphism than previously studied allozyme markers and thus, will permit fine-scale analysis and larval pool studies.

Interactions between translocated and native queen conch *Strombus gigas*: evaluating a restoration strategy

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Source: Endangered Species Research 3:259–266. December 2007.

The proactive strategy for restoring Florida's depleted queen conch *Strombus gigas* population includes increasing the spawning stock by translocating reproductively deficient individuals into existing spawning aggregations where our previous research has shown that the translocated conch will develop normally. However, there may be unintended and potentially negative ecological ramifications if the translocated conch displaces the native conch. To examine this issue, we translocated non-reproductive adult conch into two offshore spawning aggregations and used acoustic telemetry to track them relative to similarly tagged native conch. At one aggregation, the home range sizes of native conch were significantly smaller than those of the translocated conch, which led to a significant reduction in the static interaction (i.e. home-range overlap) between the two groups of conch. However, the dynamic interaction (i.e. sociality coefficient) among the translocated conch was significantly higher. We hypothesize that these results were driven by reproduction: the translocations took place in July during the breeding season, and because the translocated conch were not yet in reproductive condition they moved into forage habitats, while the natives occupied the breeding habitats. At the other aggregation, there were no significant differences in the movements or interactions between native and translocated conch, a result probably due to the mosaic of habitats at this site, where breeding and forage areas are in close proximity. Our results indicate that displacement of natives did not occur at either site, and that translocating conch into spawning aggregations does not have adverse consequences relative to the interactions among conspecifics.

Integrating customary management into marine conservation

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Source: Biological Conservation 140(3–4): 201–216, December 2007.

In many parts of the world, there is increasing interest among scientists, managers and communities in merging long-enduring customary practices such as taboos that limit resource use with contemporary resource management initiatives. Here, we synthesize the literature on the customary management of coral reefs emerging from diverse disciplines including anthropology, common property economics, and ecology. First, we review various customary management strategies and draw parallels with Western fisheries management. Secondly, we examine customary resource management and conservation. We argue that, while resource conservation often appears to be an unintended by-product of other social processes, customary management can, in fact, conserve marine resources. In the third section, we examine the resilience of customary management institutions to socioeconomic transformations. We suggest that in conditions of high population and commercialization of marine resources, property rights may become strengthened but arrangements that rely on self-restraint become weakened. Finally, we examine the commensurability of customary management and conservation. We emphasize that practical and conceptual differences exist between customary management and contemporary conservation, which have often led to failed attempts to hybridize these systems. However, when these differences are understood and acknowledged there exists a potential to develop adaptive management systems that are: (1) highly flexible; (2) able to conserve resources; and (3) able to meet community goals. In each section, we provide research priorities. We conclude by developing six key features of successful hybrid management systems.

Growth and differentiation during delayed metamorphosis of feeding gastropod larvae: signatures of ancestry and innovation

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Source: Marine Biology 153(4):723–734. February 2008.

Extent of larval growth among marine invertebrates has potentially profound implications for performance by benthic recruits because body size influences many biological processes. Among gastropods, feeding larvae often attain larger size at metamorphic competence than non-feeding larvae of basal gastropod clades. Delay of metamorphosis can further influence size at recruitment if larvae continue to grow during the delay. Some caenogastopod larvae grow during delayed metamorphosis, but opisthobranch larvae do not. Data on larval growth of neritimorph gastropods are needed to help determine which of these growth patterns for planktotrophic gastropod larvae is more derived. We cultured planktotrophic larvae from all three major gastropod clades with feeding larvae through delays of metamorphosis of 3–10 weeks. Larvae of the caenogastropod *Euspira lewisii* and the euthyneurans *Haminoea vesicula* (Opisthobranchia) and *Siphonaria denticulata* (Pulmonata) conformed to previously described growth patterns for their respective major clades. Furthermore, the caenogastropod continued to lengthen the prototroch (ciliary band for swimming and feeding) and to differentiate prospective post-metamorphic structures (gill filaments and radular teeth) during delayed metamorphosis. Larvae of the neritimorph *Nerita atramentosa* arrested shell growth during delayed metamorphosis but the radula continued to elongate, a pattern most similar to that of non-feeding larvae of *Haliotis*, a vetigastropod genus. Character mapping on a phylogenetic hypothesis suggests that large larval size and capacity for continued growth during delayed metamorphosis, as exhibited by some caenogastropods, is a derived innovation among feeding gastropod larvae. This novelty may have facilitated post-metamorphic evolution of predatory feeding using a long proboscis.

The presence of GABA in gastropod mucus and its role in inducing larval settlement

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Source: Journal of Experimental Marine Biology and Ecology 354(2):182–191. January 2008.

Chemical substances that induce larval settlement have been the focus of many gastropod studies due to the importance of wild stock recruitment and production within aquaculture facilities. Gamma-aminobutyric acid (GABA), GABA analogs, and GABA-mimetics associated with certain crustose coralline algae (CCA), are known to induce larval settlement in commercial abalone (Haliotis) species, and other gastropods. Furthermore, mucus secreted from these gastropods has been shown to induce larval settlement, but the stimulatory components of mucus have not been thoroughly investigated. We now present data confirming that GABA is the settlement-inducing effector molecule contained within abalone mucus. To do this, we initially generated anti-GABA for use in immunoenzyme and immunofluorescent microscopy. Using these techniques GABA was identified in the nerves and epithelial cells of the foot, including mucus. Dried mucus samples subject to HPLC analysis revealed a mean concentration of 0.68 mM GABA after sample rehydration. The presence of GABA in these samples was confirmed by time-of-flight mass spectroscopy (TOF-MS). In addition, GABA was detected in the mucus of several abalone species and other gastropods by immunocytochemistry. Subsequent bioassays using both dry and fresh mucus strongly promoted induction of larval settlement.

Distribution of large benthic gastropods in the Uruguayan continental shelf and Río de la Plata estuary

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Source: Journal of Coastal Research 24(1):161–168. January 2008.

We analyzed the distribution and ecology of large gastropods inhabiting the continental shelf of Uruguay and the Río de la Plata estuary, in depths ranging from 4 to 62 m. Seven species belonging to Tonnidae, Ranellidae, Muricidae, Nassariidae, and Volutidae were collected. While the seven species recorded in this study have been previously reported for the Uruguayan coast, here we provide the first detailed description of its habitat preferences in terms of depth, salinity, and sea bottom temperatures. Clustering analysis of stations based on biological data (presence/absence of species) indicated a spatial segregation of the large gastropods assemblages in three areas: estuarine, low specific richness, dominated by *Rapana venosa*; inshore (10 to 36 m), high richness, co-dominated by *Zidona dufresnei* and *Pachycymbiola brasiliana*; and offshore (21 to 62 m), intermediate richness, characterized by *Z. dufresnei*. Mean values for environmental parameters showed significant differences among clusters of stations. Direct developers were more ubiquitous than planktotrophic developers. On the other hand, the exotic planktotrophic species *R. venosa* dominated the estuarine area. This pattern is not coincident with predictions based on life history traits, such as dispersal capabilities; this suggests that generalizations in this respect are complicated and scale and species dependent.

Further twists in gastropod shell evolution

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Source: Biology Letters 4(2):179–182. April 2008.

The manner in which a gastropod shell coils has long intrigued lay people and scientists alike. In evolutionary biology, gastropod shells are among the best studied palaeontological and neontological objects. A gastropod shell generally exhibits logarithmic spiral growth, right-handedness and coils tightly around a single axis. Atypical shell-coiling patterns (e.g. sinistroid growth, uncoiled whorls and multiple coiling axes), however, continue to be uncovered in nature. Here, we report another coiling strategy that is not only puzzling from an evolutionary perspective, but also hitherto unknown among shelled gastropods. The terrestrial gastropod *Opisthostoma vermiculum* sp. nov. generates a shell with (i) four discernible coiling axes, (ii) body whorls that thrice detach and twice reattach to preceding whorls without any reference support, and (iii) detached whorls that coil around three secondary axes in addition to their primary teleoconch axis. As the coiling strategies of individuals were found to be generally consistent throughout, this species appears to possess an unorthodox but rigorously defined set of developmental instructions. Although the evolutionary origins of *O. vermiculum* and its shell's functional significance can be elucidated only when fossil intermediates and live individuals are found, its bewildering morphology suggests that we still lack an understanding of relationships between form and function in certain taxonomic groups.

Copulation behaviour of *Neptunea arthritica*: baseline considerations on broodstocks as the first step for seed production technology development

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Source: Aquaculture Research 39(3): 283–290. February 2008.

Copulation trials under three different scenarios were performed aiming to study the copulation behaviour of *Neptunea arthritica* and determine whether broodstock maintenance is required for artificial seed production. *Neptunea arthritica* showed polygamy, copulating at least three times with different partners. From all males and females used in this study, 43% of them copulated at least once. Female whelks showed rejection behaviour, which generated significant difference in copulation time between rejected (13.7 ± 10.7 min) and non-rejected (49.7 ± 44.7 min) males. The effect of body size on copula duration appeared to be superficial, while its effect on accumulative copulas played an important role as an indicator of copulation capacity because whelks varied in size. After first copula, males showed a contrasting tendency to mate copulated females over non-copulated females ($X^2 = 6.23$, d.f. = 1, $P = 0.01$). Broodstock maintenance as the first step in seed production is possible but considering low mating percentage and female rejection, it would be not economically reasonable due to the considerable number of whelks required and related logistical factors.

Do mussel patches provide a refuge for algae from grazing gastropods?

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Source: Journal of Molluscan Studies 74(1):75–78. February 2008.

On rocky shores, cover of macroalgae is often greater growing epibiotically on mussels compared to algae growing directly attached to rock. A survey of two shores on the east coast of Ireland confirmed that mussel beds contained greater percentage algal cover and more diverse algal assemblages compared to those on rock. The reasons for this difference are not clear. It has been suggested that mussel beds provide a refuge for algae from grazing gastropods. Surprisingly, we found no evidence to support this. Using wax discs, gastropod grazing patterns were found to be similar within the mussel beds as on rock. The mussel beds do not appear to provide a refuge for algae from grazing activity at this scale and we suggest other possible mechanisms for the prevalence of epibiotic algal cover on mussels. Intertidal grazers may in fact affect the epibiotic algae on mussels and thereby affect indirectly the persistence of mussel beds.

Molecular systematics of Vetigastropoda: Trochidae, Turbinidae and Trochoidea redefined

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Source: Zoologica Scripta, OnlineEarly Articles, June 2008 (to be adjusted).

Trochoidea are a large superfamily of morphologically and ecologically diverse marine gastropods. We present here an appraisal of the composition and relationships among *trochoidean* families based on molecular data, with an especial focus on the family Trochidae. Bayesian analyses of sequences from three genes (18S rRNA, 28S rRNA and COI), including data from 162 vetigastropod species, show that the gastropod family Trochidae (*sensu* Hickman & McLean (1990), *Natural History Museum Los Angeles County Science Series*, *35*, 1–169) is not monophyletic. Recognition of Chilodontidae, Solariellidae and Calliostomatidae at the family level is supported. Our new, more limited, definition of Trochidae includes the subfamilies Stomatellinae, Lirulariinae and Umboniinae and redefined Trochinae, Cantharidinae and Monodontinae. Halistylinae are provisionally retained in the Trochidae based on previous morphological studies. As redefined, Trochidae are a predominantly shallow-water radiation in the tropics and subtropics. Some subfamilies and genera previously included in Trochidae have been moved to an enlarged family Turbinidae. The family Turbinidae has been redefined to include Turbininae, Skeneinae, Margaritinae, Tegulinae, Prisogasterinae and most surprisingly the commercially important genus *Tectus* Montfort, 1810. The new definition of Turbinidae means that the family includes both predominantly shallow and deep-water clades as well as genera that are distributed across the globe from the poles to the tropics. A greater range of habitat is now seen in Turbinidae than in Trochidae. The redefined Trochidae and Turbinidae, together with Solariellidae, Calliostomatidae and Liotiidae, make up the superfamily Trochoidea. Phasianellidae and Colloniidae are recognized as belonging in a new superfamily, Phasianelloidea, and *Angaria* Röding, 1798 is recognized as belonging to a new superfamily, Angarioidea. Placement of Areneidae into a superfamily awaits further work.

Evolution of ecological specialization and venom of a predatory marine gastropod

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Source: Molecular Ecology 17(4):1156–1162. February 2008.

Understanding the evolution of ecological specialization is important for making inferences about the origins of biodiversity. Members of the predatory, marine gastropod genus *Conus* exhibit a variety of diets and the ability to capture prey is linked to a venom comprised of peptide neurotoxins, termed conotoxins. We identified conotoxin transcripts from *Conus leopardus*, a species of *Conus* that uniquely preys exclusively on hemichordates, and compared its venom duct transcriptome to that of four other *Conus* species to determine whether a shift to a specialized diet is associated with changes in the venom composition of this species. We also examined the secondary structure of predicted amino acid sequences of conotoxin transcripts of *C. leopardus* to identify substitutions that may be linked to specialization on hemichordates. We identified seven distinct conotoxin sequences from *C. leopardus* that appear to represent transcripts of seven distinct loci. Expression levels and the diversity of conotoxins expressed by *C. leopardus* are considerably less than those of other *Conus.* Moreover, gene products of two transcripts exhibited unique secondary structures that have not been previously observed from other *Conus*. These results suggest that transition to a specialist diet is associated with reduction in the number of components expressed in venoms of *Conus* and that diverse venoms of *Conus* are maintained in species with a broad dietary range.

Prolonged exposure to low dissolved oxygen affects early development and swimming behaviour in the gastropod *Nassarius festivus* (Nassariidae)

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Source: Marine Biology 153(4):735–743. February 2008.

Effects of low dissolved oxygen on early development and swimming behaviour of veliger larvae of the scavenging gastropod *Nassarius festivus* were studied. Embryonic development was significantly delayed when dissolved oxygen level was reduced to 3.0 mg O_2 L^{-1} and no embryo hatched successfully at 0.5 mg O_2 L^{-1}. Veliger larvae hatched at 4.5 mg O_2 L^{-1} had significantly smaller velar lobe, shell length and shell width. Median 48-h LC_{50} value of the veliger larvae was estimated at 1.25 mg O_2 L^{-1} with lower swimming speed (swimming velocity and dispersal velocity) being recorded for the survivors exposed to reduced oxygen levels. The percentage of veliger larvae that developed into crawling juveniles was significantly reduced and metamorphosis was delayed at 4.5 mg O_2 L^{-1} whereas all larvae at 3.5 mg O_2 L^{-1} died before they underwent metamorphosis. Juveniles developed at 4.5 mg O_2 L^{-1} were also smaller than those at 6.0 mg O_2 L^{-1}. Results indicated that dissolved oxygen levels well above hypoxia levels (2.8 mg O_2 L^{-1}) have significant impact on the hatching success and larval development in gastropods, which may lead to long-term decreases in population growth.

Original text: English

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