



Issue 15 – June 2010

# TROCHUS

and other marine molluscs

## information bulletin

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### Editorial

Greetings. First of all we would like to apologise to our readers, colleagues and contributors for the long time it took to release this new issue of the *Trochus Information Bulletin*. Unfortunately, contributions were somewhat slow to come and we had to wait this long to gather a suitable amount of material for publication. But we are proud to finally bring to your attention a suite of quality articles as well as the usual compilation of recently published papers.

This issue starts off with a contribution by Kalo Pakoa, Kim Friedman and Hervé Damlamian on the status of the trochus resource in Tonga, which provides a very comprehensive overview and a series of recommendations for management. Then comes a complete report on the population structure and abundance of *Trochus niloticus* in the Tubbataha Reefs Natural Park (Philippines), which addresses the insidious effects of poaching. This contribution is signed by Roger G. Dolorosa, Angelique M. Songco, Victor Calderon, Roy Magbanua and Jaysee A. Matillano. Finally, Ferral Lasi presents long-term data on trochus production in Solomon Islands (1953-2006), including regional comparisons and outlining interventions needed to cope with a significant decline in catches over the last decade. We sincerely thank all our contributors for taking the time to share their knowledge and expertise.

Perhaps we need to emphasise again that this *Bulletin* is yours to mould and that it welcomes contributions on all varieties of marine molluscs including bivalves and gastropods. We love trochus and will always encourage contributions on this topic, but don't be afraid to send in your reports and observations on giant clams, green snails, cowries, conches, mussels, scallops, etc. If you are studying nudibranchs or cephalopods, don't be shy, we will gladly publish your work as well.

This *Bulletin* is a unique outlet for all sorts of findings, questions and concerns. Aquaculture and fisheries projects as well as conservation and biology oriented subjects are equally well received. For instance, we would love to get notes and/or pictures of unique behaviours or interactions such as mating, spawning, egg laying, symbiotic associations, competition or predation (to name a few) to add to a special section of the *Bulletin*. Just provide the location, time of the day, any information on the available environmental factors that prevailed and your account of the activity. Short and sweet!

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For those of you who might be wondering, we accept manuscripts in French and in English. If need be, we will help you polish your contribution. If you are not sure about a prospective topic, please send us a quick email to discuss your idea. Start digging for unpublished data or forgotten observations and give them a new life by publishing them in this *Bulletin*. You never know who might benefit from or be inspired by your contribution. It would be our pleasure to bring together a diversified and colourful issue #16... but we need your help. So spread the word!

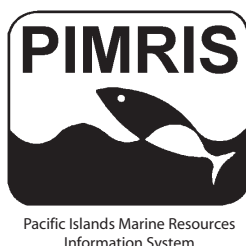
We remind you that the *SPC Trochus Information Bulletin* is distributed worldwide and indexed in databases such as Aquatic Sciences and Fisheries Abstracts (ASFA). It is also available on the Internet through the SPC webpages, where you will also find our complete instructions for authors (<http://www.spc.int/coastfish/News/SIG-instructions.pdf>).

We sincerely hope that you will enjoy this issue and we send you our warmest salutations from the faraway island of Newfoundland.

**Jean-François Hamel and Annie Mercier**

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PIMRIS is a joint project of five international organisations concerned with fisheries and marine resource development in the Pacific Islands region. The project is executed by the Secretariat of the Pacific Community (SPC), the Pacific Islands Forum Fisheries Agency (FFA), the University of the South Pacific (USP), the Pacific Islands Applied Geoscience Commission (SOPAC), and the Pacific Regional Environment Programme (SPREP). This bulletin is produced by SPC as part of its commitment to PIMRIS. The aim of PIMRIS is to improve the



availability of information on marine resources to users in the region, so as to support their rational development and management. PIMRIS activities include: the active collection, cataloguing and archiving of technical documents, especially ephemera ('grey literature'); evaluation, repackaging and dissemination of information; provision of literature searches, question-and-answer services and bibliographic support; and assistance with the development of in-country reference collections and databases on marine resources.

## The status of trochus (*Trochus niloticus*) in Tongatapu Lagoon, Kingdom of Tonga

Kalo Pakoa<sup>1</sup>, Kim Friedman<sup>2</sup> and Hervé Damlamian<sup>3</sup>

### Abstract

*Trochus niloticus* was introduced into Tonga in 1992 and 1994 at Tabana Island in the Vavau Group, and at Fukave and Euaiki islands on Tongatapu. Surveys conducted at released sites from 1995 to 2000 indicate positive recruitment of trochus on the reefs of Tongatapu. A baseline resource survey is required in order to provide stock information for management purposes. Independent surveys conducted in August 2006 by the Secretariat of the Pacific Community recorded *Trochus niloticus* at 70% of stations (total n = 1,125 individuals recorded). Trochus distribution across the lagoon was uneven, with western areas having denser aggregations than eastern areas. Aggregations were found on lagoonal reefs, fringing reefs of Atata and Poloa islands, and Sopa Reef. The mean size of trochus at Tongatapu (n = 697) was 9.5 cm ± 0.1 SE. With a mode of 10 cm, trochus stocks at Tongatapu comprise relatively young individuals, which is indicative of a young trochus resource in Tonga. The basal width of shells is split from west to east where significantly larger and older individuals were found in the eastern sector of Tongatapu Lagoon (mean size: eastern = 11.0 cm ± 0.2), while the central and western sectors had smaller individuals (central = 8.7 cm ± 0.1, western = 9.6 cm ± 0.1). It was difficult to determine (due to a lack of data) whether trochus reseeding efforts at Tongatapu contributed to this distribution pattern. We concluded that the existing stock is due to the successful recruitment from introduced breeders. Water circulation in Tongatapu Lagoon was analysed, and it was determined that there was a dominant lagoon flushing from east and north driven by 1) tidal flow from the open ocean in the north, 2) easterly winds that dominate 70% of the year, and 3) currents created from waves breaking over the reef at the southeast corner of the lagoon rim. Also, a system of weak currents develops in the central lagoon in front of Nukualofa where the currents converge. At this convergence zone, current flow weakens and any floating trochus larvae are expected to sink to the bottom and settle on suitable reefs. This finding supports the “source and sink” phenomenon, where the central lagoon area (Atata Island to Nukualofa Harbor) receives larval recruitment originating from the source population (breeding stocks) at the lagoon’s eastern sector. This result explains the dense aggregation of trochus found in the western sector of the lagoon at Atata Island.

### Introduction

#### *Trochus* biology

*Trochus niloticus* tend to be distributed according to age across the reef profile. Juveniles are found in shallow areas among coral rubble, while adults are found in increasing densities towards the reef edge. The optimum depth for trochus is between 10 m and 15 m, although they can be found as deep as 27 m. Trochus feed by grazing on corals and rocks for microscopic algae and diatoms. They reach reproductive maturity in the wild at around 2 years of age (approximately 6 cm basal diameter), while in captivity trochus reach sexual

maturity at 12 months. The lifespan of trochus is around 15–20 years, when their maximum basal diameter is around 14–15 cm. Like most other tropical gastropods *T. niloticus* is a dioecious (separate male and female individuals) broadcast spawner, and fertilisation takes place in the water column. Spawning is initiated by males, and females spawn in response to the presence of sperm in the water. Females generally spawn for 5–10 minutes, with individuals releasing more than 1 million oocytes (Nash 1985). Spawning often occurs in synchrony with lunar or tidal cycles, generally occurring at night and within one or two nights of either a full or new moon. Spawning occurs throughout the year in low latitudes and only during the warmer months

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in higher latitudes (Nash 1985). However, in the central region of the Great Barrier Reef, spawning occurs throughout the year. Hatching occurs after the larvae reach the trochophore stage (planktonic phase), approximately 12 hours after fertilisation. The larval phase lasts approximately three to five days and the veligers then settle onto the reef substrate and begin grazing on fine filamentous algae and microorganisms (Nash 1985). This short larval phase may limit long-distance dispersal, hence trochus populations are not likely to spread to reefs far away from the reproductive adults. Adult trochus are largely non-selective herbivores, grazing on the epibenthos of a wide variety of biotic and abiotic materials, including algae, foraminifera, mollusks and crustaceans. Small to medium sized individuals are cryptic, while larger specimens are often exposed and visible on the reef.

### ***Trochus* fishery in the Pacific**

Trochus shell is an important commodity for many Pacific Island communities. It has been exploited traditionally as raw material for natural shell button and jewellery. Its demand and easy access by fishers has led to overexploitation on many reefs. Adult trochus individuals have been introduced in areas that are naturally deficient. Historically, over 100 trochus broodstock transplantations have been carried out in the South Pacific since the 1920s. These transplantations were made between reefs, islands, atolls and among different countries (Gillett 2002). However, these activities have achieved varying levels of success. Trochus were introduced at Aitutaki Atoll (Cook Islands) from Fiji in 1957, and these individuals became a breeding population that provided a first harvest in 1981 of almost 200 t of shells (Sims 1988). Broodstock introduced into Tahiti in 1957 from Vanuatu (formerly New Hebrides) and New Caledonia developed a breeding population that provided a first commercial harvest of 350 t of shells 17 years later (Cheneson 1997). On the other hand, the introduction of trochus at Funafuti Atoll (in Tuvalu) from Fiji in 1985 was not successful (Wilson 1995).

### ***Introduction of trochus into Tonga***

*Trochus niloticus* was naturally absent in the Tongan islands, but was introduced from Fiji in 1992 and 1994 (Table 1). The first shipment of 250 individuals was released onto Tabana Island in the Vavau Group. The second shipment of 1,045 individuals was released on Fukave (645 individuals) and Euaiki (400 individuals) islands on Tongatapu (Manu et al. 1994; Gillett 2002). The reason for releasing trochus at Fukave and Euaiki islands was to promote the westward dispersal of the species to other reefs in the lagoon using the influence of the dominant southeasterly wind on wave currents at the southeastern end of Tongatapu Lagoon.

Monitoring surveys conducted at Fukave Reef by Tonga's Department of Fisheries staff from 1994–1996 continually recorded trochus, indicating the survival of broodstock. Surveys from 1999 and 2000 recorded an increased number of trochus at Fukave and an increasing number of trochus at other locations west of Fukave (Table 2) at sizes ranging from 50–125 mm. These findings confirmed that the newly introduced trochus had established a spawning population, and that recruitment had begun to spread to other reefs in the lagoon. Release sites at Euaiki and at Vavau were not assessed during this time, but local sources confirm that trochus have been observed at both of these sites (Ulunga Fa'anunu, Tonga Ministry of Fisheries, pers. comm. 2006).

### ***Trochus mariculture and seeding***

Mariculture provides an option for using artificially produced juvenile trochus for stock enhancement. The Tonga trochus breeding programme, funded by the Japanese government, began in 1994. The aim of the breeding programme was to supplement the introduction programme. The first trochus seeds were released in 1998 in the Haapai and Vavau groups, at an average size of 50 mm (Ministry of Fisheries Tonga 2004). More releases were made between 1999 and 2003, one in the Haapai Group and the rest at Fukave and Euaiki islands. Table 3 provides a summary of juvenile trochus that have been reseeded in Tonga. All released juveniles were tagged and measured at the hatchery before being transported to their release sites in plastic boxes. Juveniles were released by carefully placing them in an upright position inside a reef crevice for protection from predators.

Monitoring surveys of released juveniles were planned for 1, 12, 24 and 36 months after their release in order to assess survival, mortality, growth and dispersal (Kikutani and Yamakawa 1999). However, despite requests to Tonga's Ministry of Fisheries and the Japan International Cooperation Agency (JICA) expert (Kenichi Kikutani) in charge of the Tonga mariculture programme, no data were made available. We conclude that it is likely that juvenile recovery data were never collected, otherwise the information would have been made available to us or would have been published.

### ***Trochus distribution and dispersal***

There is currently little understanding of recruitment patterns in *T. niloticus* and the impacts of environmental factors, particularly water circulation, on trochus population and distribution. However, studies have been made on other invertebrate species, such as the coral-eating crown-of-thorns sea star, *Acanthaster planci*. Studies on *A. planci* on the

**Table 1.** Summary of trochus introductions into Tonga.

Date	Origin	Number	Alive	Release site
8/1992	Lakeba, Fiji	250	250	Tabana Island, Vavau (250 untagged)
5/1994	Lakeba, Fiji	1092	1046	
11/5/1994				Fukave, Tongatapu (400 untagged)
11/5/1994				Euaiki, Tongatapu (400 untagged)
30/5/1994				Fukave, Tongatapu (100 tagged) 140 adult trochus were reserved for breeding purposes at Tonga's Ministry of Fisheries hatchery.

Source: Gillett 2002; Manu et al. 1994

**Table 2.** Recapture of released trochus broodstock and newly recruited trochus at Tongatapu Lagoon.

	1994	1995	1996	1997	1998	1999	2000	2001	2002
Fukave	147	57	78			208	125		
Euaiki	65								
Onevao						1			
Nuku						0			
Velitoa						2			
Malinoa						0			
Fafa						2			
Pangaimotu						4	5		
Makaha					1	4			
Manima							2		
Kolonga							1	41	15
Navutoka								8	
Ulanga Lalo					3			93	

Source: Niumeitolu et al. 1999; Fa'anunu et al. 2000; Kikutani et al. 2006

**Table 3.** Hatchery-produced trochus seeding in Tonga.

Year	Release site	No. released	Size (mm)	Comments
1998	Haapai	350	50 +	sites unknown
	Vavau	380	50 +	sites unknown
1999	Haapai	450	50 +	sites unknown
2000	Fukave, Tongatapu	350	50 +	
	Haapai	500	50 +	sites unknown
2001				
2002	Ulanga Lalo, Tongatapu	400	50 +	
	Atata, Tongatapu	400	50 +	
2003	Ulanga Lalo, Tongatapu	600	50 +	

Source: Ministry of Fisheries Tonga 2004

Great Barrier Reef show that ocean current movements and speed, and water residence time are responsible for larval recruitment, which leads to outbreaks of *A. planci* in certain areas (Moran et al. 1992). The final destination of a recruiting larva is known as the “sink” where settlement occurs. Larval dispersal depends also on the pelagic larval duration; when considering the relatively short larval phase for *T. niloticus* (i.e. three to five days), localised recruitment is expected. However, studying recruitment behavior and patterns where a resident population exists can be difficult due to the ambiguity of results. The Tongatapu trochus is a new population that can provide a good case study in understanding the role of hydrodynamic conditions on the distribution of *T. niloticus*.

### Study site

Tongatapu is the largest and main island in Tonga. It is an upraised atoll with a land area of 259 km<sup>2</sup>. The lower northern side of the island is only a few meters above sea level while the southern coast is 65 m above sea level. Tongatapu has a bifurcated shallow lagoon (Fangauta Lagoon) with an average depth of about 1.2 m and a total area of 2,788 ha. Corals are found at the mouth of Fangauta Lagoon but are absent from most of the lagoon’s interior due to low salinity levels.

Tongatapu Lagoon, the study site for our survey work, includes all the waters outside of Fangauta Lagoon, and is bounded by the western barrier reef, eastern barrier reef and the waters just north of Mainoa Island (See Fig. 1). The barrier reef system opens up at the northern end of Tongatapu Lagoon, thus representing the sunken part of the atoll formation. A series of fringing reefs, barrier reefs and coral islands are spread across the lagoon, making up 90% of the island’s coral reef. Tongatapu Lagoon is 321.5 km<sup>2</sup> with a total reef area of 63.1 km<sup>2</sup>. The lagoon’s western sector has 14.3 km<sup>2</sup> of reef area, the central sector has 17.3 km<sup>2</sup> and the eastern sector 12.1 km<sup>2</sup>.

Temperatures on Tongatapu range between 11°C and 32°C, with a mean of 23°C. Southeast trade winds blow for nine months of the year and influence water circulation dynamics within the lagoon. There is a distinct wet season from November to April, but rainfall is generally moderate by Pacific Island standards (Lovell and Palaki 2003). Most fishing activity on Tongatapu takes place along the northern leeward coast on the reefs and shelf area.

### Objectives of this study

The objective of this survey was to provide baseline information on trochus, and to recommend man-

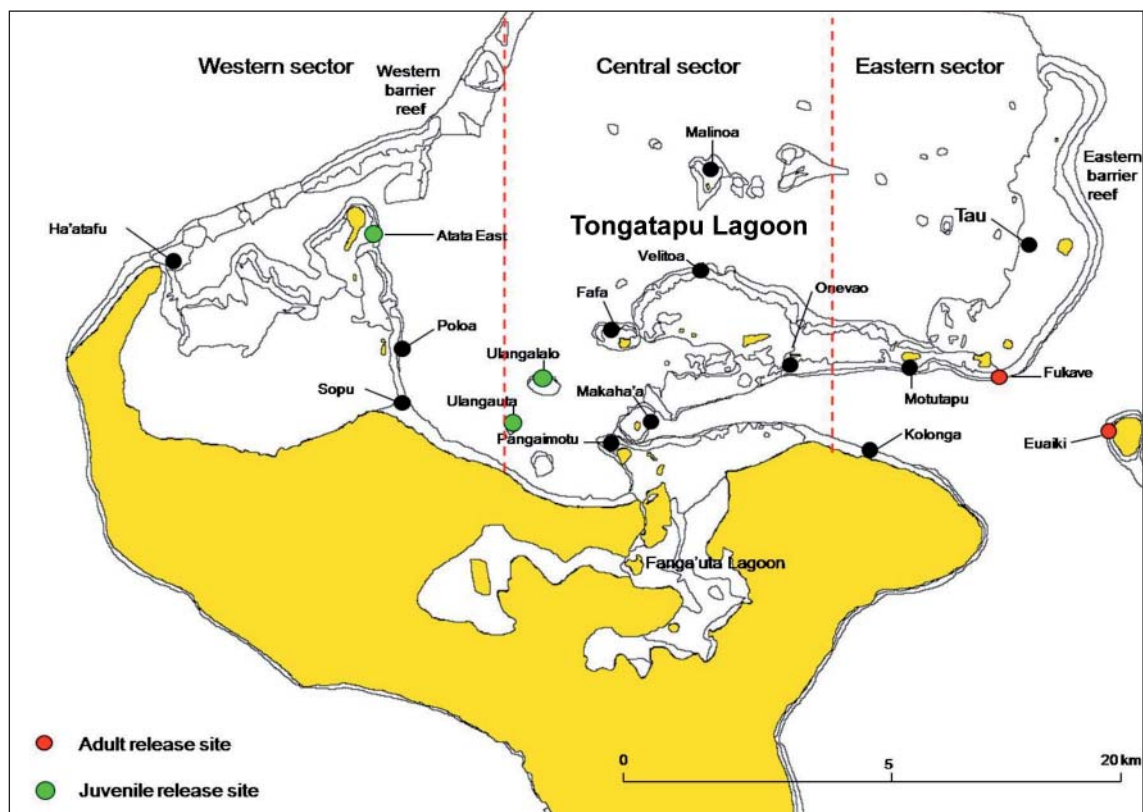


Figure 1. Tongatapu Lagoon and trochus study sites.

agement measures to manage this resource sustainably. In addition, the present work on the Tongatapu trochus provides a good case study for understanding the population dynamics and the role of environmental factors, particularly the impact of water circulation, on recruitment patterns. Specifically the survey aimed to provide:

- baseline information about the resource;
- information on the impacts of adult release and the juvenile seeding programmes;
- information on distribution patterns of *T. niloticus*;
- information on abundance and size distribution of trochus in the lagoon; and
- information on water circulation dynamics in the lagoon and its influence on trochus distribution and abundance.

## Methodology

### Resource surveys

The baseline trochus resource survey was conducted from 29 August to 8 September 2006, 12 years after broodstock were introduced, and 3–8 years after the beginning of the juvenile reseeding programme. The survey was designed to provide a comparative assessment across the lagoon by dividing the study area into three arbitrary sectors: western, central and eastern (Fig. 1). Euaiki was not included in this survey due to time limitations. The actual positions (longitude and latitude) of

sampling stations were recorded using a Garmin GPS 72 (Garmin Corporation, 2002).

The regional invertebrate resource survey techniques used in this survey included: 1) reef benthos transects (RBts), 2) reef front searches (RFs), 3) mother-of-pearl transect (MOPt), and (4) mother-of-pearl searches (MOPs) (survey type naming developed by PROCFish/C). The profile in Figure 2 shows the different survey techniques and the locations where they are typically used. These protocols were carried out by two surveyors working side by side or on either side of the transect in order to record epi-benthic invertebrate resources, with a particular emphasis on commercial invertebrate species.

### Reef benthos transects

Reef benthos transects were conducted in areas representative of suitable trochus habitats. Six 40-m transects (1-m wide) were surveyed at each station by snorkeling. Transects were positioned randomly across environmental gradients where possible (usually across reefs and not along reef edges). A waypoint was logged for each station (to an accuracy of ~ 10 m), and habitat recordings were made for each transect.

### Reef front timed swim search

Timed swims, referred to here as reef front searches, were done by snorkelling along the reef front, usually when swell conditions were favorable. Every



**Figure 2.** Reef profile showing typical locations of invertebrate surveys conducted by PROCFish/C, in the Pacific Islands region. Trochus surveys are numbers: 2 – reef benthos transects, 5 – reef front searches, 6 – reef front search walk, and 7 – mother-of-pearl searches and mother-of-pearl transect.

five minutes, observers recorded large invertebrates such as trochus (*Trochus niloticus*), green snail (*Turbo marmoratus*), giant clams and sea cucumbers such as surf redfish (*Actinopyga mauritiana*), all of which aggregate in this reef zone. Each surveyor completed a set of three swims that made up a total of six swims (or replicates), which completed a station. The start and end positions of the station were recorded and used to calculate the total distance swum using MAPInfo. The distance of swims varied between stations depending on conditions such as wind and currents and on the swimmers themselves.

### **Shallow dive transect and shallow dive timed searches**

These assessments were made using scuba in depths typically 4–10 m, never exceeding 15 m. A 40-m transect (2-m wide) was run perpendicular to the reef edge where suitable habitat exists for gastropods. A hip-mounted chainman® measurement kit with a thread release was used to measure transects. This allowed swimmers to work with their hands free, and saved time and energy on tape retrieval in the often dynamic conditions where *T. niloticus* are found. In sites suspected to have low densities, preliminary searches were conducted to rapidly check the reef for the presence of trochus. Once trochus were located, transects were run. The start and end positions of each station were noted.

### **Lagoon water circulation**

The data used for this study came from various projects of the South Pacific Applied Geoscience Commission (SOPAC) and from the Government of Tonga. Bathymetric data were obtained from two SOPAC/European Union bathymetric surveys, which collected multibeam data on the periphery of Tongatapu, singlebeam data from Fangauta Lagoon, and data extracted from LANSAT imagery. Lagoon bathymetry was determined from marine charts of Tongatapu, and deep ocean data were extracted from the coastal and marine geology Infobank (<http://walrus.wr.usgs.gov/infobank>). Tidal data were obtained from a permanent gauge at Nukualofa wharf, and wind data came from Tonga's Meteorological Services. Wave climate data were extracted from Barstow and Haug (1994). These data were used to develop a model circulation system for Tongatapu Lagoon.

## **Results and discussion**

### **Survey coverage**

The structure of Tongatapu's reef system is complex. Although there is a barrier reef and lagoon, the barrier reef does not encircle the lagoon entirely,

and inshore and midshore (middle) reefs are a mix of land-influenced and ocean-influenced structures, due to water flow characteristics and the presence of lagoonal islands and sub-lagoons. Reefs in the northern lagoon and the outer reef constitute an extensive suitable habitat for *T. niloticus*, and this area could potentially support significant trochus populations. The whole lagoon is 321.5 km<sup>2</sup> with a total reef area of 63.1 km<sup>2</sup>. The western sector of the lagoon has 14.3 km<sup>2</sup> of reef area, the central sector has 17.3 km<sup>2</sup> and the eastern sector 12.1 km<sup>2</sup>.

Potentially suitable trochus habitats at the barrier and outer reefs are estimated to be 6.8 km<sup>2</sup> for the western sector, 1.5 km<sup>2</sup> for the central sector and 11.1 km<sup>2</sup> for the eastern sector. Table 4 provides a summary of stations and the number of survey types completed. Figure 3 shows the actual positions of survey stations at Tongatapu.

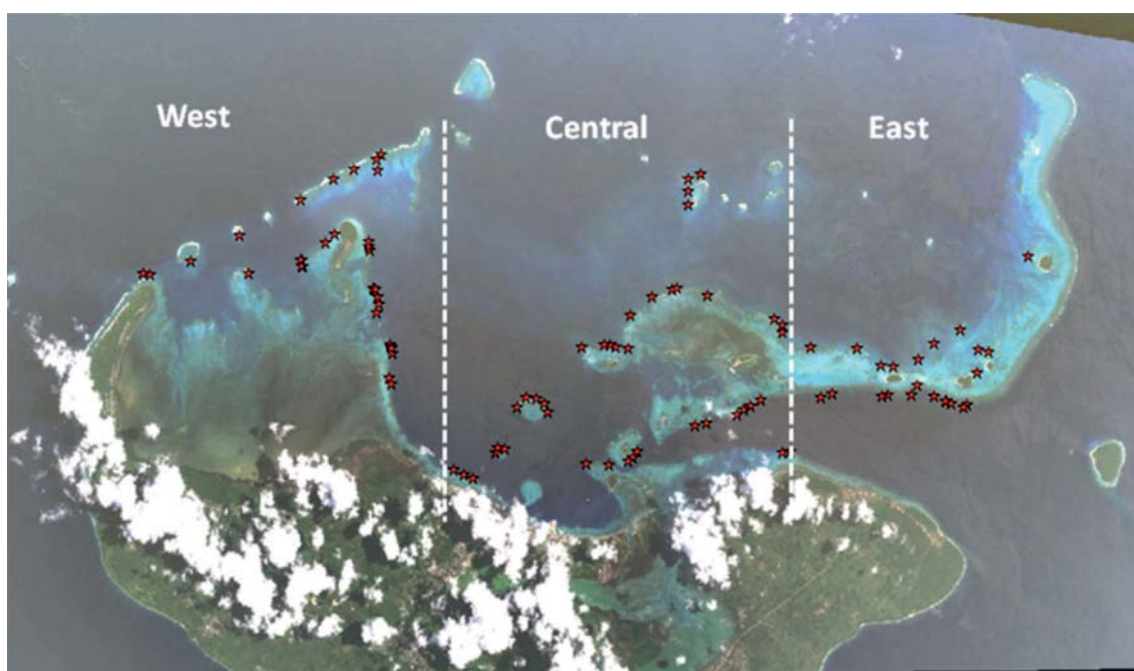
**Table 4.** Replicate measures of the independent assessment types in the three sectors.

Sectors	RBt	RFs	MOPs	MOPt
Western	42	48	24	45
Central	66	48	12	42
Eastern	51	63	0	24

### **Presence, abundance and density of trochus**

The presence and density of trochus were independently determined using a range of survey techniques designed for specific reef and benthic habitats (Table 5). Distribution patterns (e.g. rareness, commonness, patchiness) and the abundance (i.e. density ha<sup>-1</sup>) of trochus in target areas were assessed in order to describe the status of the resource in those areas of naturally higher abundance and/or most suitable habitats. *T. niloticus* were present at many locations (total n = 1,125 individuals), but unevenly distributed across lagoonal reefs. The density results of the deep water assessment by mother-of-pearl transects (Fig. 4) show a clear distribution pattern from east to west compared with the density distribution for shallow water reef benthos transect assessments (Fig. 5).

Larger densities were present at central and western inner fringing reefs, while lower densities were observed at eastern reefs. Comparative analysis of densities showed that the westerly sector held denser aggregations than the eastern sector (Fig. 6). This result was not ubiquitous, as the barrier reef in the western sector did not have significant quantities of trochus (Figs. 4 and 5), despite having suitable habitat (no trochus were found during RBts).



**Figure 3.** Resource survey coverage at Tongatapu Lagoon (red stars are start and end positions of stations).



**Figure 4.** Density (ind  $\text{ha}^{-1} \pm \text{SE}$ ) distribution of *Trochus niloticus* at Tongatapu Lagoon in mother-of-pearl assessments (4–10 m).



**Figure 5.** Density (ind  $\text{ha}^{-1} \pm \text{SE}$ ) distribution of *Trochus niloticus* at Tongatapu in reef benthos transect assessments (0.5–3 m).

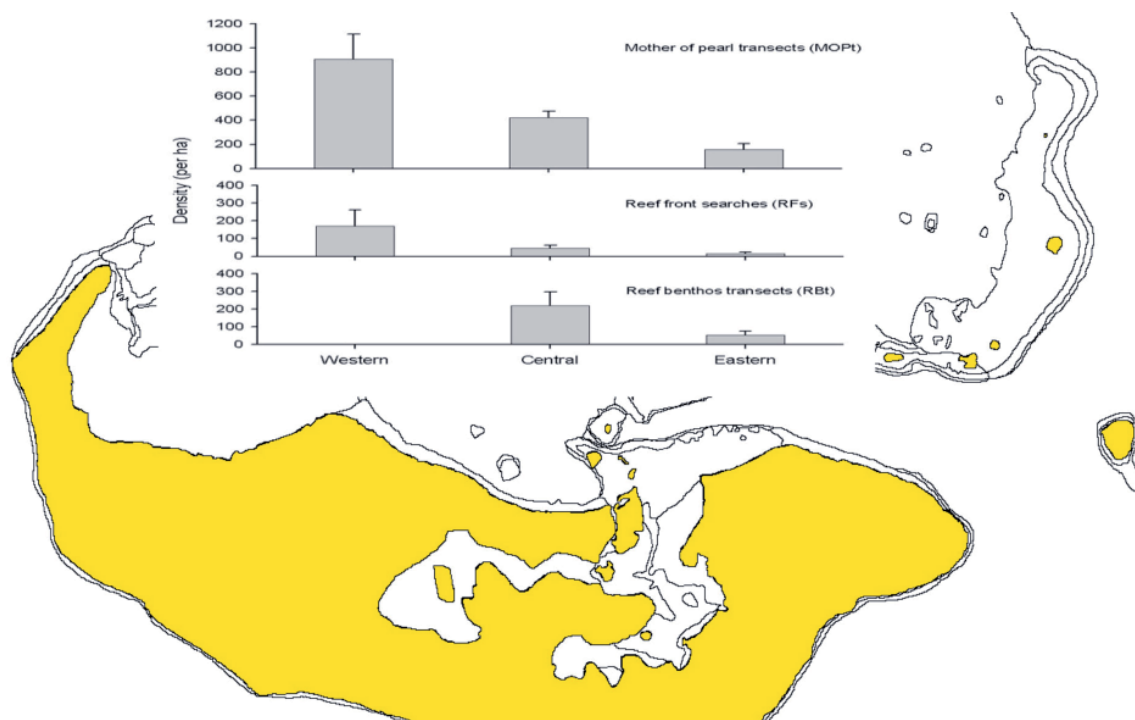


Figure 6. Mean density (ind ha<sup>-1</sup> ± SE) of *Trochus niloticus* in the three sectors by survey types.

Dense aggregations were found on fringing reefs in the lagoon east of Atata and Poloa islands, in relatively shallow depths.

Atata and Poloa reefs experience a mix of oceanic and terrigenous influences from northern oceanic inflow, easterly winds that influence ocean currents, and coastal runoff from the Sopa area. *Trochus* inhabit the edges and slopes at 1–10 m depth. Reef complexity is moderately high, ensuring live coral cover (mainly *Acropora*) at 30%. The habitat on the lagoon side becomes less substantial in areas below 10 m, with increased siltation. Habitat at the lagoon's fringing reef (near Nukualofa harbor) is limited to the face of a drop-off to 7–8 m depth. Both adults and juveniles were recorded along the reef face in this study. A rubble zone on the fringing reef platform provides good juvenile habitat (i.e. algae-covered rubble and boulders) but exposure at low tide is a problem as dead juvenile trochus shells (>40 mm, occupied by hermit crabs) were recorded in the area.

The reef on the seaward side of the east barrier reef is quite substantial, sloping gently into deeper water. The barrier reef platform is affected by wave action, but "embayments" behind undulations provide some protection in this high-energy environment.

Mean density comparisons (ind ha<sup>-1</sup> ± SE) with other mother-of-pearl species (i.e. *Tectus pyramis* and *Pinctada margaritifera*) (Table 5) show that *T.*

*niloticus* was present in much higher densities in all surveys than the other two species. The mean density of trochus was higher than the sustainable harvest limit (500 shells ha<sup>-1</sup>), although it should be noted that this high density was recorded in only one station at Atata.

### Shell size distribution

Shell size (basal diameter) distribution is an indicator of stock condition (e.g. the occurrence of spawning in recent years and successful recruitment with the presence of juveniles entering the adult population). Shell size data can also show spatial differences in population dynamics, which are important in understanding the "source" and "sink" areas acting as "supplier" and "receiver" of new individuals. The sampled population in Tongatapu (Fig. 7 all sites) is representative, covering a wide range of sizes from small juveniles (3 cm basal diameter) up to large adults (14 cm basal diameter). The mean basal diameter of trochus shells at Tongatapu Lagoon (n = 697) was 9.5 cm ± 0.1 cm SE, with a dominant mode around 10 cm, which highlights that the stock in Tongatapu Lagoon includes many individuals that are relatively young (10 cm shells characterise individuals just over four years old). *Trochus* are male or female, and reach first sexual maturity at 7–8 cm (data from another relatively southerly site, New Caledonia) but only become significant producers of viable gametes when they are larger. In fact, the largest female trochus are by far

**Table 5.** Mean density comparison for trochus and two other mother-of-pearl species by assessment types.

	Density (ind ha <sup>-1</sup> )	± SE	% of stations	% of transects or search periods
<i>Trochus niloticus</i>				
RBt	109	37.7	12/26 = 46	30/159 = 19
RFs	72.8	29.9	14/20 = 70	83/159 = 52
MOPs	16.2	11.8	2/5 = 40	6/36 = 17
MOPt	536.9	110.2	16/16 = 100	97/111 = 87
<i>Tectus pyramis</i>				
RBt	52.9	12.1	15/26 = 58	26/159 = 16
RFs	9.4	2.6	10/20 = 50	38/159 = 24
MOPs	15.2	11.7	2/5 = 40	6/36 = 17
MOPt	0	0	0/16 = 0	0/111 = 0
<i>Pinctada margaritifera</i>				
RBt	3.2	3.2	1/26 = 4	2/159 = 1
RFs	0.4	0.2	2/20 = 10	3/159 = 2
MOPs	4.5	4.5	1/5 = 20	3/36 = 17
MOPt	1.3	1.3	1/16 = 6	1/111 = 1

RBt = reef benthos transect, MOPt = mother-of-pearl transect, RFs = reef front search

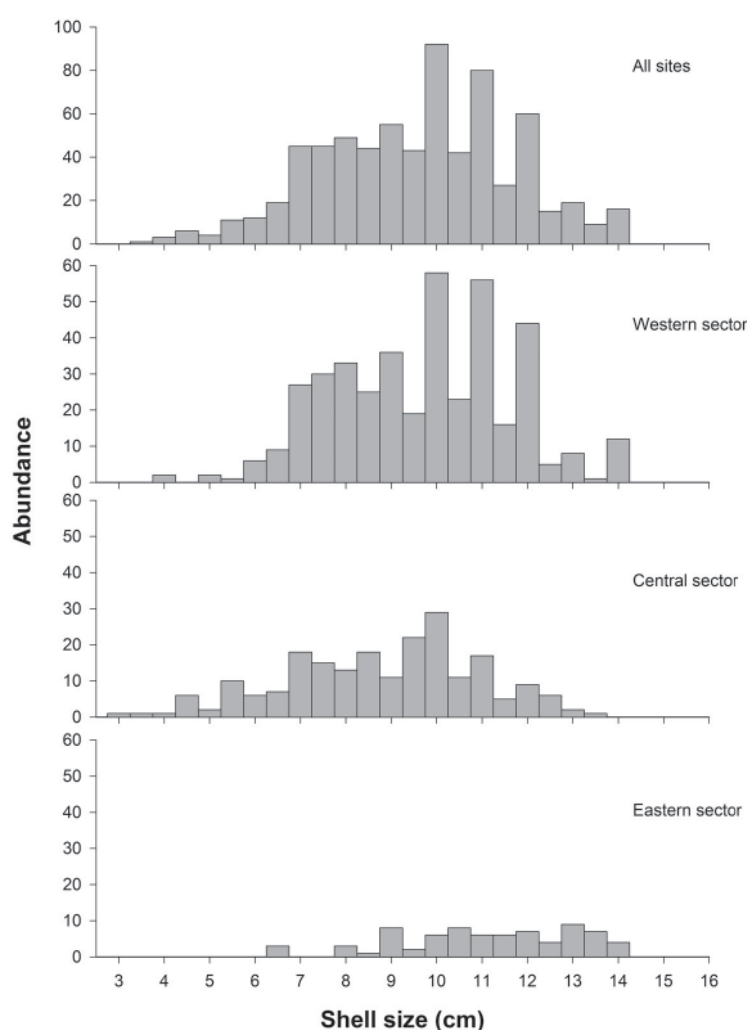
the most fecund. A 10-cm female trochus produces approximately 2 million oocytes, whereas a 13-cm trochus produces up to 6 million (Heslinga 1981; Bour 1990; McGowan 1958).

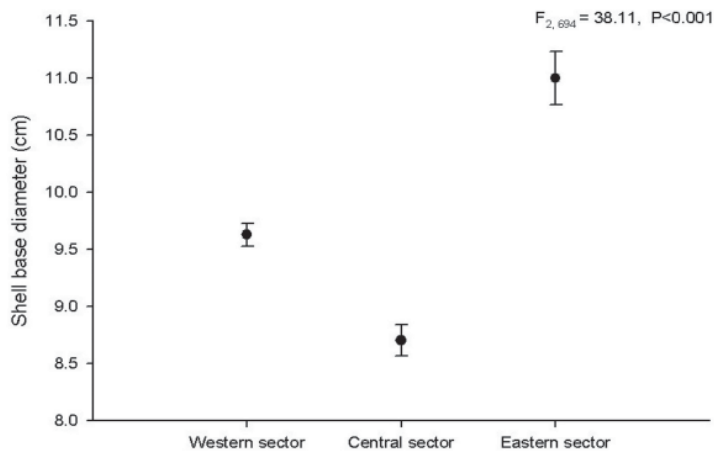
Shell size analysis revealed a regional split from west to east (Fig. 8). Significantly larger and older trochus are found in Tongatapu's eastern sector (mean size: eastern =  $11.0 \pm 0.2$  cm, SE) and smaller and younger individuals in the central and western sectors (central =  $8.7 \pm 0.1$  cm, western =  $9.6 \pm 0.1$  cm). This result could be due to fishing preferences, or alternatively, be an indicator that the central and western sectors are acting as "sinks" for recruitment originating from the eastern sector. Because Tongatapu Lagoon's population is unfished (under monitoring), fishing preference as a mechanism for driving such results, is effectively ruled out.

**Figure 7.**

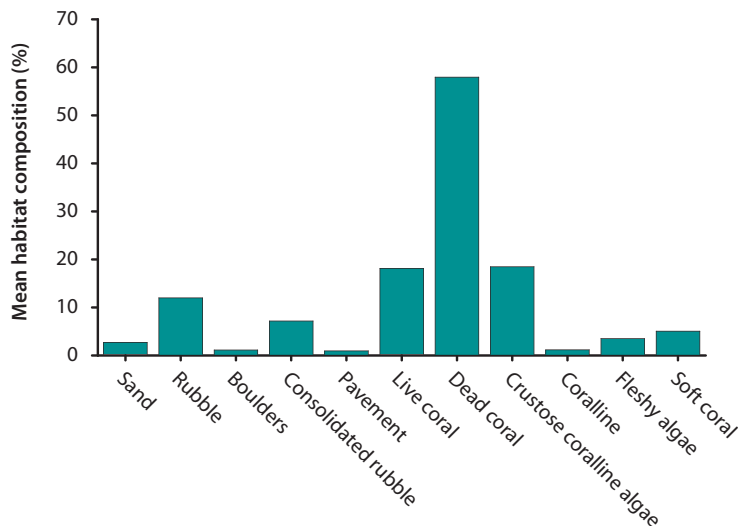
Trochus population structure in Tongatapu Lagoon for all sites combined and for the three sectors.

Note: Abundance on y-axis is the number of trochus found during the surveys.





**Figure 8.** Trochus shell mean basal diameter (cm) for the three sectors. All sectors have trochus of significantly different mean sizes ( $P > 0.001$ , unequal n HSD).



**Figure 9.** Mean habitat composition at Tongatapu Lagoon.



**Figure 10.** The alga *Turbinaria ornata* is common on the reefs of Tongatapu Lagoon. Note also the presence of an adult *Trochus niloticus*.

### Broodstock transplantation versus juvenile seeding

None of the trochus surveyed in 2006 can be identified as originating from the hatchery-produced juveniles that were released at Tongatapu. Despite recapture surveys that were planned for 1, 12, 24 and 36 months after release (Kikutani and Yamakawa 1999), no data were available, suggesting that data may not have been collected. It is thus impossible to determine if the existing trochus population at Tongatapu Lagoon is being contributed to also by hatchery-produced juveniles. Juvenile seeding in Tonga stopped in 2000 when it became obvious that the transplanted broodstock had become established (Kenichi Kikutani, JICA expert, pers. comm. January 2008). It is thus believed that the established spawning population is the main contributor to the newly recruited trochus at Tongatapu (Niumeitolu et al. 1999; Fa'anunu et al. 2001). Seeding success with hatchery-produced juvenile trochus is once again questionable due to a lack of data on the recovery of released juveniles.

### Reef habitat condition

Reef habitat data were collected in order to understand the status of resources in relation to habitat condition. Mean habitat condition was analyzed as a percentage of habitat composition, and is presented in Figure 9. Dead coral was the dominant substratum, representing approximately 60% of the composition. Dead coral covered by encrusting crustose coralline algae (CCA) was moderately high (20%). Therefore, dead coral with or without algae accounts for approximately 80% of the substratum, indicating that a large part of the reef at Tongatapu Lagoon is dead. Growth of CCA on dead coral rocks is the main component of "live rock", which is one of Tonga's main export products for the aquarium trade. Most live rock is harvested from Tongatapu Lagoon, mainly

around the central reefs such as Ulanga Uta and Ulanga Lalo and up to Fafa and Onevai.

In some areas, such as back reefs of the western barrier reef in front of Haatafu and along the back reef areas of the main central lagoon reef from Fafa to Onevai and Motutapu, *Acropora* tabulate rubble dominates the bottom. Rubble bottoms are unsuitable for trochus, because they lack microhabitats and food resources (few trochus were found in these habitats). Similarly, in consolidated rubble areas — such as those present at Fafa, Ulanga Lalo and Ulanga Uta — despite the presence of good CCA growth, inadequate topography and low habitat complexity limit the ability of these areas to support a greater increase in trochus populations.

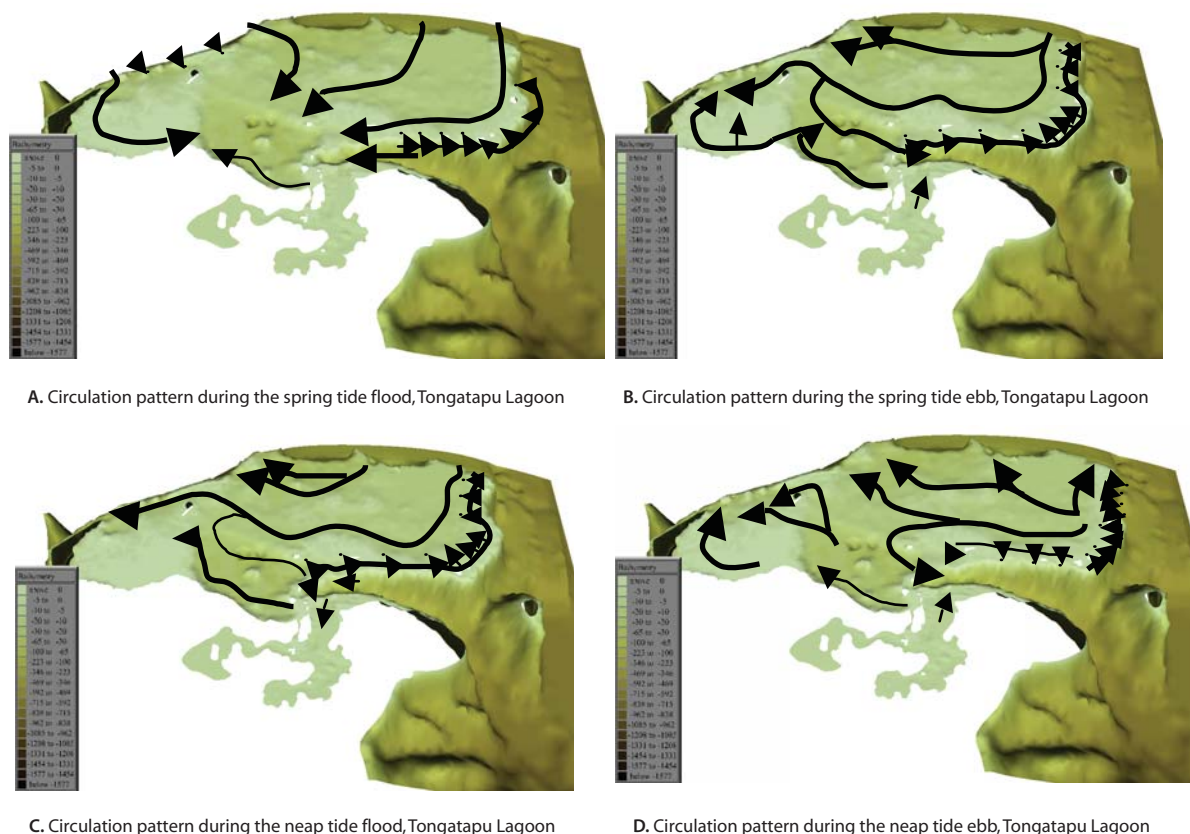
Live coral coverage was relatively low at most stations, comprising 20% of the substratum. Notable live coral coverage was present along lagoonal fringing reefs at Atata. Significant coverage of fleshy algae, mainly *Turbinaria ornata*, was recorded at Ulanga Lalo and Ulanga Uta and along the shallow reef slope at Motutapu, Onevao, and Makahaa (Fig. 10). Dense macro-algal mats such as those present in these areas can effectively reduce grazing sur-

faces for gastropods such as trochus, and have been found to inhibit larval settlement of benthic organisms (Heslinga 1981). Despite good topography and complexity in some of these sites, very few trochus were recorded in areas covered with *Turbinaria* mats in this survey. Soft coral is present in some areas of the central and eastern reef slopes.

The population of the crown-of-thorns sea star *Acanthaster planci* is relatively low ( $n = 16$ ) and does not seem to be a major problem within Tongatapu Lagoon. However, one small aggregation recorded at the inner reef west of Atata has killed significant live coral growth and could, in the future, spread to other areas. Past aggregations of *A. planci* have been recorded at Haatafu and Pangaimotu by Zann and Muldoon (1993). Live coral coverage at these sites is relatively low, suggesting that predation by crown-of-thorns sea stars may have had an impact in the past.

### Water circulation at Tongatapu Lagoon

A water circulation model for Tongatapu Lagoon, which was developed by SOPAC (Fig. 11), was used to assess water movement patterns in the lagoon. Easterly winds dominant the area, with annual



**Figure 11.** Tongatapu Lagoon water circulation systems (light = shallow water; dark = deep water).

mean direction of 130°, more than 70% of the year, at a mean speed of 4 m s<sup>-1</sup>. Seasonal wave height is 2.2 m from November to March, increasing to 2.4 m between May and September. The eastern barrier reef is exposed to southeast waves hitting the reef at a height of 1.0–1.5 m. The model indicated fairly well the involvement of tides and currents induced by wind and waves in the lagoon's circulation pattern. During spring tide floods, tidal current largely controls the circulation, while the influence of wave-induced and wind-induced currents is slight. At the peak of the flood, the lagoon is filled from all sides. Inflows weaken as they meet in the central lagoon region (Fig. 11). Waves break over the reef at the southeast corner of the lagoon and create a westward current toward the central lagoon. During ebb tides, tidal current pushes water out of the lagoon. Again, this westward flow is assisted by flushing over the reef at the southeast and east corners of the atoll rim, as the wave-induced current is the strongest at this location. Inside the lagoon, the current is directed towards the west, and highlights the wind's effect on this circulation system. During neap tides, tidal current decreases and westerly winds dominate.

The rate of discharge (as calculated by the model) highlighted the dominant movement westward across the lagoon. Indeed, more than 95% of the flush on the western reef is towards the ocean, and almost 90% of the flush on the eastern reef is towards the lagoon. A relatively high water residence time occurs in the basin adjacent to Nukualofa where current speeds weaken (0.07–0.03 m s<sup>-1</sup>). The mean water speed in the lagoon is around 0.06 m s<sup>-1</sup>. A low water speed region occurs in the middle reef, islets reefs and the lagoon fringing reef (Atata to Sopa). Past studies using small-scale modeling (Black et al. 1995) have shown that local retention of larvae around reefs or within reef groups is critically dependent on current strength (because faster current speeds decrease larval settlement). In slow currents, larvae could be retained in greater numbers, at both an individual reef as well as on a regional scale. Trochus spawn throughout the year in low latitudes, but only during warmer months in higher latitudes (Nash 1985). According to this model, trochus aggregations in the central region where there are weak currents represent the "sink" for recruitment coming from the "source" in the eastern region.

## Conclusion

The *Trochus niloticus* resource in Tonga is new and represents another recent successful introduction for the species. Trochus is less well distributed in the lagoon, and some reefs are still lacking trochus. Assistance through translocation is needed on Tongatapu and other islands to increase distribution and further develop the resource base. Any form of

fishing should be discouraged or made illegal, and harvest control regulations should be developed and enforced in order to ensure maximum protection.

As a newly established population in an area naturally lacking the species, this area served as a good case study for understanding trochus recruitment patterns. The results of the water circulation model indicated that water dynamics are the main influence on trochus distribution patterns in Tongatapu Lagoon. Releasing adult trochus spawners at Fukave Island reef was, therefore, a good decision, which showed that even without the best scientific information on water dynamics, good decisions on release sites could be made from observatory information and local knowledge of winds and currents. This paper demonstrates that future trochus releasing activities should take into account water and wind dynamics.

The impact of the juvenile releasing programme cannot be fully measured because there are no data available on the recovery of the released trochus. Despite plans for data collection, a lack of data suggests that none were ever collected. This is understandable as the project focused on mariculture and reseedling rather than solely on reseedling. We thus conclude that the seeding programme in Tonga has, once again, failed to produce any concrete results to support the usefulness of this option as a tool for helping trochus to establish a breeding population. This adds to similar results of reseedling studies in the Asia-Pacific region (Purcell et al 2003; Hoang et al 2007; Lee 2000).

## Management and recommendations

- The trochus resource in Tonga is a young population with the potential to spread to more reefs in the lagoon and reefs of the main island. Time should be given for the resource to mature and become suitable for a fishery. Only 12 years have passed since introduction; a minimum of 20 years is recommended before a fishery potential can be re-assessed.
- So far, no re-introduction has been carried out locally. The first harvest(s) should be used for re-introduction purposes only in order to expand the resource to other reefs and islands in Tonga. A stronger resource base can better support the fishery.
- Authorities should consider moving spawners from some of the aggregations in the western sector (Atata reef) to areas that have not received recruitment or where recruitment has been slow. Some of these areas are the outer and inner lagoonal reefs of the eastern barrier reef (from Fukave to Tau) because the dominant westerly flow would make it impossible

for larvae from the Fukave stock to disperse northward. Other reefs to consider for transplantation are Malinoa, the western barrier reef and the inner reefs at Haatafu, and the south-eastern end of Kolonga to increase the capacity of recruitment in those areas.

- Any form of fishing or sale of trochus at this stage would not help the spread of the species and would instead hamper development of the stock. Efforts should be made to educate the community and encourage its members to assist in protecting trochus, while any form of harvesting and selling should be discouraged at this point.
- Public awareness and education are urgently required to inform fishers about preserving trochus. This could be achieved through posters, newspaper articles, radio and television ads, and billboard notices placed at the main beaches.
- Trochus shells should not be offered for sale as souvenirs — even dead shells — as this would indicate to fishers that the resource has been officially opened for harvest.
- The development of management regulations to ban the collection of trochus for meat or for sale is necessary in order to give maximum protection to the resource. This regulation and its enforcement are a matter of priority. Legislation on minimum or maximum harvest sizes should be developed as a priority before the fishery opens.
- Trochus at Euaiki, Eua, Haapai and Vavau need to be assessed in order to establish baseline data. Tonga's Department of Fisheries staff have been trained on the standardised invertebrate assessment protocols used by SPC (PROCFish) in this survey. It is important that the same assessment techniques be used in all other areas so that results can be compared. It would be useful to notify SPC in advance about plans to undertake such surveys so that advice can be provided (if necessary) to assist local staff in planning.
- Lack of available data on the reseeded activities conducted in Tonga from 1998 to 2003 made it impossible to draw any conclusions about the juvenile reseeded programme. More organised data collection and record keeping on reseeded activities would be helpful in assessing the impact of such programmes in the future. Reseeding with hatchery-produced trochus has not yet delivered any results to suggest that this method is useful for establishing a trochus breeding stock.
- Trochus was present around the edges at Ulanga Lalo (one of the main reseeded sites), while none were recorded in the middle reef flat zone. Ulanga Lalo is one of the prime live rock collection sites by aquarium trade exporters. It would

be beneficial to look into what the impact of removing the rocks has on juvenile trochus settlement. Perhaps this activity has some effect on trochus recruitment on the reef flat.

## Acknowledgements

We acknowledge the assistance of Tonga's Ministry of Fisheries staff, in particular Mr Sione Matoto, Secretary of Fisheries, for overall support; Tala'ofa Loto'ahea, Sione Mailau, Martin Finau and Kite Fanua, for their assistance in the survey work; and Mr Masanori Kawaguchi, manager of Tangle Nano Seaweed company, for lending us his scuba tanks. Personal communication was also made with former JICA long-term expert to Tonga, Mr Kenichi Kikutani who was based in Vanuatu.

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## Population structure and abundance of *Trochus niloticus* in Tubbataha Reefs Natural Park, Palawan, Philippines with notes on poaching effects

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### Abstract

The topshell *Trochus niloticus* is a highly valuable reef invertebrate that flourishes in the Tubbataha Reefs Natural Park (TRNP), Palawan, Philippines. At present, it is heavily poached inside the park premises, which justifies the present study. The average size of trochus at TRNP was found to be smaller than those harvested from other Pacific Island countries, but the density was very high, ranging from 3,000 to 11,000 ind ha<sup>-1</sup>. An associated species, *Tectus pyramis*, which occurs in very low numbers, are some of the other shells that have been confiscated from the park. The estimated value of sequestered trochus from 2006–2007 was assumed to be very low compared with the overall amount of poached trochus. The declining trend in the size structure of confiscated trochus from 2006–2007 reflects the effects of poaching. If left uncontrolled, this illegal activity is expected to cause considerable decline and eventual extinction of this high-value reef species in TRNP.

### Introduction

*Trochus niloticus*, commonly called topshell or trochus, is one of the most valuable and sought-after reef gastropods because its shell is used in the manufacture of mother-of-pearl buttons (Nash 1988). This species and the less commercially important *Tectus pyramis*, and some other trochids, are naturally distributed in the Indo-West Pacific Ocean including the Philippines (Carpenter and Niem 1998). Its current distribution extends to other tropical islands of the eastern Pacific as a result of numerous successful translocation efforts — between 1927 and the late 1990s — within and outside its natural geographical distribution (Gillett 2002).

Commercial exploitation of *T. niloticus* was observed as early as 1907 (Bour 1987) but early trade statistics are often unavailable. Hahn (2000) reported that the average world harvest of trochus in the 1980s was about 4,000–6,000 t with a wholesale value of USD 4 million and a retail value of about USD 28 million. With the continuous unregulated harvest of trochus, export records from various countries in the Pacific show wide fluctuation, with an overall downward trend (e.g. Etaix-Bonnin and Fao 1997; Gillespie 1997). This declining trend has prompted actions to improve management and continued research on the biology and stock enhancement of trochus (e.g. Hoang et al. 2007; Purcell et al. 2003; Amos and Purcell 2003; Smith et al. 2002; Nash 1988).

Although the Philippines was historically one of the major world trochus exporters, little is known about the current status of its wild populations and information on harvest volume is fragmentary. Before World War II, the harvest in the Philippines was estimated to have reached over 1,000 t yr<sup>-1</sup> but was reduced to less than 300 t annually in 1948 (see Hahn 2000). The estimated annual volume of exported *Trochus* sp. from the Philippines decreased from 200–300 t from 1985–1987 to < 100 t from 1995–2002 (Floren 2003). Because trochus populations were reduced to near extinction (Gapasin et al. 2002), conservation measures were initiated. These measures included: 1) artificial breeding and eventual restocking initiatives of a Japanese private company based in Binduyan, Puerto Princesa City since early 2000; 2) breeding refinement at the Aquaculture Department of the Southeast Asian Fisheries and Development Center (SEAFDEC) in Iloilo (Gallardo 2003); and 3) the passing of national policy declaring trochus a threatened species through Fisheries Administrative Order No. 208, Series of 2001 (BFAR 2006; Floren 2003). Unfortunately, the breeding program at SEAFDEC was short-lived due to budgetary constraints and species prioritization (Gapasin pers. comm.). Also, illegal exploitation remained a major threat to trochus, especially in Tubbataha Reefs Natural Park (TRNP), where large numbers of trochus are found. Given the dearth of information about trochus in the Philippines, this paper presents the current population structure, abundance and the effects of poaching on trochus populations in TRNP.

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## Materials and methods

The study site is TRNP (located at 8°56'00.68"N; 119°48'23.15"E), which was established in 1988 and inscribed in the UNESCO World Heritage List in 1993. The park is an offshore atoll reef area in the middle of the Sulu Sea, about 150 km southeast of Puerto Princesa, the capital city of Palawan, Philippines. It covers an area of 968 km<sup>2</sup> and comprises two atolls and a reef flat. North and South atolls are separated by an 8-km-wide channel. North Atoll is oval shaped, and about 18.5 km long and 5.6 km at its widest portion. South Atoll is triangular shaped, about 9.3 km long and 5.6 km wide. An exposed reef flat at low tide of approximately 200–500 m wide encloses an 8–24 m deep lagoon that has a steep seaward drop-off down to about 70 m (Palaganas et al. 1985). The Jessie Beazly Reef lies 20 km north of North Atoll. It is a small reef flat with a sand bar of about 100 m exposed at low tide. The reef was made part of the park on 23 August 2006 through Presidential Proclamation 1126, expanding the park from 332 km<sup>2</sup> to its present size.

Surveys were conducted between 16 September and 19 October 2006. Seven roughly 1-m-deep sites where trochus abound were established as permanent monitoring sites. Stations 1 to 4 are at North atoll, while the remaining three were established at South atoll. For each site, a 2-m-wide, 150-m-long transect line was laid parallel to the shoreline and was surveyed by snorkelling. *Trochus niloticus* and *Tectus pyramis* found within the transect line were measured for their maximum basal diameter (MBD) using a plastic ruler glued to a slate board. After measuring, the animals were immediately returned to their habitat in an upright position.

Two out of five sacks of trochus that were confiscated in June 2007 were haphazardly selected,

and the shells were measured to establish an MBD to dry weight relationship. In an October 2007 poaching incident in TRNP, MBD of confiscated trochus was again measured using callipers. Information from a local resident who shared his experiences in collecting trochus at TRNP is included in this study.

## Results

### Population structure

The surveys along permanent transects revealed that the average sizes of both species vary among sites. The largest individuals were found at Sites 1, 4 and 5. The MBD of *Trochus niloticus* ranged from 17–130 mm with an average of  $67.0 \pm 14.6$  mm, while that of *Tectus pyramis* only ranged from 23–63 mm with an average of  $46.6 \pm 5.1$  mm (Fig. 1).

*Trochus niloticus* was found in much higher numbers than *Tectus pyramis*, comprising around 98% of the 1,242 individuals sampled (Fig. 2).

Around 55% of the population of *Trochus niloticus* fell below the average size. Those that measured 52–77 mm were dominant, forming almost 51% of the population. Smaller shells with sizes <50 mm comprised 14% of the collected individuals.

### Abundance

The densities of trochus vary among sites with *Trochus niloticus* showing great abundance compared with *Tectus pyramis*. *Trochus niloticus* occurred at densities between 4,000 ind ha<sup>-1</sup> and 11,000 ind ha<sup>-1</sup>, except at Site 5 where it was a little above 3,000 ind ha<sup>-1</sup>. The average density of *Trochus niloticus* was about 6,000 ind ha<sup>-1</sup>. *Tectus pyramis* was rare, having only an average density of 119 ind ha<sup>-1</sup> (Fig. 3).

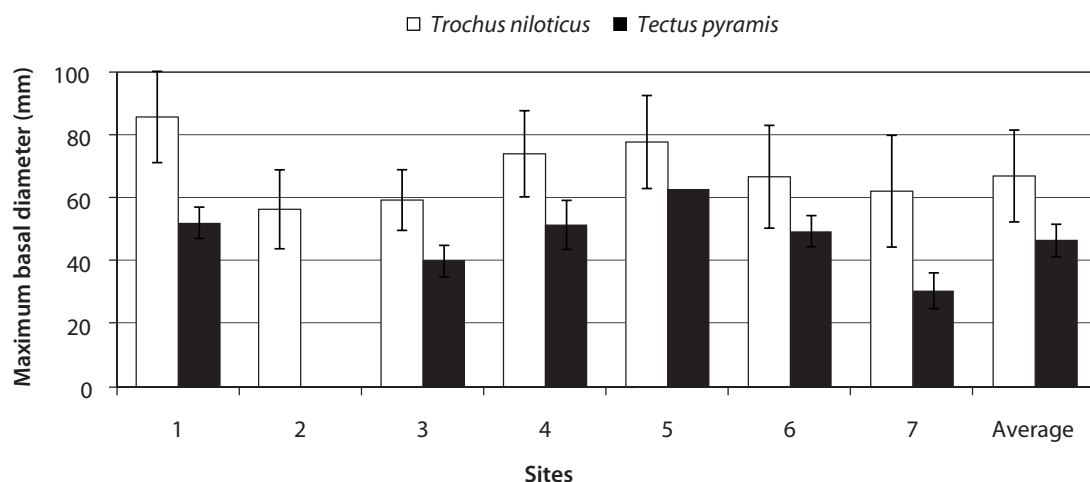
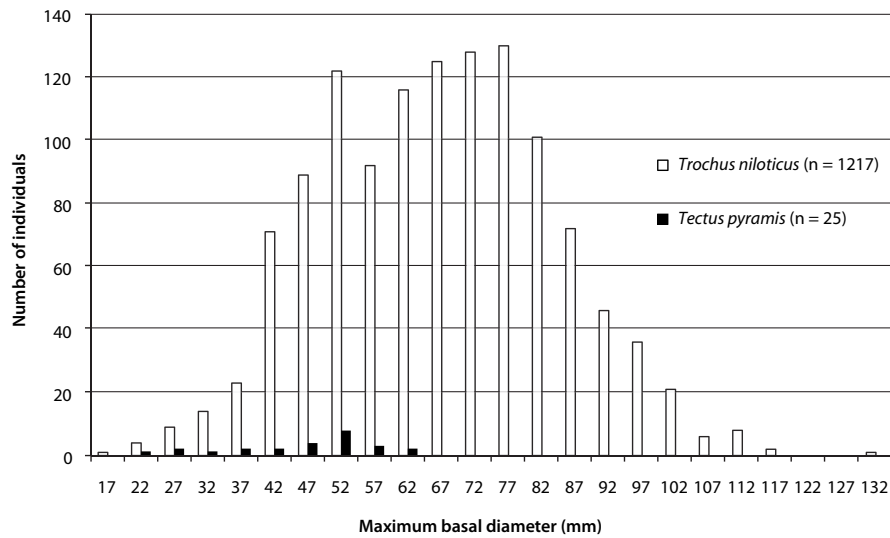
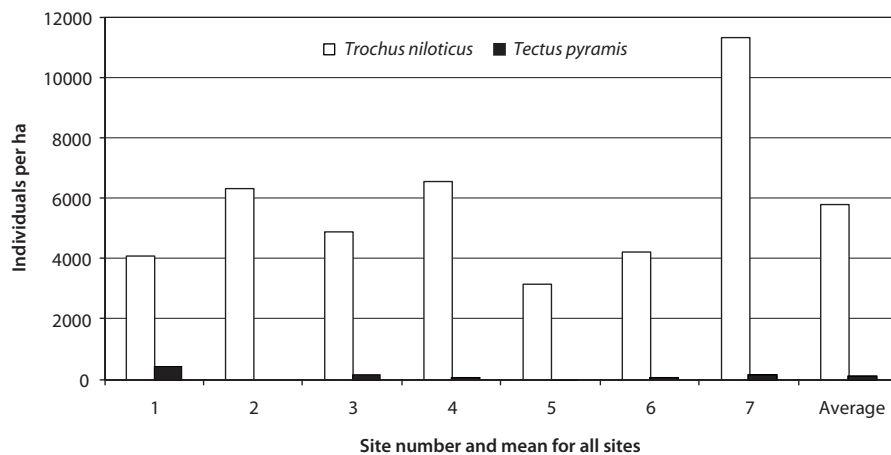


Figure 1. Mean ( $\pm$  standard deviation) maximum basal diameter of *Trochus niloticus* and *Tectus pyramis* per station.



**Figure 2.** Population structure of *Trochus niloticus* and *Tectus pyramis* at Tubbataha Reefs Natural Park (September–October 2006).



**Figure 3.** Density (ind ha<sup>-1</sup>) of *Trochus niloticus* and *Tectus pyramis* in survey sites at Tubbataha Reefs Natural Park in 2006.

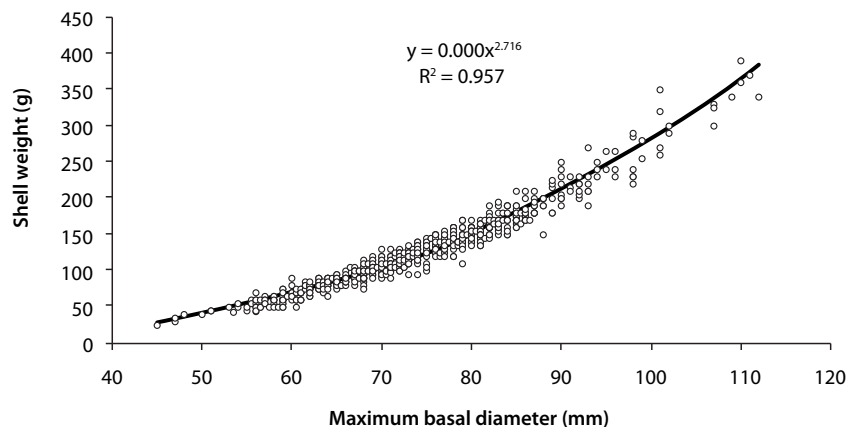
#### Mean basal diameter–dry shell weight relationship

There is a very high positive relationship ( $r^2 = 0.9577$ ) between MBD in *T. niloticus* and its dry shell weight. The weight of dry shell could be estimated using the equation:

$$W = 0.0008X^{2.7763}$$

(W = dry shell weight and X = MBD).

Variability between size and weight tended to increase as the individual got bigger (Fig. 4).



**Figure 4.** Scatter graph of *Trochus niloticus* maximum basal diameter–dry shell weight relationship.

### Notes on poaching

Data obtained from confiscated *T. niloticus* reflect that trochus harvested in June 2007 were larger than those in October 2007 (Fig. 5). In June 2007, the mean size was  $74.1 \pm 10.8$  mm while it was only  $63.8 \pm 7.1$  mm in October 2007 — a 10 mm difference. By comparing maximum sizes, a decrease was even more obvious. The largest individual harvested in June was 15 mm, which was smaller than the largest one collected in October 2007. Assuming specimens to be sexually mature when their shell size is 50–65 mm MBD, around 22.2% and 61.2% of these sizes were among the confiscated shells in June and October 2007, respectively.

From 2002–2007, 59% of 17 apprehended groups of poachers at TRNP were from mainland Palawan. About 24% came from other regions of the Philippines, and the rest were from China, whose target species were not trochus but fishes, marine turtles, dolphins and giant clams. Trochus poachers, mainly from mainland Palawan, began their operation in early 2006. Eight of the 10 apprehended poachers from Palawan in 2006–2007 engaged exclusively in harvesting trochus.

In April 2006, five sacks and 119 individuals of trochus were confiscated, while 81 sacks and 761 individuals were sequestered in 2007, which together weighed more than 3 t. Using the data from June 2007 as the baseline, and a purchase price of PHP 300.00 kg<sup>-1</sup>, the value of the trochus confiscated in those two years represented about PHP 1,000,000 (Table 1), roughly USD 20,000.

### Discussion

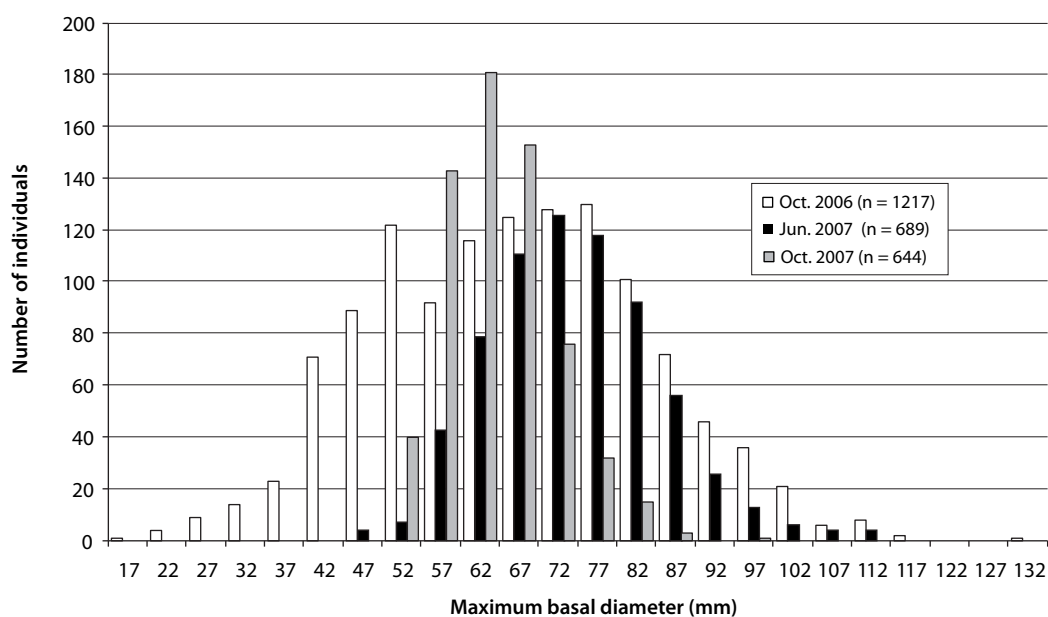
#### Population structure and abundance

The mean size of trochus recorded in 2006 at TRNP ( $67.0 \pm 14.6$  mm) was small compared with that measured from Penrhyn, Cook Islands (84.0 mm) (Ponia et al. 1997). Similarly, the mean sizes (74.1 mm and 63.8 mm) of confiscated *T. niloticus* at TRNP are smaller than those harvested in Cook Islands and in Saipan with an average of 86.2 mm (fore-reef slope individuals about 92.1 mm and reef-flat individuals about 76.9 mm; Trianni 2002).

In undisturbed areas, the density of *Trochus niloticus* was generally lower in deeper parts of the reef (Hahn 2000) in contrast with overfished areas (Smith et al. 2002). *Tectus pyramis* on the other hand had higher densities in the subtidal reef slope at TRNP (Dolorosa and Schoppe 2005).

In the present study, surveys were done in intertidal areas where the shells are plentiful, thus a thorough survey of the reef flat is needed to better understand its ecology and the effects of poaching on TRNP's trochus population. More sampling sites at the inundated reef flat are needed to develop a clear picture of its abundance, especially that of juveniles. An area estimate of suitable habitat is paramount in approximating its total population.

Compared with other open access areas in Palawan where density ranges from 0–100 ind ha<sup>-1</sup> (Dolorosa and Matillano 2005; Dolorosa et al. 2007; Gonzales et al. 2005, 2006, 2008), the trochus popu-



**Figure 5.** Size structure of confiscated *Trochus niloticus* in June and October 2007 in comparison with those obtained in September–October 2006 baseline sampling.

lation had recovered from overexploitation at Tubataha Reefs after its declaration as a national park in the early 1990s to reach several thousand individuals per hectare. Because it took about a decade or more for trochus to recover at TRNP after closure, and for the introduced trochus in countries such as French Polynesia (Cheneson 1997) and Cook Islands (Ponia et al. 1997) to reach a commercially viable population level, reviving populations in other parts of Palawan and the Philippines appears to be a huge challenge.

With the scarcity of trochus in areas around mainland Palawan and in offshore islands such as the Spratleys, TRNP serves as the only potential seed bank for trochus and many other species. Although the planktonic larval stage of *T. niloticus* is short (3–4 days) and larvae may only settle locally (Nash 1988), settlement may be delayed for about 10 days when appropriate substrate is unavailable (Nash 1993) with the potential to drift outside the park boundaries. In this case, it would be possible for larvae to help replenish depleted reefs on mainland Palawan and other areas within the Sulu Sea. By contrast, if TRNP becomes thoroughly devoid of trochus, recruitment within and outside the park would be more unlikely. Given the scarcity of the species in other areas, the probability that drifting planktonic larvae would settle at TRNP remains low.

### **Mean basal diameter–dry shell weight relationship**

The *T. niloticus* MBD to dry weight relationship is comparable to that measured in Penrhyn, Cook Islands (Ponia et al. 1997), where  $r^2 = 0.979$  and dry shell weight is determined by the equation  $W = 0.00034L^{2.943}$ . It appears that specimens of *T. niloticus* at TRNP have thicker shells than those from Cook Islands. This variation in shell growth may occur in different geographical regions (Lemouellie and Chauvet 2008) and with exposure to specific habitat characteristics (Nash 1985).

### **Notes on poaching**

The low average MBD at Stations 2, 3, 6 and 7, and uneven densities observed especially at South Islet's Stations 5, 6 and 7 are presumed effects of poaching activities that started as early as April 2006. Without harvesting, mean individual sizes and densities could be more uniform given that all stations were in the rocky intertidal zone. Should poaching continue to occur, trochus in TRNP might be overfished again and will suffer the same fate as it has in many other countries (see Smith et al. 2002; Foale and Day 1997; Nash 1985), including the rest of the Philippines. The inclusion of *Tectus pyramis* in the poachers' catches — even though it is of no commercial value for the button industry (Gillespie

1997) — could eventually affect its population. *Tectus pyramis* are rarely noted on the reef flat and comprise only about 17% of all trochid species in an intertidal area at South Islet (Dolorosa and Schoppe 2005) and only about 2.3% (or a range of 0–8.9%) during the present survey.

It seems that larger shells were prioritized by poachers in the early part of 2007, with smaller shells becoming their next target. Harvesting smaller shells is also a common problem in many Pacific Island countries despite government policies (e.g. Trianni 2002; Smith et al. 2002). Such a practice could lead to isolated extinction, as the continuous removal of a large proportion of immature trochus could reduce recruitment and cause the population to collapse (Nash 1985; Foale and Day 1997).

With the use of the dry shell MBD–weight formula, the projected average dry shell weight of *T. niloticus* at TRNP in September–October 2006 was 109.6 g each, or 636 kg ha<sup>-1</sup>, considering the average density at 5,805 ind ha<sup>-1</sup>. Further, it was determined that the two sacks of shells confiscated in June 2007 contained 220 individuals (mean size = 81 mm) and 388 individuals (mean size = 69 mm) and weighed 36 kg and 41 kg, respectively. The shell generally makes up 75–77% of the weight of a live animal (Heslinga 1981), so that each sack could contain about 50 kg of live trochus, manageable enough for each poacher to carry while wading, or during loading and unloading from or into the boat.

When poachers are detected and chased by park rangers, they tend to drop sacks of trochus from their motorized outrigger boat; hence, it is obvious that our estimated value — based on volume of confiscated trochus — is much lower than what has actually been plundered. Given the inadequate surveillance equipment at the ranger station, the number of apprehensions made may only constitute a small fraction of poaching operations. One local resident met by one of the authors claimed that in the summer of 2006, his group of 7–8 poachers was able to undertake 10 poaching operations in one month at Bird Islet (North Atoll). This means that these poachers must have collected trochus near or at Sites 2 and 3. The poacher also claimed that they collected some seabird eggs and were able to gather about 20 sacks of trochus per operation. Each operation of trochus gathering lasted for about three hours per night. Given such information, this group had a catch per unit of effort of around 250 shells ha<sup>-1</sup> or about 200 sacks in all. If each sack weighed 38 kg of dry shells with a purchase price of PHP 300.00 kg<sup>-1</sup>, this group of poachers alone was able to generate more than 2 million pesos in 10 operations. It is of little wonder that despite its remoteness, the park remains a prime poaching destination for both local and foreign nationals. Given the instant high

income, the poachers ignore the distance and risk of apprehension and incarceration. However, it will be difficult to monetize the value of biodiversity in TRNP and in other parts of the country, much less the value of trochus and other organisms that are spared from poachers, and the importance of allowing them to flourish at the park for aesthetic, educational, scientific and other purposes.

Most reefs in the Philippines are now heavily damaged and overfished (Licuanan and Gomez 2000), including some reef areas in Palawan (Anda and Tabangay-Baldera 2004), which harbors few commercially important species (Ablan et al. 2004). If overfishing also occurs at TRNP, Filipinos and the whole world stand to lose an astounding biological wealth, as this reef area is considered one of the most biologically rich. Therefore, the survival of trochus and other species harbored in this World Heritage Site within the Philippines' national territory lies on effective enforcement against poachers — a key to possible habitat conservation and restoration in other parts of the Sulu Sea and the country as a whole. Upgrading surveillance equipment is essential to increasing park rangers' capabilities in detecting illegal fishermen. Conducting day and night patrols around the park is also needed. With the support of relevant national authorities, the Tubbataha Protected Area Management Board needs to put an end to the illegal trade in trochus that is occurring in Palawan Province. Given the ecological and high commercial importance of trochus, the revival of its population in the Philippines must be addressed on a broad scale.

### Acknowledgements

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## Trochus production in Solomon Islands from 1953 to 2006

Ferral Lasi<sup>1</sup>

### Introduction

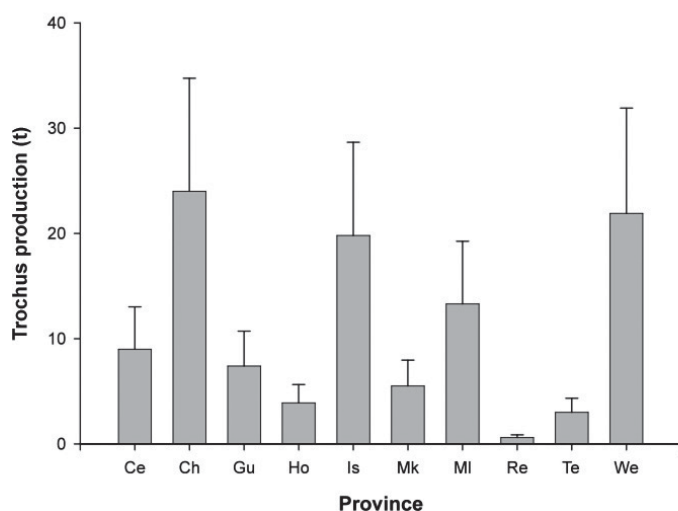
Trochus (*Trochus niloticus*) is an important resource for coastal communities in the Solomon Islands because it is easy to harvest, and is non-perishable, which is essential in rural areas where storage facilities and transportation services are poor or irregular. Trochus is commercially exploited mainly for the nacre (shell), which is processed into high-quality buttons for the fashion industry. In addition, the meat is highly regarded as a food by the locals.

In the 1950s, prior to the establishment of the commercial tuna industry in Solomon Islands, trochus was ranked second after copra as an export commodity (Pel 1956). However, with the emergence of tuna and other industries, such as oil palm and mining in the 1970s and 1990s, its rank as an export commodity dropped. Nevertheless, trochus accounted for >50% of the value of all non-fish marine exports between 1985 and 1990

(Richards et al. 1994), and still remains an important source of income for coastal rural communities that do not have alternative means of income generation. Between 2001 and 2006, national catches averaged  $108 \pm 73$  t and were taken mainly from Choiseul, Western, Isabel and Malaita provinces (Fig. 1). In 2006, the catch was 132 t worth SBD 5.5 million (USD 785,000).

### Historical production

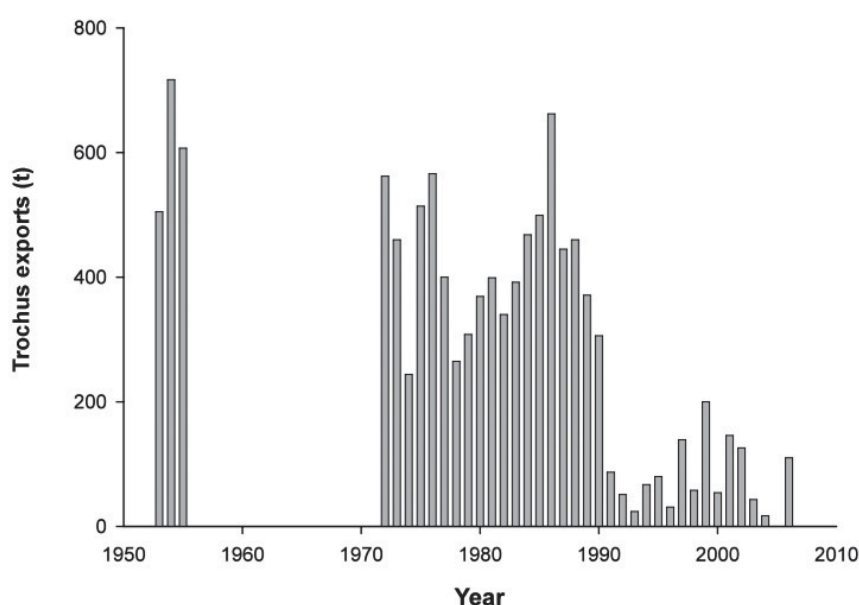
Evidence from the 1990s shows that recent harvests of trochus are well below potential production due to overexploitation. Adams et al. (1992) found that average trochus densities around Gizo and Rendova in the Western Province were  $< 20$  shells  $\text{ha}^{-1}$ , well below the density of around 100–300 shells  $\text{ha}^{-1}$ , which is typical of optimally fished stocks (Adams et al. 1992; Foale 1998). Extensive trochus surveys in West Gela by Foale (1998) also found relatively low densities of trochus (i.e. a maximum of 40–75 shells  $\text{ha}^{-1}$ ). The extent of overexploitation elsewhere in Solomon Islands could not be gauged because no dedicated studies were done in other parts of the country. However, in this paper, I use historical export data to determine exploitation patterns of trochus back to 1953.



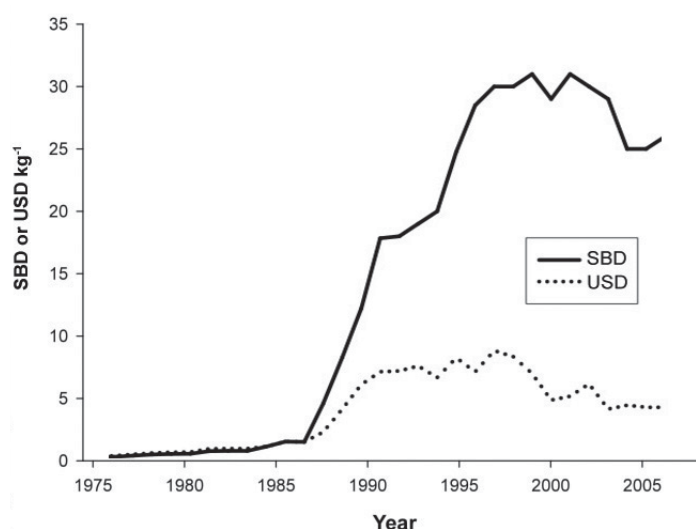
**Figure 1.** Average annual production of trochus for each province from 2000–2006. Ce = Central, Ch = Choiseul, Gu = Guadalcanal, Ho = Honiara, Is = Isabel, Mk = Makira, MI = Malaita, Re = Renbel, Te = Temotu and We = Western. Vertical bars represent standard errors.

The various sources of data included: 1) an early marine resources survey of Solomon Islands by Pel (1956), covering the period 1953–1955; 2) a country report to a regional trochus workshop held in the early 1990s by Leqata (1997), covering the period between 1972 and 1989; 3) publications by Richards et al. (1994); 4) a WorldFish Center database (unpublished) for exports between 1990 and 2004; and 5) data from Solomon Islands Department of Fisheries and Marine Resources

<sup>1</sup> At the time this article was written (mid-2009), the author was working with SPC's PROCFish Project as Reef Fisheries Officer. He now works with the Solomon Islands Ministry of Fisheries and Marine Resources as Deputy Director of the Offshore Fisheries Management Unit. Email: flasi@fisheries.gov.sb



**Figure 2.** Annual trochus production for Solomon Islands from 1953–2006.



**Figure 3.** Buying price of trochus in Solomon Islands between 1976 and 2006.

(DFMR) licensing section for 2006. Data from 1955–1971 proved difficult to obtain.

### Economic value of trochus

In 1954, 717 t of trochus were exported (Fig. 2), representing the highest annual production ever recorded from Solomon Islands (worth ~USD 300,000). Annual catches of trochus in the 1970s were variable, but averaged 410 t for the period 1972–1979 (Fig. 2). However, the price was low at SBD 0.60 per kg (~USD 0.60 per kg) (Fig. 3). From

1980–1989, catches were less variable except for 1986, when ~700 t were exported (Fig. 2).

From 1987 onwards, there was a rapid increase in the price paid for trochus (Fig. 3). By 1990, it was SBD 15 per kg, and by 1996 it rose to SBD 28 per kg. During this period, substantial proportions of the catch were sold to a number of local button factories. Despite the high and steady price for trochus, production leveled off and fell to its lowest level in the fishery's history (< 100 t yr<sup>-1</sup>). From the late 1990s to the early part of 2000, average annual production

increased only slightly to  $>150 \text{ t yr}^{-1}$ . This indicates that stocks suffered serial depletions in many parts of the country and had been overfished during the 1980s and early 1990s. Serial depletion refers to the process when fishers exploit the closest productive reefs and move on to other reefs as resources from nearby reefs become depleted. In so doing, national production remains fairly constant for a protracted period of time. However, it then declines rapidly once all available reefs have been heavily fished.

The slight peak in production in 1999 corresponded with the period of ethnic tension when many people lost their sources of income and fished for trochus. This is evidenced by a huge consignment of under-sized trochus ( $\leq 6 \text{ cm}$  basal diameter) intercepted and confiscated by the Fisheries Department during this period (Ben Buga,<sup>2</sup> pers. comm.).

### Comparison with other Pacific Island countries and territories

It is now imperative that remaining trochus stocks in Solomon Islands are properly assessed and protected from excessive fishing. A survey of invertebrates at four sites in Solomon Islands in 2006 by SPC's PROCFISH/C project found that the density of trochus averaged only  $11 \text{ shells ha}^{-1}$  in what were once leading trochus fishing areas (Sandfly, Marau, Chumbikopi and Rarumana). The mean densities of

trochus at these four sites were low compared with mean densities at other sites in the Pacific (Fig. 4).

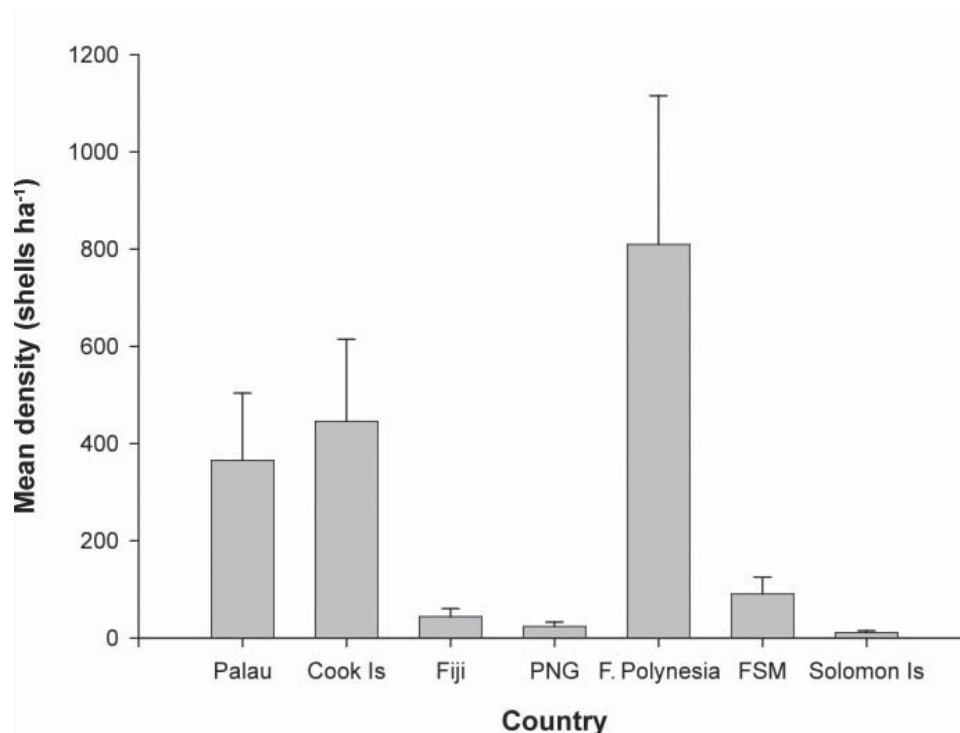
### Recommendations

In light of the significant decline in trochus catches over the last decade, the Solomon Islands Ministry of Fisheries and Marine Resources needs to take remedial measures to rebuild its trochus fishery to more productive levels.

Solomon Islands fisheries regulations include a prohibition on harvesting specimens smaller than  $8 \text{ cm}$  and larger than  $12 \text{ cm}$  basal diameter. It is apparent from the sharp fall in production since the mid-1990s that this regulation alone is insufficient to control overfishing. Instead, as evidenced from successfully managed trochus fisheries in Cook Islands and Palau — where densities exceed  $300 \text{ shells per ha}$  (Fig. 4) — tightly controlled open and closed seasons are required, in addition to imposing maximum and minimum size limits, in order for the fishery to be successful.

Given the critically low status of stocks in Solomon Islands, several other interventions are needed.

- 1) A moratorium on trochus exports should be implemented immediately, and maintained until stocks recover to more productive levels



**Figure 4.** Mean densities of trochus in countries surveyed by SPC between 1999 and 2007. Vertical bars represent standard errors.

<sup>2</sup> Fisheries and Marketing Officer. Ministry of Fisheries and Marine Resources, Solomon Islands.

(i.e. 200–300 shells ha<sup>-1</sup>). While the moratorium is in place, a management plan should be prepared to properly address management of this resource in the future.

- 2) During the moratorium, selected stocks from the Arnavon Islands Marine Conservation Area should be transplanted to reefs elsewhere in the country (such as in Olevugha, Gela) that have been depleted of trochus, in order to fast-track the recovery of spawning populations.
- 3) Three to five years after imposing the moratorium, stock assessments should be conducted in representative areas of the country to determine if stocks have been restored to target levels. If not, surveys should be repeated every one to two years thereafter until it is evident that the fishery can be re-opened. (It is likely that the fisheries for some provinces will be re-opened before others.)
- 4) Before opening the fishery in any province, a sustainable total allowable catch (TAC) should be determined based on the densities of trochus per hectare, total area of trochus habitat, and sustainable harvest level (30–40% of harvestable stock). Practical management relating to administering provincial TACs may prove difficult in which case it may be necessary to revert to only one national TAC.
- 5) Identify the period for and duration of open season required to take the recommended TAC for each province. Arrangements for implementing and monitoring the open season should be well planned in consultation with local fishing communities.
- 6) Practical open seasons for each province should be sequential in order to provide exporters with a continuity of supply throughout much of the year.
- 7) The slot size limit for trochus with a basal diameter of 8–12 cm should be maintained and applied to each province's TAC.

## Acknowledgements

I would like to thank Dr Johann Bell (fisheries specialist at SPC) for providing useful comments, Ms Rosalie Masu of Solomon Islands Department of Fisheries and Marine Resources (DFMR) for providing recent trochus production figures and prices, Dr Christain Ramofafia head of Solomon Islands DFMR, and Dr Kim Friedman (previously Fisheries Scientist for SPC's PROCFISH/C project) who also made useful suggestions to improve this paper.

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## Abstracts & publications

### **Annual cycle of reproduction in *Turbo brunneus*, from Tuticorin south east coast of India**

*R. Ramesh, S. Ravichandran and K. Kumaravel*

World Journal of Fish and Marine Sciences (2010) Volume 2(1):14–20

This research work mainly focus on the reproductive and spawning season of *Turbo brunneus* a mollusk in the south east coast of India. Random samples from *Turbo brunneus* were collected from littoral tidal pools in Tuticorin coast, during May 2002 to April 2003. The number of male and females in the monthly samples was counted to determine the male: female ratio in the population and chi-square test was applied to test whether the population adheres to 1:1 ratio. The overall male and female ratio is found to be 1: 0.96 indicating only a slight variation in the evenness of male and female in the population. Both sexes of *T. brunneus* attain sexual maturity between 23 and 27mm. The mean gonadal index (G.I) was high (21.82%) in males during May, 2002 and then it decreased gradually and reached 15.52% during October 2002, which showed the low mean GI value in males for the whole study period. While for females it was high during May 2002 (23.09%) and low during September 2002(14.83%). The GI values for both the sexes were generally low until December 2002. The limited percentage of matured oocytes which exists even after spawning indicates the high possibility for partial spawning in *T. brunneus*. It was concluded that the reproductive behavior of *T. brunneus* is highly influenced by the seasonal factors.

### **Predation on juveniles of *Crepidula fornicata* by two crustaceans and two gastropods**

*J.A. Pechenik, O.V. Ambrogio and S. Untersee*

Journal of Experimental Marine Biology and Ecology (2010) Volume 384(1–2):91–98

*Crepidula fornicata*, the slippershell snail, while native to New England, has now become a successful invasive species along coastlines in many other parts of the world. This study considers the possible control of native populations by several common predators: the invasive shore crab *Hemigrapsus sanguineus*, one species of pagurid hermit crab (*Pagurus longicarpus*), and juveniles of the drilling gastropods *Nucella lapillus* and *Urosalpinx cinerea*. In the laboratory, juveniles of *C. fornicata* were especially vulnerable to the two crustacean predators tested, and to a lesser extent vulnerable as well to predation by the oyster drill *U. cinerea*; in choice tests, young oyster drills ate barnacles and mussels rather than slippershell snails, but ate *C. fornicata* when offered no other choice. Juveniles of two other *Crepidula* species (*C. plana* and *C. convexa*) were less susceptible to predation by hermit crabs, probably due to differences in juvenile shell morphology and growth trajectories. Remarkably, juvenile dogwhelks (*N. lapillus*) ate no *Crepidula* prey over several months in the laboratory, even in the absence of alternative food and although they readily consumed blue mussels. Additional work is needed to determine the role of crustacean and other predators in regulating the growth of native populations of *C. fornicata* in the field and to determine the extent to which the explosive growth of at least some invasive *Crepidula* populations reflects escape of juveniles from native predators.

### **Coral reef associated gastropods in Tuticorin coast of Gulf of Mannar Biosphere Reserve, India**

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Indian Journal of Science and Technology (2010) Volume 3(2):204–206

Coral reef associated gastropods diversity study was undertaken in Tuticorin group of islands (Hare, Vaan and Koswari). Underwater survey was made in three quadrants (10 sq.m) in each site. A sum of 40 species of gastropods were recorded from the study area. Most of the species are commonly found in three islands. Twelve were rare viz., *Ficus ficus*, *Colubraria muricata*, *Casmaria erinaceus*, *Natica didyma*, *Nerita polita*, *Rapana bulbosa*, *Purpura rudolphi*, *Strombus* sp., *Architectonica perspectiva*, *Cypraea tigris*, *Cymatium lotorium* and *Haustellum haustellum* were reported from the study area. Species diversity and richness were found to be higher in the Vaan island.

### **Temporal patterns of arrival of beachcast green-lipped mussel (*Perna canaliculus*) spat harvested for aquaculture in New Zealand and its relationship with hydrodynamic and meteorological conditions**

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Aquaculture (2010) Volume 302(3–4):208–218

The substantial Greenshell mussel aquaculture industry in New Zealand is heavily reliant on one major source of wild spat at Ninety Mile Beach, at the northern end of the country. The spat of *Perna canaliculus* arrives intermittently at the beach attached to seaweed and other debris whereupon it is harvested for seeding mussel farms around the country. Periods of low or non-existent spat arrival at the beach have caused major disruption to the aquaculture production of this species. In an attempt to better understand the daily, monthly, and inter-annual patterns in the arrival of spat at Ninety Mile Beach, the harvesting records of spat harvesters for 1990 to 1999 were analyzed in relation to historical records of wind speed and direction, tidal range, water temperature, and modeled swell height and direction. For the long-term data set, spatfall events and the amount of spatfall increased markedly with strong offshore winds. On days with high tidal range, there tended to be an increase in the amount of spatfall, but this trend was not significant statistically. Daily and seasonal water temperature records did not show a significant effect on the timing or the scale of spatfall events. However, low swell height in the onshore direction was associated with a significant increase in spatfall events and amounts. Within the 9 year data set, storm events (wind speeds  $> 20 \text{ m s}^{-1}$ ) were most frequent during May to October. An average lag time of 4 months was found between peak storm events and the subsequent peak in spatfall events and amounts of spatfall occurring in September to October. Years with a greater number of storm events were also associated with significantly higher number of spatfall events and amounts of spatfall. Storminess and water temperature are associated with El Niño/La Niña episodes, which greatly influence the wind climate of New Zealand. During El Niño periods mussel farm managers could greatly reduce their risk of a shortfall in natural spat supply interrupting mussel production by securing sufficient spat to stock their farms from the large but less frequent spatfall events. Overall, the results provide valuable insight into possible ecological and oceanographic processes involved in spat arrival and will help with better utilization of the spat resource for this major mussel aquaculture industry.

### **Batch-tagging blacklip abalone (*Haliotis rubra*) for identification of hatchery-reared individuals on natural coastal reefs in New South Wales, Australia**

*R.C. Chick*

Journal of Shellfish Research (2010) Volume 29(1): 209–215

The identification of hatchery-reared larvae and juveniles is fundamental to assessing the success of their release when restocking. Hatchery-reared *Haliotis rubra* larvae and juveniles were successfully batch-tagged with distinct and persistent marks, enabling unambiguous differentiation from wild conspecifics when recaptured. Larvae were batch-tagged with the epifluorescent dye calcein. Experiments demonstrated that the batch-tagged larval shell was clearly visible in the spire of juvenile shells after 260 days. The recapture of batch-tagged and released larvae from natural reefs after 533 days at liberty also confirmed the persistence of this tag. A reliable and cost-effective method for batch-tagging juveniles was achieved with the use of an artificial diet that resulted in a distinctive blue-green coloration of the shell. This coloration differentiated released juveniles from wild conspecifics, was easily observed with the naked eye, and persisted on the spire of individuals for 777 days at liberty. These batch-tagging protocols allow large numbers of *H. rubra* larvae and juveniles to be distinctly tagged for long periods of time, enabling reliable estimation of survival after release and individual growth. It is likely that these techniques could also be applied to other abalone species.

### Bivalves and gastropods of the Gulf of Tehuantepec, Mexico: A checklist of species with notes on their habitat and local distribution

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Journal of Marine Biology (2009) Volume 2009:1–12

The taxonomic composition of 160 species of bivalves and gastropods recorded in the Gulf of Tehuantepec is presented with information on their habitat and distribution along 10 different localities of the shoreline and 42 stations of the continental shelf. The species were on sandy and rocky beaches, coastal lagoons, estuaries, mangroves, rocky breakwaters of ports, and shallow subtidal areas (14–47 m depth). A total of 78 bivalve species and 82 gastropod species were recorded. Most of these were associated with sandy and rocky beaches and breakwaters of ports. The estuaries host 30 species and the coastal lagoons only two. In the shallow subtidal there were 18 gastropod species and 40 bivalve species representing 36.3% of all. This study adds 24 bivalve species and 29 gastropod species not recorded in previous studies for a total count of 213 species (102 bivalves and 111 gastropods) for Gulf of Tehuantepec.

### Spatial patterns of wild oysters in the Hawkesbury River, NSW, Australia

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Journal of Shellfish Research (2009) Volume 28(3):447–451

The native Sydney rock oyster, *Saccostrea glomerata*, is under increasing threat from QX disease, competition with nonnative *Crassostrea gigas* and coastal development. Knowledge of the distribution and population structure of *S. glomerata* and *C. gigas* is essential if oysters and their ecosystem services are to be successfully managed. We determined spatial patterns of abundance, condition, and size-structure of *S. glomerata* and *C. gigas*, across two key habitats, mangroves, and rocky shores of the Hawkesbury River, a highly modified estuary 50 km north of Sydney. Sampling of five sites per habitat, spanning a 15 km stretch of river, revealed abundant populations of *S. glomerata*, averaging  $514 \pm 185 \text{ m}^{-2}$ , in mangroves and on rocky shores. The native oyster accounted for 99% of all oysters sampled, with *C. gigas* found only at two of the five sites sampled within each habitat. Overall, rocky shores supported over eight times the oyster cover as mangroves. Among rock sites, live oyster cover and condition generally decreased with distance upstream. Although, at present, the Hawkesbury River estuary supports abundant wild oyster populations, ongoing monitoring of oyster populations is required to ensure that appropriate management strategies are established to ensure the persistence of this important component of the ecosystem. Our sampling of two key oyster habitats provides an important baseline against which future studies can assess change.

### Growth of cultured pearl oyster (*Pinctada martensii*) in Li'an Lagoon, Hainan Island, China

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Journal of Shellfish Research (2009) Volume 28(3):465–470

Growth of pearl oysters, *Pinctada martensii* was studied from June 2003 to March 2005 in Li'an Lagoon of Hainan Island in China. Shell height (SH) and total weight (TW) were measured monthly and temperature was recorded daily. The growth of oysters is characterized by fast initial growth of SH in the first year, followed by rapid increase of TW in the second year. Growth of SH was influenced by temperature, showing reduced growth rate in summer, fitting the extended Von Bertalanffy model:

$$y = 92.99(1 - e^{(-0.002070(t-13.63)+0.04164 \sin(2\pi/365.25)(t-193.03))}) \quad (y: \text{SH in mm, } t: \text{time in day}).$$

Growth rate of total weight increased steadily, except during typhoons or spawning, fitting the logistic model:

$$y = 53.63 / (1 + e^{-0.009770(t-463.33)+0.1938 \sin(2\pi/365.25)(t-564.73)}) \quad (y: \text{TW in g, } t: \text{time in day}).$$

It is also established that in Hainan, most oysters were mature and suitable for pearl nucleus insertion after 16–20 mo of farming; hence to meet the implantation season in April to June, it is more advisable to conduct hatchery operation in autumn than in spring.

### Annual reproductive effort of Pacific winged pearl oyster *Pteria sterna* and its relation with the timing for planning pearl seeding operation

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Journal of Shellfish Research (2009), Volume 28(3):471–476

Using a combination of stereological and calorimetric methods, we studied reproductive effort of Pacific winged pearl oyster *Pteria sterna* during an annual cycle in Bahía de La Paz, B.C.S., Mexico. The relationship between changes in the volumetric fraction of germinal and somatic tissues (gonad, digestive gland, adductor muscle, and mantle tissue) and changes in their energy content was analyzed. These data were also correlated with changes in water temperature and availability of food (seston). Because *P. sterna* spawns several

times a year, reproductive effort was estimated ~ 400% in terms of energy increase from early development in October 2006 to the spawning occurring in January to February 2007. During this period, when water temperature was decreasing and seston concentration was increasing, *P. sterna* followed a conservative strategy for allocating energy from reserves previously stored in somatic tissues. In contrast, when productivity dropped in spring, the species followed an opportunistic strategy for sustaining gametogenesis from food energy. In decreasing order, total energy channeled for reproduction came from the digestive gland (23 KJ g<sup>-1</sup>), adductor muscle (19 KJ g<sup>-1</sup>), and mantle tissue (16 KJ g<sup>-1</sup>). Based on these results, we recommend that commercial pearl culture practices be conducted from mid-autumn (October) through early spring (April), when *P. sterna* is energetically more resistant to manipulation. An additional recommendation is to avoid grafting during the summer (June through September), when the species is energetically exhausted and highly vulnerable to manipulation.

### **Studies on glycosaminoglycans isolated from bivalves molluscs *Tridacna maxima* and *Perna viridis***

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Our Nature (2009) Volume 7:10–17

The glycosaminoglycans (GAGs) in two marine invertebrate molluscs such as *Tridacna maxima* and *Perna viridis* were analyzed. Both the species was found to contain variable amounts of GAGs in the form of heparin biomolecules as identified by metachromatic activity and agarose gel electrophoresis analysis. Anticoagulant property of the biomolecules was assessed by anti factor Xa activity. Their molecular weight was estimated as 15000 and 9000 Daltons through GPC-HPLC. The <sup>1</sup>H NMR analysis of heparin was used to predict binding sites of the heparin. Structural characterization studies clearly demonstrated that heparin is the major GAGs constituents in the test animals.

### **Exotic *Perkinsus* sp. protozoa in an imported Vietnamese ornamental clam (*Tridacna crocea*) maintained in a home aquarium**

B.J. Sheppard and C.F. Dungan

Journal of Zoo and Wildlife Medicine (2009) Volume 40(1):140–146

An adult, hermaphroditic *Tridacna crocea* ornamental clam imported from Vietnam into the USA became terminally moribund with sloughed byssal tissue and incomplete extension of the poorly responsive mantle and was necropsied. Necropsy findings included emaciation, visceral mass edema, and rare multifocal, 1-mm diameter, off-white to light tan gill nodules. Histopathology revealed marked inflammation and necrosis within the visceral mass and gills, with interstitial edema and atrophy of glandular, gonadal, and muscular tissues. Inflamed tissues contained large numbers of 10–15 µm extracellular, spherical organisms with a signet-ring morphology consistent with *Perkinsus* spp. trophozoites. The organisms often formed clusters of two to four cells and were surrounded by a host reaction consisting of a 1–4 µm rim of amorphous eosinophilic material and two to four host hemocytes. Incubation of infected host tissues in alternative Ray's fluid thioglycollate medium (ARFTM) confirmed the presence of *Perkinsus* sp. hypnospores that stained blue-black with Lugol's iodine. Polymerase chain reaction assays with sequencing of products revealed a high level of nucleotide similarity, but no exact match, to known *P. olseni* isolates. *Perkinsus* sp. organisms, including *P. olseni* and *P. marinus*, which are internationally reportable, are highly pathogenic destructive protozoa capable of disrupting ecosystems populated by naïve mollusks within the USA and negatively affecting both domestic and international shellfish industries. This is the first report of an exotic *Perkinsus* sp. pathogen in an imported ornamental clam maintained long term in a home aquarium. However, ongoing research indicates that *T. crocea* from Vietnam are commonly infected by such organisms. Veterinarians, aquarium facility managers, and veterinary clients with hobby aquariums should use appropriate caution and responsible disposal practices for clam carcasses and for water in which imported ornamental clams have been housed. Such practices will reduce the possibility of dispersing viable, exotic *Perkinsus* sp. organisms into domestic waters.

### **Can artificial substrates enriched with crustose coralline algae enhance larval settlement and recruitment in the fluted giant clam (*Tridacna squamosa*)?**

M. Lin Neo, P.A. Todd, S. Lay-Ming Teo and L. Ming Chou

Hydrobiologia (2009) Volume 625(1): 83–90

Habitat recognition and selection can greatly increase the early-life survival of sessile reef organisms. This study describes the settlement and recruitment responses of the fluted giant clam, *Tridacna squamosa*, to concrete tablets and tiles containing different concentrations of crustose coralline algae covered coral rubble (CCACR). Crustose coralline algae is known to induce settlement in a variety of benthic animals, but it has

not been used previously as an aggregate in concrete—potentially a way of encouraging colonization of man-made structures erected on or near coral reefs. After being given the choice of small tablets made with 0%, 30% or 60% CCACR for 4 days, 11 days old larvae preferred the substrate containing the most CCACR. Recruitment responses of juvenile clams to larger tiles made with the same three CCACR concentrations were also tested. These tiles were further divided into rough and smooth surface textures. After 6 weeks, more juvenile clams had recruited to the rough surfaced tiles than the smooth ones, but no significant differences among the CCACR treatments were found. Thus, even though concrete made with CCACR is initially attractive to larvae, it has no effect on recruitment of juvenile *T. squamosa*.

***Trochus kotschy*, the first Indian Ocean record of the genus *Osilinus* (Mollusca: Gastropoda: Trochidae)**

D.G. Herbert

Journal of Zoology (2009) Volume 233(3):345–357

The species *Trochus kotschy* Philippi, 1849, and *Priotrochus obscurus* (Wood, 1828) have been much confused in the past. Consistent differences between these taxa in respect of shell morphology, external anatomy and radular and opercular form are demonstrated. The distribution of *T. kotschy* and the extent to which it and *P. obscurus* are sympatric are discussed. *T. kotschy* is referred to the genus *Osilinus* Philippi, 1847, a new combination and the first record of the genus from the Indo-West Pacific. The species is thought to be a pre-Miocene relict reflecting a mid-Tethyan origin of the genus. A note on the type species designation of *Osilinus* is provided.

**Strong genetic population structure in the boring giant clam, *Tridacna crocea*, across the Indo-Malay archipelago: implications related to evolutionary processes and connectivity**

M. Kochzius and A. Nuryanto

Molecular Ecology (2008) Volume 17:3775–3787

Even though the Indo-Malay Archipelago hosts the world's greatest diversity of marine species, studies on the genetic population structure and gene flow of marine organisms within this area are rather rare. Consequently, not much is known about connectivity of marine populations in the Indo-Malay Archipelago, despite the fact that such information is important to understand evolutionary and ecological processes in the centre of marine biodiversity. This study aims to investigate the genetic population structure of the boring giant clam, *Tridacna crocea*. The analysis is based on a 456-bp fragment of the cytochrome oxidase I gene from 300 individuals collected from 15 localities across the Indo-Malay Archipelago. *Tridacna crocea* shows a very strong genetic population structure and isolation by distance, indicating restricted gene flow between almost all sample sites. The observed  $F_{ST}$ -value of 0.28 is very high compared to other studies on giant clams. According to the pronounced genetic differences, the sample sites can be divided into four groups from West to East: (i) Eastern Indian Ocean, (ii) Java Sea, (iii) South China Sea, Indonesian throughflow, as well as seas in the East of Sulawesi, and (iv) Western Pacific. This complex genetic population structure and pattern of connectivity, characterised by restricted gene flow between some sites and panmixing between others can be attributed to the geological history and prevailing current regimes in the Indo-Malay Archipelago.

**Energy storage and allocation during reproduction of Pacific winged pearl oyster *Pteria sterna* at Bahía de la Paz, Baja California Sur, Mexico**

N. Vite-García and P.E. Saucedo

Journal of Shellfish Research (2008) Volume 27(2):375–383

Seasonal variations in storage, partitioning, and allocation of energy reserves (proteins, carbohydrates, lipids, and triglycerides) between germinal and somatic tissues (gonad, digestive gland, mantle tissue, and adductor muscle), were investigated related to reproduction of Pacific winged pearl oyster *Pteria sterna*. Tissue samples were collected every three months and analyzed with histological and biochemical techniques. Energy coefficients were also calculated with data from chemical composition of tissues. Gonad samples in almost all developmental stages occurred throughout the year, suggesting that *P. sterna* is a multispawning species. The evidence indicates that the main reproductive season runs from January through April (21°C to 22°C) and was identified by higher frequency of ripe gonads, more and larger postvitellogenic oocytes and higher protein, lipid, and triglyceride levels in gonad tissue. Within this study period, there were two spawning peaks, July 2003 and January 2004. Gametogenesis was sustained from energy mainly obtained from the digestive gland and secondly from the adductor muscle. Only proteins from these two tissues were mobilized to the gonad for maturation of sex organs, because carbohydrates were stored despite the progress of gametogenesis. The role of mantle tissue was negligible. *P. sterna* appears to use a combination of stored reserves (conservative

strategy) and food supply (opportunistic strategy) as an overall strategy to regulate reproduction.

### **Seasonal variations in reproductive activity and biochemical composition of the cockle *Fulvia mutica* (reeve) from the eastern coast of China**

W. Liu, Q. Li, Y. Yuan and S. Zhang

Journal of Shellfish Research (2008) Volume 27(2):405–411

Seasonal variations in condition index and biochemical composition of the cockle *Fulvia mutica* (Reeve) were studied from March 2004 to February 2005 in eastern coast of China in relation to reproductive cycle. The condition index declined during gametogenesis and spawning, recovered when the gonad was in resting phase. Histological analysis and measurements of protein, glycogen and lipid levels and RNA:DNA ratio from gonad-visceral mass, mantle, adductor muscle, and foot of *F. mutica* were performed. Gametogenesis took place during winter and spring at the expense of reserves (glycogen in various organs, protein in the foot, lipid in the adductor muscle), which were accumulated previously during summer and autumn. Spawning occurred in May to June when water temperature was higher and food availability was abundant. The RNA:DNA ratio is a good indicator of sexual maturity in the gonad-visceral mass; the increasing RNA:DNA ratio in the gonad-visceral mass appears to show the rising synthetic activity of vitellin within the gonad. The results demonstrated that *F. mutica* may be considered a conservative species in gametogenic pattern. The useful information obtained in this study can be applied for management of populations and to initiate aquaculture activities in this species.

### **Volutid snails as an alternative resource for artisanal fisheries in northern patagonic gulfs: availability and first suggestions for diving catches**

G. Bigatti and N.F. Ciocco

Journal of Shellfish Research (2008) Volume 27(2):417–421

Volutid snails have been identified as a potential resource for artisanal fisheries in northern patagonic gulfs. We explored their availability in two gulfs of Chubut Province (Patagonia, Argentina) by means of SCUBA diving and baited traps. CPUE and biomass were estimated from visual counting densities. CPUE of all the volutes was 65.85 kg·diver<sup>-1</sup>·h<sup>-1</sup> and 59.5 kg·diver<sup>-1</sup>·h<sup>-1</sup> in San Matías (SMG) and San Jorge (SJG) Gulfs, respectively. Estimated biomass was 89.7 (±28.9) and 44.4 (±19.2) tons in SMG and SJG. The species *Adelomelon ancilla* and *Odontocymbiola magellanica* could supplement the potential clam fishery existent at SJG. In SMG *Zidona* followed by *O. magellanica* could be the main commercial target. We suggest minimum catch sizes of 16 cm for *Z. dufresnei*, 9 cm for *O. magellanica*, and 12 cm for *A. ancilla*. Protection of the egg capsules and females would help the protection of the resource. These measures could ensure the sustainability of a small-scale multispecific fishery.

### **Suminoe oyster (*Crassostrea ariakensis*) culture in Korea**

H. Seop Yoon, H. Taek Jung and S. Duk Choi

Journal of Shellfish Research (2008) Volume 27(3):505–508

The Suminoe oyster *Crassostrea ariakensis* is considered a potential aquaculture species in Korea, potentially supplementing or supplanting culture of the Pacific oyster *Crassostrea gigas*, currently the focus of commercial production and research. Production of cultured Suminoe oysters in Korea is limited, in part because of limited information on its biology and ecology. Commercial production is presently restricted to two rivers (Seomjin and Kawha). Here we describe the current status of *C. ariakensis* in Korea, focusing on its ecology and factors affecting development of aquaculture for this species. Preliminary investigations suggest that the Suminoe oyster shows excellent potential for expanded cultivation. A comprehensive monitoring program is needed to detect natural and anthropogenic ecosystem changes affecting production of the Suminoe oyster.

### **Establishing a baseline for management of the rock scallop, *Spondylus calcifer* (Carpenter 1857): growth and reproduction in the upper gulf of California, Mexico**

R. Cudney-Bueno and K. Rowell

Journal of Shellfish Research (2008) Volume 27(4):625–632

The rock scallop (also known as “donkey thorny oyster,” “spiny oyster,” and “thorny oyster”), *Spondylus calcifer*, is the largest member of any Panamic Province *Spondylus* and has played important economic, political, and cultural roles in coastal communities of the Eastern Tropical Pacific for thousands of years. Despite its importance, knowledge of its biology is scant. We assessed seasonal variations in shell and

adductor muscle growth, longevity, reproductive age and period, and population sex ratios in the upper Gulf of California, Mexico, the northernmost area within the geographic distribution of this species. Information on shell growth and age was obtained *via* the use of stable oxygen isotope profiles of shell aragonite cross-referenced with mark recapture data. *Spondylus calcifer* forms white growth bands during winter and spring months. Shell growth accelerates during warmer months and diminishes during colder months. Likewise, the adductor muscle increases in size and weight during colder months, affecting fishermen's distribution of fishing effort. These seasonal variations in growth are likely a result of energetic shifts related to resource allocation pre and post reproduction, which takes place in July–August as water temperatures reach 28°C to 30°C. The species reaches sexual maturity between 2.5–4 y of age and can live to at least 12 y. Overall sex ratios consisted of 1:1 male:female, a population structure in accordance with previous reports for the southern Gulf of California. We discuss our findings in the context of management and conservation of the species.

### **Prospective culture of the Cortez oyster *Crassostrea corteziensis* from northwestern Mexico: growth, gametogenic activity, and condition index**

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Journal of Shellfish Research (2008) Volume 27(4):711–720

This study examined growth, gametogenic activity, condition index, as well as the relationship of the life cycle to environmental parameters of the Cortez oyster *Crassostrea corteziensis*, which was cultured for 25 mo in the lagoon of Las Guásimas (Sonora, Mexico). We used oocyte diameter and cytological characteristics of the gonad to determine reproductive stages in females and males. The condition index was used to describe the oyster's physiological health. Temperature, salinity, seston, and chlorophyll *a*, *b*, and *c* were recorded at the study site. The Cortez oyster had isometric shell growth, reaching  $103.2 \pm 1.82$  mm height and  $150.3 \pm 4.98$  g total weight. Data were adjusted to the von Bertalanffy growth equation ( $L_{\infty} = 132.2$  mm and  $K = 1.08$  y<sup>-1</sup>), and survival was about 70%. This native species exhibited a distinctive gametogenic cycle, with the beginning and end of the cycle controlled by seawater temperature fluctuation (15–33°C), which once started, is continuous over a 9-mo period (March to November). Elevated temperature (>25°C) produced high gametogenic activity, exhibiting primary, growing, and mature oocytes, and partial spawning in April, September, and November. The peak spawning event occurred in August, when seawater reached peak temperatures of 31°C to 33°C, which was followed by a significant reduction of the condition index. During winter, storage of nutrients took place, and this appears to be used in the following season for gametogenesis. In general, the condition index was high throughout the study period. Energy for growth and reproduction came from phytoplankton blooms in summer and high concentration throughout the year of nonchlorophyll particulate organic matter. Observations show that this oyster is a protandrous species. High survival, elevated yields, and a long, continuous gametogenic cycle indicate that *C. corteziensis* has importance in aquaculture in Gulf of California.

### **Assessment of genetic diversity of the eastern oyster *Crassostrea virginica* in Veracruz, Mexico using microsatellite markers**

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Journal of Shellfish Research (2008) Volume 27(4):721–727

Genetic variation was evaluated in populations of the eastern oyster *Crassostrea virginica* (Gmelin) from the coast of Veracruz, eastern Gulf of Mexico. We sampled six lagoons and analyzed variation at five microsatellite loci. Significant Hardy-Weinberg deviations occurred at all loci and were attributed to the presence of null alleles. We found no isolation by distance among the populations in these lagoons, but significant heterogeneity was observed among some adjacent lagoons, possibly reflections of geographical factors and local reductions in population size. Certain extreme north and south localities were not genetically different in terms of nonsignificant pairwise  $F_{ST}$  values. Gene flow is attributed to seasonal shifts in coastal currents, larval production throughout the year, human interference with the natural lagoon processes, and restocking efforts. The observed pattern of variation could be another example of chaotic genetic patchiness in marine organisms.

### Prospect of oyster culture in Pakistan: pathology assessment of two commercially important oyster species

Ghazala Siddiqui, Zarrien Ayub, Inke Sunila

Journal of Shellfish Research (2008) Volume 27(4):795–800

Nine different species of oysters belonging to the genera *Crassostrea*, *Saccostrea*, and *Ostrea* occur naturally along Pakistan's coastline in the northern Arabian Sea. At the present time, no commercial harvesting or hatchery culture of oysters exists in Pakistan. The world's oyster aquaculture industry is seriously affected by diseases caused by parasites, such as *Bonamia ostrea* in the European flat oyster *Ostrea edulis*, and *Haplosporidium nelsoni* or *Perkinsus marinus* in the Eastern oyster *Crassostrea virginica*. Pathogens may be endemic or recently introduced and may cause epizootic mortalities and catastrophic economic losses. To evaluate if there are parasites or diseases in Pakistan's oysters that could limit prospective aquaculture development, histopathological analyses were performed on two oyster species, *Ostrea nomades* and *Crassostrea belcheri*. Oysters were sampled year-around, and fixed and processed for histology. Slides (217 cases for *O. nomades* and 76 cases for *C. belcheri*) were examined for the presence of parasites or pathological changes. *Ostrea nomades* was infected by a protozoan parasite, *Nematopsis* sp. Sneider, 1892 (Apicomplexa, Porosporidae), at 67% prevalence, and *C. belcheri* at 1.3% prevalence. *Nematopsis* spp. did not induce pathological changes in the oysters. *Stegotricha*-like ciliates (Thigmotrichida, Ancistrocomidae) were present in the stomachs of *O. nomades* with a prevalence of 1%, and 25% of *C. belcheri* presented ceroid deposits in their tissues. Historically, *Ostrea* and *Crassostrea* genera have been associated with epizootic diseases, but in the present samples, no known, economically important parasites or diseases were found. Absence of any pathology in these samples projects a positive future for oyster aquaculture in Pakistan. These oyster populations should be protected from nonendemic bivalve importations, which could transmit new parasites to these potentially susceptible, previously unexposed, native oysters.

### Survival, growth and recruitment of abalone *Haliotis diversicolor* in Sagami Bay, Japan

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The occurrence of newly settled postlarvae (<500 µm of shell length [SL]) and subsequent growth and survival of the abalone, *Haliotis diversicolor*, were observed from 2001–2004 at two stations in the rocky shore of Nagai on the coast of Sagami Bay, Japan. Seawater temperature, current velocity, and distance of the weekly stone movement were monitored at both stations to determine factors affecting survival and growth of postlarvae. There were newly settled postlarvae in August and September of 2001, October 2002, August 2003, and September 2004. A total of 6 cohorts were identified between 2001 and 2004. Initial density of each cohort was generally higher at Station 1 than Station 2, but recruits at Station 1 had greater mortality than Station 2. Results from measurements of the physical environmental factors suggested that higher mortality rate of postlarval and juvenile *H. diversicolor* at Station 1 were produced by greater water turbulence and stone movement caused by storms. Growth rates in the first month after settlement varied between cohorts (35–62 µm SL day<sup>-1</sup>), and growth rates were slower for cohorts settling later in the spawning season and experiencing lower water temperature. The timing of typhoon-triggered spawning in *H. diversicolor* population was also suggested to be an important factor affecting growth and survival of postlarvae and early juveniles, along with their subsequent recruitment. The cohorts from 2001–2004 attained 17–40 mm SL in about one year after settlement. To estimate the size and age at the first stage of maturation, the increase in shell length and gonad development of a single cohort from 2001 were measured. This cohort attained 30–55 mm SL and showed high gonad index at 22 mo after settlement, indicating the first stage of maturation of *H. diversicolor* is achieved at age 2.

### Analysis of the decline of the abalone fishery (*Haliotis fulgens* and *H. corrugata*) along the west-central coast of the Baja California Peninsula, Mexico

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We analyzed the decline in the abalone harvest of two species *Haliotis fulgens* and *H. corrugata*, from one region composed of six study zones along the Baja California peninsula, Mexico. Survey data from 1991 to 2001 were used and density estimations with a  $\chi^2$ -distribution were computed. The results showed a dramatic decline in density (kg/10 m<sup>2</sup>) for both species. The decline in densities of *H. fulgens* and *H. corrugata* is consistent with a pattern observed since 1975. The current condition of the abalone stock is an example

of an uncontrolled fishery. An increase in fishing effort or harvest rate must be avoided because we do not know the equilibrium density of these populations.

### **Population assessment of the conch *Strombus galeatus* (Gastropoda, Strombidae) in Pacific Panama**

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Populations of *Strombus galeatus* Swainson 1823 have been severely overfished in Pacific Panama. In this study, we assessed the status of the *S. galeatus* population in Las Perlas and Coiba Archipelagos. Average densities per site were dismal:  $0.45 \pm 3.8$  ind ha<sup>-1</sup> and  $6.0 \pm 18$  ind ha<sup>-1</sup> in Las Perlas and Coiba, respectively. In Las Perlas, low densities occurred on the southwest coast of Del Rey, the south coast of Chaperas, and Bolaños, whereas intermediate densities were found on the eastern coast of Saboga. In Coiba, high relative densities occurred only on the west coast of Coiba Island and at the north and south of Bahía Damas. Environmental variability and depth did not explain the differences found between densities nor the low abundances in the archipelagos. Shell length of *S. galeatus* from Coiba ranged from 91.0–213.3 mm ( $156 \pm 22.2$  mm). We fitted a von Bertalanffy growth model to juvenile data using the following parameters:  $L_{\infty} = 315$  mm,  $K = 0.029$  mo<sup>-1</sup>, and  $t_0 = 0.5$  mo. The model suggests that 27–28 mo are required (on average) before the outer lip begins to form. Two years after the enactment of Decree No. 159 in September 2004, which banned the *Strombus* fisheries in Panama for five years, the conch populations in Las Perlas and Coiba have not recovered. The Las Perlas population is recruitment limited and we recommend that a program of law enforcement and monitoring should be implemented immediately to protect this species, conducive to increase spawning and settlement in nursery grounds.

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