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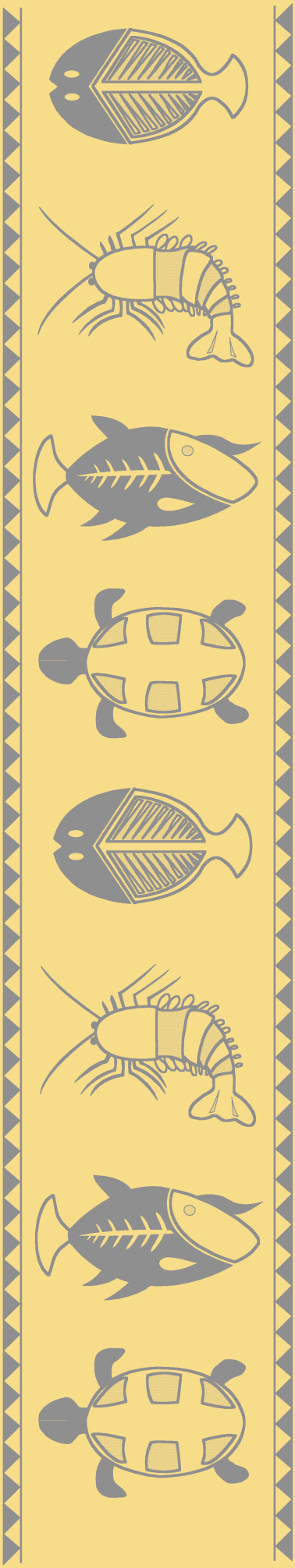

WORKSHOP ON TROCHUS RESOURCE ASSESSMENT, MANAGEMENT AND DEVELOPMENT

Report and selected papers

South Pacific Commission
Noumea, New Caledonia

Integrated Coastal Fisheries Management Project
Technical Document No. 13

WORKSHOP ON TROCHUS RESOURCE ASSESSMENT, MANAGEMENT AND DEVELOPMENT

Report and selected papers

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Foreword

The topshell, *Trochus niloticus*, is one of the key commercial export fisheries of the Pacific Islands region. Although trochus is native to the western part of the region, its range has been considerably extended eastwards since 1930 through transplantation and now reaches French Polynesia. Although the cost of these transplants has been small, the resultant economic returns, following the 10–20 year establishment period, have been comparatively large. More importantly, these economic returns have largely benefited outer islanders and rural villagers, to whom non-perishable high unit-value export products form an essential component of their ability to earn an income.

The importance of trochus fisheries to Pacific Islanders is reflected in the number of requests for assistance that have been made to the South Pacific Commission over the years. Indeed, the first regional SPC fisheries training activity involved a workshop on trochus, in 1957, and led directly to the introduction of trochus to the Cook Islands. The importance of this fishery has not decreased. Although the world market price has fluctuated and different stocks have occasionally been overfished, the demand is sufficient and the organism resilient enough to maintain fisheries that are more economically and biologically sustainable than many reef fisheries.

The workshop reported here was held in response to the wide regional interest in this resource, and the need to familiarise the new generation of Pacific Island fisheries officers with the issues, but was particularly prompted by the sharp decline in trochus export market prices that many countries experienced in 1990. This workshop was not only to provide training in trochus resource assessment and management, and to enable fisheries staff from different countries to compare notes, but to 'troubleshoot' the apparent economic problems that the fishery was facing and provide a basis for deciding future national policies on this resource.

The workshop was organised by the United Kingdom SPC Inshore Fisheries Research Project, but was heavily sponsored by various other organisations including the Commonwealth Secretariat, the FAO South Pacific Aquaculture Development Project, the Canadian International Center for Ocean Development and others. Special thanks are due to the Vanuatu Fisheries Department for facilitating local arrangements and providing the tutorial skills of Moses Amos, to the Department of Primary Industries and Fisheries of Tasmania for releasing workshop co-organiser Warwick Nash, and to the French-funded SPC Fisheries Information Project for editing and producing this report.

Julian Dashwood
SPC Fisheries Programme Manager

Avant-propos

Le troca, *Trochus niloticus,* est l'une des principales ressources halieutiques exportées par la région du Pacifique Sud. Le troca, originaire de la zone occidentale de cette région, a vu son habitat s'étendre considérablement vers l'est depuis 1930, suite aux efforts entrepris pour sa transplantation, et on le trouve désormais jusqu'en Polynésie française. Le coût de ces transplantations est modeste, mais leurs retombées économiques, au terme d'une période d'établissement allant de 10 à 20 ans, relativement importantes. Il convient de souligner que ce sont les îles éloignées et les communautés rurales qui tirent largement parti de ces nouveaux bénéfices économiques, car ce produit d'exportation non périssable et doté d'une forte valeur par unité, constitue un élément essentiel de leurs activités rémunératrices.

Le nombre de demandes d'assistance reçues par la Commission du Pacifique Sud au sujet de l'exploitation du troca témoigne de la valeur que les Océaniens attachent à cette ressource. Ainsi, la première action de formation halieutique conduite par la CPS, en 1957, comportait un atelier sur le troca, qui a débouché directement sur l'introduction de ce gastéropode marin aux Îles Cook. L'importance de cette ressource ne s'est pas démentie. Son cours mondial a connu des fluctuations, et certains stocks ont parfois souffert de surexploitation, mais la demande est suffisante, et la capacité de récupération de cet organisme permet d'assurer la viabilité de cette pêcherie, meilleure du point de vue économique et biologique que celle de nombre d'autres pêcheries récifales.

Si l'intérêt que suscite cette ressource dans l'ensemble de la région et la nécessité de la faire connaître à une nouvelle génération d'agents des services des pêches ont en partie motivé l'organisation du séminaire qui nous intéresse ici, c'est en premier lieu la baisse rapide des cours à l'exportation dont ont souffert de nombreux pays en 1990 qui s'est trouvée à l'origine de cette initiative. Ce séminaire devait permettre non seulement de conduire des actions de formation à l'évaluation et à la gestion de la ressource en troca, et de confronter les expériences des halieutes de divers pays, mais aussi de résoudre les difficultés d'ordre économique que la pêcherie semble connaître, et d'établir le fondement des futures décisions de politique nationale concernant cette ressource.

Mis sur pied dans le cadre du Projet de recherche sur les ressources côtières (financé par le Royaume-Uni sous l'égide de la CPS), ce séminaire a bénéficié du généreux concours d'autres entités, dont le Secrétariat général du Commonwealth, le Projet de développement de l'aquaculture dans le Pacifique Sud (FAO) et le Centre international d'exploitation des océans (Canada). Il convient de remercier tout particulièrement le service des pêches de Vanuatu, chargé de l'organisation locale, qui a mis à la disposition des participants les compétences pédagogiques de M. Moses Amos, le ministère des industries primaires et de la pêche de Tasmanie, qui a prêté les services de M. Warwick Nash, co-organisateur, et enfin, les agents du Projet d'information halieutique de la CPS (financé par la France), responsables de la mise en forme et de la publication de ce rapport.

Julian Dashwood
Directeur du Département des pêches

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Background to the workshop and narrative report

Garry Preston

Introduction

The topshell, *Trochus niloticus,* is native to countries of the Western Pacific and has been introduced to many additional locations throughout the Pacific Islands. This shell is collected and exported for button making and other mainly decorative uses, providing an important source of income for rural and outer island dwellers in the region.

The Pacific Islands are the most important trochus-producing area in the world. Accurate figures on harvests from all regions of the Pacific are not available, but the present volume of production is thought to range between 1,500 and 2,000 t/yr. At 1991 prices, this would have a value to fishermen of around US$ 7 million. Most of these earnings accrue to coastal communities whose alternative earning opportunities are frequently limited.

In recent years, the market value of trochus shell has increased markedly. As a result, the level of exploitation has also increased in many Pacific Island countries. There are fears in some locations that present levels of harvesting will not be sustainable and that serious resource depletion will occur if management regimes are not developed and instituted. This will result in undesirable consequences for those communities to which trochus harvesting is presently economically important.

The 22nd SPC Regional Technical Meeting on Fisheries, held in Noumea in August 1990, discussed this issue in some depth. The meeting also discussed several related topics, including:

(a) factors determining regional and global variation in trochus quality, and therefore value;

(b) the merits of regional cooperation in the marketing of marine products, including trochus, as a means of increasing economic returns to Pacific Island countries from the resource; and

(c) appropriate management approaches for trochus and other marine resources, including the use of hatchery-produced juveniles to replenish depleted natural populations.

As a result of these discussions, the meeting recommended that the South Pacific Commission take action to assist Pacific Island countries in maximising the returns they obtain from their trochus resources by promoting regional collaboration and information exchange in the development of effective exploitation, marketing and management systems. Given the interdisciplinary nature of the topic, the meeting also recommended that the Commission seek the active cooperation of other regional agencies, in particular the South Pacific Regional Aquaculture Development Project and the Forum Fisheries Agency, in this work.

As part of its response to these recommendations, the Commission, through its Inshore Fisheries Research Project, organised a three-week Workshop on Trochus Resource Assessment, Development and Management between May and June 1991. The overall aims of the workshop were:

(a) to update participants on recent developments in trochus processing and marketing;

(b) to expose participants to current biological and aquacultural information relevant to trochus fishery resource assessment and management;

(c) to train selected participants in the conduct of field work aimed at providing assessment of the status of local trochus resources;

(d) to develop a standard trochus survey methodology for use within the region, so as to allow direct comparison of survey data in the future;

(e) to promote an exchange of trochus fishery management experiences in the region, in order to promote effective management of this important resource.

Venue and funding

The workshop lasted slightly more than three weeks, from Monday 13 May to Sunday 2 June 1991 inclusive. The workshop was hosted by the Fisheries Department of the Government of Vanuatu and executed in collaboration with the FAO South Pacific Regional Aquaculture Development Project.

Funding support was provided by the International Centre for Ocean Development (Canada), the UK Overseas Development Administration, the Commonwealth Secretariat, the Food and Agriculture Organization of the United Nations, and the South Pacific Commission.

Workshop structure

The workshop was structured as three segments, each lasting about one week. All participants attended for the first week (13–18 May inclusive): selected participants stayed on for the second and third weeks (13–26 May inclusive, and 26 May – 2 June inclusive). Participants were not permitted to join the workshop part-way through.

Week 1 was aimed at a broad range of individuals involved in work on trochus, from those dealing with aspects of resource assessment and the provision of management advice, to those involved in decision-making at a senior level, or in product quality assessment, control or marketing. Parts of Week 1 were also relevant to individuals from the private sector.

Sessions during Week 1 consisted of lectures and discussion groups covering aspects of trochus biology and life history, population dynamics, basic resource assessment methods, hatchery technology and juvenile propagation, resource management, shell processing and quality assessment, and marketing.

Some attention was also given to the species *Tectus pyramis* and *Turbo marmoratus,* which occupy similar habitats and are traded in similar ways as *Trochus niloticus.* Site visits to commercial shell-processing factories and to the government trochus hatchery were organised, and participants were able to observe trochus spawning and subsequent larval development.

Week 2 was aimed at individuals involved in survey and assessment work on trochus and other sessile marine invertebrate resources. Participants in Week 2 were required to have completed Week 1.

Week 2 consisted of two main elements:

1. The comparison of field-survey methods for trochus. It was intended to develop a standardised survey methodology for future use in Pacific Island trochus surveys as part of this exercise;

2. An experiment to intensively monitor the short-term effects of a mass release of trochus juveniles in a selected location. Such experiments will be essential for effective assessment of the usefulness of the juvenile release programmes for fishery enhancement that are being considered in some parts of the region.

Week 3 provided an opportunity for participants to assist in an intensive field survey in Aneityum island, using the standardised methodology developed during Week 2. Participants in Week 3 were required to have first completed Weeks 1 and 2.

The survey formed part of Vanuatu Fisheries Department's national trochus assessment project and thus provided important support for trochus resource development in Vanuatu.

Participants

Thirty-seven participants from 16 countries took part in various stages of the workshop. A participants list is shown on page 7.

Resource persons

The individuals listed in Table 1 and Table 2 acted as resource persons, by making keynote presentations, chairing sessions, or reporting on discussions.

Week 1

Presentations and discussion sessions during Week 1 were extremely productive, and highly interactive, with all but a very few participants taking an active role in the interchange. The presence of a large number of technical specialists, especially the shell industry and trade representatives, led to a large body of otherwise inaccessible information being made available.

Table 1: Resource persons of the Workshop on Trochus Resource Assessment, Development and Management

Name	Country	Organisation	Weeks
Garry Preston	New Caledonia	South Pacific Commission	1–3
Warwick Nash	Australia	Tasmanian Sea Fisheries Department	1–3
Hideyuki Tanaka	Fiji	Regional Aquaculture Development Programme	1–2
Seamus McElroy	UK	Private	1

Table 2: Resource persons for short periods (one or two hours) in support of specific items on the workshop programme

Name	Country	Organisation	Weeks
Serge Bordet	Vanuatu	Private	1
Robert Gillett	Fiji	FAO – UNDP Regional Fishery Support Programme	1
William Bour	New Caledonia	ORSTOM (*French overseas research agency*)	1
George Joe	Vanuatu	Melanesian Shell Products Ltd	1
Hirofumi Kubo	Japan	Okinawa Prefectural Fisheries Experimental Station	1
Masayoshi Murakoshi	Japan	Okinawa Prefectural Sea Farming Centre	1
Nory Ozaki	Japan	Kiyohara Co. Ltd.	1

The following original papers were copied and distributed:

- Country statement – Queensland
- Resource statement – Western Australia
- Country statement – Cook Islands
- Status of trochus in Fiji
- Situation de la ressource en trocas en Polynésie française
- Country statement – Palau
- Country statement – Papua New Guinea
- Trochus assessment, development and management in Solomon Islands
- Trochus resource in Tuvalu
- History and present status of the trochus resource in Vanuatu
- Trochus resource of Western Samoa
- Country statement – Okinawa
- Kiyohara Company outline: Where trochus shell and shell button stand in Japan
- Processing and trade of Melanesian Shell Products Ltd
- Mass seed production and restocking of trochus in Okinawa
- Methodology of trochus seed production in Vanuatu
- Juvenile release in Palau
- Updated table of Pacific trochus introductions
- Studies on trochus ecology and its propagation in Micronesia (abridged translation)
- Remote sensing of trochus habitat on Tetembia Reef, New Caledonia

Week 2

The 24 participants remaining for Week 2 relocated to Erakor island where accommodation and classroom facilities are conveniently located close to a fringing reef with a viable trochus population. This week and Week 3 were more in the nature of a training course than a workshop per se. Participants were given instruction in statistical procedures and survey design by the resource specialists, and were required to put this instruction into practice by carrying out survey work on the reef flat, and completing analysis of the results.

Heavy surf made diving over the reef-edge dangerous, so survey work during the early part of the week focussed on benthic invertebrates easier to access than trochus. This did not detract from the purpose of providing instruction in the basic principles of conducting and designing a trochus survey. During the later part of the week, weather and tides permitted access over the reef and it was possible to specifically target trochus.

A juvenile release experiment was also conducted during this week. Two thousand juvenile trochus were tagged and released in four replicates at different places on the reef. Instantaneous monitoring was carried out the following day, and on subsequent days. (A further check on the animals was conducted by one or two participants who remained for a few days in Port Vila before departing at the end of Week 3). The Vanuatu Fisheries Division has been monitoring the site since the time of the release. Survival rates have been extremely encouraging, far better than anticipated or that achieved in any other trochus release experiment, including the large programmes carried out in Japan. Vanuatu Fisheries Department now plan to carry out additional releases in order to obtain further improvements in survival rates.

Week 3

Week 3 involved 16 of the 24 Week-2 participants, who travelled to the island of Aneityum, in the south of the Vanuatu archipelago, to carry out survey work on the island's trochus population. This was a change in the original schedule, in which it was planned to carry out this field work on the island of Emae. The change was requested by the Vanuatu Fisheries Department, who needed management-related information in order to advise the Island Council on re-opening the fishery. Trochus and green snail harvesting had been banned for three years previous to the study teams visit and the situation thus presented an ideal opportunity both to assess the effects of the closure, and to provide useful advice to the Island Council.

The week was spent on board the chartered vessel *Coriolis.* Steaming to Aneityum took about 28 hours in each direction, in very rough weather. Most participants were seasick and unable to function on the trip down, but by the end of the week some were sufficiently adapted to carry out data analysis and write-up of results on the return leg. After arrival at Aneityum, the *Coriolis* anchored in a sheltered location, and survey work was carried out using the vessel's two outboard-powered dive tenders.

The four management plans (Appendix II) were compared and discussed in depth during a final session in Port Vila after the vessel returned. Although each has individual features, there is a consistency in approach which strongly suggests that workshop participants had effectively absorbed the information and techniques covered in the workshop. The merits and demerits of each plan were discussed, and based on this information the Vanuatu Fisheries Department has provided management advice to the Island Council which has been accepted.

National workshop

Subsequent to the main workshop, a smaller gathering of ten representatives from the various islands of Vanuatu was convened for two days by the participants from the Vanuatu Fisheries Department. This element was administered entirely by the Vanuatu Fisheries Department, and funded by ICOD.

The purpose of the national workshop was to advise Island representatives on management of their own local trochus resources, based on information from the main workshop. The presentations were made in the local Bislama language by two of the ni-Vanuatu participants in the main workshop, and stimulated considerable interest and discussion. Island representatives were made aware of the likely biological and economic con-

sequences of different approaches to managing this fishery. At the same time, the Fisheries Department staff used the opportunity to gather information on current patterns of exploitation in different areas, and to discuss means of gathering additional research information through cooperation with local fishermen. The workshop was a valuable extension exercise which the Vanuatu Fisheries Department intends to repeat and capitalise on in the future.

Workshop documentation

Most of the papers that were presented at the Trochus Workshop have been edited for publication and follow this narrative account of the workshop and field activities.

Recommendations

The following recommendations arose from Week 1 of the workshop:

1. that the South Pacific Commission assist Pacific Island countries to make use of remote sensing and image processing in survey work on trochus and other marine resources, especially benthic invertebrates (*The Commission was unable to secure funding to develop its own remote sensing facility, and as such assistance in this sector to member countries has been limited*);

2. that the Commission establish a new Special Interest Group (SIG) on shells and the shell trade, focussing especially on trochus (*This was subsequently established in 1991 by the Coastal Fisheries Programme's Information Section and the first trochus bulletin published in 1992. To date a total of four bulletins have been produced*);

3. that the Commission encourage the detailed study of the Aitutaki trochus fishery as a case study, in order to provide management-related information that will be applicable to the developing fisheries in other atolls of the region (*This study was subsequently conducted in August and September 1992 by the Inshore Fisheries Research Project and the Cook Islands Ministry of Marine Resources, with a draft report submitted shortly afterwards to the Cook Islands Government. The results of the survey and comparison of different survey methods was published in 1995 as* Inshore Fisheries Research Technical Document No. 9 *by the South Pacific Commission*); and

4. that the Commission encourage the adoption of standardised survey techniques for trochus and other benthic marine invertebrates in Pacific Island countries, so as to enable comparison of results by different workers and from different areas (*The publication of the Aitutaki trochus survey report partially fulfilled this recommendation, however, it is still planned to produce a handbook of standardised survey techniques*).

The recommendations were subsequently endorsed by the 23rd SPC Regional Technical Meeting on Fisheries in August 1991, and approved by the South Pacific Conference in October 1991. Where action has been taken is indicated in parentheses after each recommendation.

Evaluation

The weakest part of the workshop was during Week 2, when it became clear that the numerical skills of some of the participants were inadequate for them to develop a clear understanding of some of the more complex statistical concepts involved in the design of surveys and the analysis of the resultant data. This problem was anticipated since it was understood that participants would be from a wide educational and technical background. However, the difficulty was not completely overcome, and if repeating this exercise it would be desirable to increase the amount of time and the number of resource people allocated to this element.

Apart from this issue, feedback from the participants was extremely positive throughout the course of the workshop. Most individuals had a genuinely strong desire to participate fully and to take home information that would be of direct application in their own situations, and this attitude greatly encouraged the free flow of information and the sharing of experience.

The enthusiasm of the participants was much greater than anticipated. During Week 1, there were numerous sessions in the evenings and on Saturday morning, and all were fully attended. During Week 2, participants spent many hours on the reef in the middle of the night or before dawn, checking the released trochus juveniles and preparing early surveys so as to take full advantage of the tide. Many participants carried out additional transects on Sunday so as to ensure their data achieved the desired level of precision. During Week 3, participants were expected to dive regularly at night, to work in surf or rough weather, and to carry out data analysis at other times. All these activities were carried out without complaint and with considerable enthusiasm. After an extremely rough 28-hour boat trip, everyone was still keen to participate in the final discussion of the management plans, which began mid-Sunday afternoon and continued until 8 p.m.

The workshop proved to be both an invaluable source of information on all aspects of the trochus resource, and an effective means of heightening awareness of factors influencing fishery management decisions on the part of the Pacific Island participants. In particular, the socio-economic aspects of management, and the requirements of the shell trade, were emphasised, so as not to be outweighed by biological considerations alone. This approach ultimately resulted in participants developing considered management plans that were likely to be acceptable to rural people dependent on the fishery for their income.

Participants names and affiliations

Name	Country	Occupation/Affiliation	Weeks
Jim Gillespie	Australia	Principal Scientific Officer, Queensland Department of Primary Industry	1
Erik Hunter	Australia	Bardi Aboriginal Association, One Arm Point, Broome, Western Australia	1
Karina Magro	Australia	Student, University of Western Australia	1–3
Alex McCarthy	Australia	Bardi Aboriginal Association, Broome, Western Australia	1
Jeremy Prince	Australia	Bureau of Rural Resources, Canberra	1
Kelvin Passfield	Cook Islands	Fisheries Research Officer, Ministry of Marine Resources	1–3
Patricia Tuara	Cook Islands	Senior Fisheries Officer, Ministry of Marine Resources	1–3
Esaroma Ledua	Fiji	Fisheries Division, Ministry of Primary Industries	1
Abdul Rahim	Fiji	Senior Fisheries Assistant, Fisheries Division	1–2
Apisai Sesewa	Fiji	Resource Assessment Programme, Fisheries Division	1–3
Ronald Cheneson	French Polynesia	Service de la Mer et de l'Aquaculture	1
Simpson Abraham	Federated States of Micronesia	Marine Resources Division, Kosrae State	1–2
Flynn Curren	Federated States of Micronesia	Aquaculture Consultant, Marine Resources Division, Pohnpei State	1–2
Donald David	Federated States of Micronesia	Fisheries Officer, Division, Pohnpei State	1–2
Jerry Faholimul	Federated States of Micronesia	Marine Resources Division, Kosrae State	1–2
Joe Fanafal	Federated States of Micronesia	Marine Research Specialist, Marine Resource Management Division, Yap State	1–3
Temawa Taniera	Kiribati	Assistant Fisheries Officer, Fisheries Division	1–3
Nena Kilma	Marshall Islands	Fisheries Officer, Marshall Islands Marine Resources Authority	1–3
Hilary Kobaia	Marshall Islands	Private Industry Council	1–3
Bernard Fao	New Caledonia	Extension Officer, Bureau des Pêches et de l'Aquaculture, Province Sud	1–3
Ken-ichi Kikutani	Palau	Micronesian Mariculture Demonstration Centre	1–3
Steven Patris	Palau	Marine Resources Division	1
Molean Chapau	Papua New Guinea	Fisheries Biologist, Kavieng Fisheries Research Laboratory	1–3
Joshua Ako Kari	Papua New Guinea	Trade Promotion Branch, Ministry of Internal Affairs	1
John Leqata	Solomon Islands	Assistant Fisheries Officer, Fisheries Division	1–2
John Mao	Solomon Islands	Western Pacific Shell Ltd	1
Edwin Oreihaka	Solomon Islands	Fisheries Officer, Fisheries Division	1
Peter Ramohia	Solomon Islands	Fisheries Officer, Fisheries Division	1–3
Suia Gaualofa	Tokelau	Temporary Extension Officer, Dept. of Agriculture and Office of Tokelau Affairs	1–3
Tevita Finau Latu	Tonga	Fisheries Officer, Fisheries Department	1
Nikolasi Apelinu	Tuvalu	Assistant Fisheries Officer, Fisheries Division	1–3
Moses Amos	Vanuatu	Fisheries Biologist, Fisheries Department	1–3
Albert Carlot	Vanuatu	Senior Fisheries Biologist, Fisheries Department	1–2
Felix Nguyen	Vanuatu	Research Technician, Fisheries Department	1–2
Henrietta Winterstein	Western Samoa	Fisheries Officer, Fisheries Division	1–2

Management plans produced by the four groups during Week 3

Group 1: Proposed management plan for trochus fishery at Aneityum Island, Anelgowhat village

Molean Chapau, Bernard Fao, Suia Gaualofa & Felix Nguyen

Background

Aneityum is one of the 15 island groups that make up the country of Vanuatu, stretching in a north–south direction. The island is approximately 400 km South of Vila, the national capital of Vanuatu. There are 300–400 people on the island living in four main villages and numerous small family houses sparsely distributed around the island.

The island is administered by a local government, and chiefs control the common property belonging to the people. Administrative services are not very regular. The Fisheries Department visits the island about twice a year. The island is served by two flights per week and coastal boats are not regular.

In 1989 the Island Council became concerned about their trochus fishery which appeared to be declining. As a result of this concern, the Island Council imposed a four-year moratorium. Before the moratorium the only management plan for Vanuatu was a minimum size limit of 9 cm and the total allowable catch (TAC) of 70 t for Vanuatu. By this period the government had imposed a ban on exports of raw trochus shell to encourage secondary processing within Vanuatu. This resulted in four button blank factories competing for the raw shell supply.

Factory boats would regularly visit Aneityum and buy empty shell at US$ 1.80–2.70 (US$ 1.00 = VT 110) per kilogramme beach price, and some boat crews were reported to be diving for trochus shell.

Since the moratorium, two surveys have been conducted for this area to monitor changes in relative abundance. The first survey was conducted by the Vanuatu Fisheries Department in May 1990 and the most recent is by PC/FO in May 1991. Only the results of the PC/FO are available and form the basis of this proposed management plan. The Island Council wished to re-open the fishery and requested a management plan be drawn up with the aim of maximising the socio-economic benefit from the resource for the people of Aneityum. The chiefs do not want to see another moratorium imposed and advised that the management plan for the fishery should ensure a steady income.

This was basically a management exercise utilising the results of this survey, the historical knowledge of the island trochus fishery, the government's general development policies and the wisdom of the Island Council to provide the best possible management plan that would fulfil most of the island and government development objectives and, most importantly, ensure that the resources can sustain the level of harvesting.

Management principles

The group feels that the management of the Aneityum trochus fishery should be directly controlled by the Island Council and co-ordinated by the local government of the island. This would give the Island Council almost full autonomy to manage their own resource. Any infringement of the management regulations can be handled by the village court system.

The advantage of this approach is that it minimises the government's involvment, and the enforcement cost of the management regulations becomes a lot more effective. Above all, the people of the island will over time become more responsible and aware of the need to manage the trochus resources on a long-term sustainable basis so it generates maximum benefit for the Island people.

We feel that the trochus fishery should be managed by size limitation and Total Allowable Catch (TAC) Quota and provide a simple administrative arrangement that requires setting up a Trochus Resource Management Advisory Committee (TRMAC). The Committee would have a small trained staff to carry out survey work, collect catch and effort data. The function of the TRMAC is to advise the Island Council. The administrative cost will be taken from allocating 3 t of the total trochus TAC of 43 t to the Committee.

The TRMAC would have the power to employ four to six trained staff whose responsibility would be to carry out transect or quadrat sampling and collect catch and effort data. The Fisheries Department would be in charge of this group and data would be processed and reporting available for the TRMAC meeting, which should be held each year. The Committee should review the TAC in the first two years after the fishery has been opened.

Enforcement of management regulations

The Island Council would enforce the management regulations and all offenders would be dealt with by the Village Court. The penalty would also be decided by the Village Court. Serious offences would be dealt with by the Island Council.

Group 2: Proposed management plan for trochus fishery at Anelgowhat Village, Aneityum Island

Temawa Taniera, Niko Apelinu, Moses Amos & Kelvin Passfield

Introduction

Suggested regulations to allow regular fishing of a sustainable resource are as follows:

1. Apply a minimum size limit of 8 cm and a maximum size limit of 12 cm

These sizes are selected to allow approximately one year for animals to breed before they get into the fishery and also to allow the larger, less commercially valuable and more fecund animals to continue spawning. Also, smaller shells may command higher prices.

2. Apply a total allowable catch (quota) of 52,000 kg, based on the following calculations:

Legal size range 8 to 12 cm

Size (cm)	Mean weight (kg) from length–weight relationship	Approx. ratio (%) of total popul. from length/cumulative catch graph
8–9	0.19	12
9–10	0.22	14
10–11	0.31	9
11–12	0.42	16

Therefore in a population of 1000 trochus:

120 are 8–9 cm and weigh 0.19 kg each,
therefore total weight = 22.8 kg

140 are 9–10 cm and weigh 0.22 kg each,
therefore total weight = 30.8 kg

90 are 10–11 cm and weigh 0.31 kg each,
therefore total weight = 27.9 kg

160 are 11–12 cm and weigh 0.42 kg each,
therefore total weight = 67.2 kg

Total = 148.7 kg

So, in a population of 1000 animals, the legal size range constitutes 148.7 kg. Taking an arbitrary figure of 60 per cent of animals within the legal size range to be fished gives 89 kg.

So, for every 1000 animals, 89 kg can be fished.

Crest/slope trochus density = 1.861 / 20 m^2
(for 5,000,000 m^2 = 465,250 trochus)

Mid-reef area density = 0.575 / 20 m^2
(for 3,000,000 m^2 = 86,250 trochus)

Inner reef area = 0.316 / 20 m^2
(for 2,000,000 m^2 = 31,600 trochus)

Total = 583,100 trochus

We know 89 kg can be harvested for every 1,000 trochus.

Therefore a total quota of 51,895.9 kg can be allocated

It is suggested that this catch could be divided up into Individual Transferable Catch Quotas (ITCQs) in order to ensure an equitable distribution of the benefits from the resource. With a population of only 300 people, this should not be difficult to administer.

If the community relies on the resource as a regular source of income, this quota could additionally be broken down into 12 by monthly quotas of 4,330 kg. This would probably suit the shell buyers as well, as they would have a more continual supply.

3. Establish at least two sanctuaries:

   i. a good adult habitat, and

   ii. a good juvenile habitat in an area where spat from the adult habitat is likely to fall.

4. Policing of size limits be controlled by the council at the buyer

This would require least administration. Trochus shipments/bags could be checked at random. Any undersize shell found would initiate more thorough investigation. Suggested a fine to the buyer of VT 5,000 per undersized shell.

5. The emphasis of this management plan is on leaving control of the fishery to the Island Council based on sound management advice from the Fisheries Department.

Future research requirements

It should be pointed out that the foregoing advice has been based on a limited amount of field work. In order to improve, refine, and generally monitor the effectiveness of this management strategy, the Fisheries Department would like to continue their research/field work as follows:

1. More thorough surveys to determine if the catchability (i.e. apparent stock size) varies with the time of

day, month, tide, moon phase etc. Also to arrive at the number of transects needed to achieve statistical precision of $p < 0.1$.

2. Continue to monitor the size distribution of the stock, to determine if the management strategy is affecting the size distribution. For example, if stock size in legal range is diminishing, then the quota may be too high, or vice versa. Special attention in this regard should be given to the reserve areas, to determine if juveniles are in fact settling at a reasonable rate.

3. Continue tag/recapture experiments to monitor migration and growth.

4. Depending on ultimate success of seeding experiments in Port Vila, seeding could be tried at Aneityum to allow increased catches.

Group 3: Proposed management plan for trochus fishery at Anelgowhat Village, Aneityum Island

Karina Magro, Joe Fanafal, Nena Kilma, Ken-Ichi Kikutani

Introduction

Our aim for the fishery is summarised easily by the following flow chart:

- Conservative management
- Sustained resources
- Create steady income

Assumptions

The following assumptions have been made regarding the fishery (although they may not necessarily be true).

1. The trochus market in Vanuatu is stable and the Melanesian Shell Products (MSP) button factory will buy all the shell, of any size, that is made available. The current value is VT 200/kg for all shell sizes.

2. There is a breeding season (with higher frequency and intensity of spawning) during summer (October to May).

3. January to May are unfavourable times for fishing due to cyclone activity and bad weather.

4. The total area of reef surfaces are:

   reef crest/slope = 3 km^2
   reef top = 5 km^2
   inner reef = 2 km^2

   These values have been calculated from surface area estimation techniques (rather than linear measures).

5. All size classes are equally catchable.

6. Results from abundance surveys at Anelgowhat can be applied to similar zones throughout the entire island.

7. Abundance results have low confidence levels and high precision.

Considerations

1. There is very little survey data available for Aneityum.

2. There is no record of past fishing activity in the area.

3. Tradition and local custom play an important role in managing the fishery.

4. Problems exist with illegal shells fetching higher prices on the market.

5. The majority of the 300 people living in Aneityum are likely lo be involved in the fishery.

Recommendations

1. Place management decisions and enforcement at the level of local government (i.e. the Island Chief and his Council).

2. Keep detailed records of fishing activity to monitor the progress of the fishery.

3. Develop future survey programmes to monitor the progress of the fishery.

It may be useful to define the roles and responsibilities of key players in the Aneityum trochus fishery.

i. The Island Head Chief is responsible for management decisions and enforcement. He is the major voice for local custom and tradition and is the most likely person to see that management decisions are adhered to.

ii. A position for a Local Council Fisheries Officer should be created. This person is directly responsible to the Island Chief and may be a member of the local village or a representative from the buyer.

His/her responsibility is to: collect shell from the fishermen, keep accurate fishing records, sell shells to the buyers, ensure good prices and enforce management decisions.

These are important in the overall management strategy.

Management strategies

Size limits

The minimum size limit will remain at 9 cm. This size allows collection of around 50 per cent of the total numbers in the population but around 75 per cent of the total population biomass. This is a conservative minimum size limit and will be reviewed after a year's fishing activity. A conservative minimum size limit combined with light fishing pressure will ensure a stable size distribution within the trochus stocks.

Quotas

The total biomass (standing stock) of 9-cm-plus individuals has been estimated at 76,400 kg. An annual harvest of 45,000 kg will provide a conservative level of exploitation. There are two buffers in this quota. Firstly, the standing stock has been calculated from the survey data and does not include the estimated 50 per cent of the population that was not observed in the surveys, and secondly, the quota has been set at 60 per cent of the estimated total standing stock.

This quota will be divided between 60 families (each with 5 members) that comprise the Aneityum population of 300 people. This calculates to an annual harvest of 750 kg per year per family. This quota can be removed by continuous exploitation through the 7-month fishing season at 107 kg per month or may be set at 750 kg for a short annual harvest.

Closed season

No fishing activity should be permitted during January to May. This is appropriate because bad weather occurs during this time of year and it allows protection of stocks during the intense summer spawning period.

Restriction of fishing gear

A total ban on hookah or SCUBA gear should be imposed. Harvesting methods should be restricted to dry collecting from exposed reefs and sub-tidally with snorkel gear. This will assist in keeping the fishing pressure low whilst providing a low maintenance and low-cost harvest method.

Sanctuary reef

The reef to the south of Aneityum will provide a good sanctuary location. The northern side is suitable juvenile habitat and the southern side is suitable for adult stocks. The local currents will facilitate dispersal of larvae to reefs immediately to the north. It is expected stocks will flourish in this area as the bay is well protected. The sanctuary will also act as a baseline area (of virgin stocks) for comparison with fished areas. This function alone is important—even if the sanctuary fails to facilitate long distance larval dispersal.

Other comments

Management strategies not suitable for Aneityum are juvenile re-seeding and adult transplantations (as abundant stocks are currently present). However, suitable locations for these activities should be located in the event the Vanuatu Government decides to adopt these management methods. A moratorium is also undesirable.

Future assessment of the fishery

1. Pre- and post-harvest surveys should be conducted to provide the total available stock, particularly in relation to size distribution, abundance and biomass. This will assist in providing the quota level and time of fishing seasons in the immediate future. (In the same way the survey data for the 28 to 31 May 1991 period has been used to develop this management guideline).

2. Exploratory surveys to look for other local aggregations of trochus around the island and to confirm (or dispute) the assumption that the results here can be extrapolated across the entire reef systems around Aneityum.

3. Maximum and minimum size limits will be reviewed after considering a breakdown of numbers and biomass within each size class and determining the reproductive contribution of each size class. (There is a need to understand egg per recruit to assess size limits).

4. The possibility of setting quotas for reef zones will be reviewed after breaking down each zone in terms of the numbers and biomass of shells in each size class.

5. Growth studies in the area will be continued.

6. An attempt to understand the stock-recruitment relationship should be considered to accurately decide on the proportion of the total standing stock that can be exploited.

Group 4: Proposed management plan for trochus fishery at Anelgowhat Village, Aneityum Island

Apisai Sesewa, Peter Ramohia & Patricia Tuara

Introduction

1. Minimum size limit = 8 cm (35% of total stock):

   Because sexual maturity is at 6 cm.

   At 8 cm trochus are 3-year-old, and have therefore had one year for spawning.

   Eight centimetres is a favourable size for button manufacturing.

2. Maximum size limit = 11 cm:

   Greater than 11 cm in size enables greater production of eggs. Legal size of 8–11 cm = 35 % of stock which is a conservative estimate for the first harvest. Such a figure is preferred in order to enable greater research of stock abundance/size and frequency/catchability before the next harvest. For the first harvest it is preferred that under-exploitation, rather than over-exploitation, of stock is carried out before further research.

3. Total Allowable Catch (TAC) quota of trochus:

   909,000 trochus standing stock estimate
   x 35 % of trochus in legal size range
   =
   318,150 trochus in legal size range
   x 60% harvest percentage
   =
   190,890 trochus for harvest
   x 0.00025 t average shell weight of legal trochus
   =
   47.7 t shell quota
   =
   190,890 trochus for harvest
   x 0.00033 t average live weight of legal trochus
   =
   63.0 t live trochus quota
   out of 300.0 t total live trochus stock estimate

4. Licence required to harvest:

   - non-transferable, and
   - administered by Island Council

5. Trochus must be collected and inspected live by fisheries officers/Island Council in order to enable undersize/oversize to be returned to reef. A central depot is used for inspection. This will ease monitoring/management.

6. Restriction on harvest method. No SCUBA diving equipment to be used. This will minimise catch rate.

Further required research data

1. Research required on:

   - growth rate (tagging),
   - trochus catchability,
   - stock movements, and
   - production and exportation of trochus by button factories.

2. Based on information from research it will be possible to reassess stock abundance estimates and thus amend the total allowable catch (TAC) quota for future harvests.

Country reports

Queensland's trochus fishery

J.A. Gillespie

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Queensland Department of Primary Industries

Introduction

Much of the available information for Queensland's trochus fishery was assembled by Warwick Nash in his 1985 report submitted to my Department and the Great Barrier Reef Marine Park Authority.

Harvests

The trochus fishery in Queensland began on the Great Barrier Reef (GBR) in 1912 in the Torres Strait when sample shipments of shell were sent to Austria and Japan.

Figure 1, based on Nash's study, shows production in the years 1912–62. The fishery began slowly in the first three years of commercial harvesting but expanded rapidly to a peak production of 966 tonnes in 1915; another peak of 1,097 tonnes in 1927 and other peaks in 1946, 1950 and 1953.

By 1919 the reefs as far south as Mackay were being fished, and in 1927 the Swains Reefs complex at the southern end of the GBR was found to contain trochus in commercial quantities.

The increasing use of plastics led to the collapse of the industry in the 1950s, which was followed by virtual inactivity for 20 years. I do not have catch figures for the period 1962–86.

Table 1 gives the catch figures for 1987–90, which show catch levels increasing from 92 tonnes in 1987 to 611 t in 1990. Figures for the period since 1987 are based on inspection reports from the Queensland Boating and Fisheries Patrol.

I consider it is highly probable that the actual harvest since 1987 has been greater (perhaps up to 100 per cent greater) than the official figures because of income tax avoidance through black marketing.

Table 1: Trochus catch figures (t), 1987–1990

	1987	1988	1989	1990
Torres Strait	23	70	186	231
East Coast	69	77	114	380
Total	92	147	300	611

Socio-economic aspects

The trochus fishery in Queensland is managed in two parts:

1. Torres Strait:

   Permits are issued to island communities, with trochus harvesting by individual village inhabitants in small dinghies and also through larger vessels, about a dozen in total, mostly owned and crewed by Torres Strait Islanders.

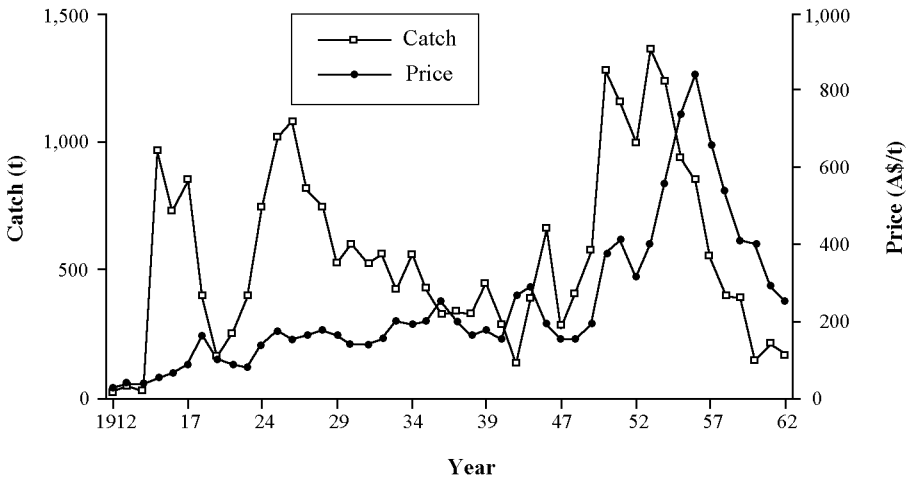

Figure 1
Production of the Queensland trochus fishery from 1912 to 1962 (from Nash, 1985)

2. East Coast[1]:

   Licences under the Fisheries Act were issued in 1991 to 5 Europeans, 3 Torres Strait islanders resident on mainland Queensland and 2 Torres Strait islanders through the Torres Strait Island Coordinating Council.

A price decline would adversely effect employment and increase the need for government welfare, particularly in the Torres Strait.

Processing and marketing

In 1991, 22 pearl dealer licenses were issued, although not all would be involved in buying and selling trochus.

There are no specific figures on exports. Virtually all trochus product is exported to markets in Europe and Asia.

Introductions

The commercial species *Trochus niloticus* is native to Queensland waters, as is the main non-commercial species *Trochus pyramis*. No introductions are planned.

Stock assessment

The *Trochus niloticus* resource is found in commercial quantities from the Torres Straits south to Swains Reef, a distance of some 2,000 km. Nash estimated in 1985 that the maximum sustainable yield for the entire region is approximately 500 t. His estimate was based on annual catch records from 1912 to 1960.

Management

Management measures include the following:

- minimum legal size of 8.0 cm base diameter;
- maximum legal size of 12.5 cm base diameter;
- 500 t total quota: 150 t Torres Strait, 350 t East Coast;
- individual quotas of 25 or 50 t to 10 licensees on the East Coast;
- no individual or Island Community quotas in the Torres Strait; and
- issue of licences for the East Coast Fishery including: Pearling Vessel Licence, Master Pearlers Licence, Pearl Divers Licence, Diver Tender Licence, Pearl Dealers Licence.

East Coast licence holders are limited to one primary vessel and up to four tenders less than five metres in length. Licences and quotas are not transferable. Catches must be inspected by the Queensland Boating and Fisheries Patrol. Logbooks have been distributed to collectors for recording catch and effort.

The East Coast licensees implemented a voluntary closure on collection in the region between Lizard Island and Cape York for the period January to March 1991.

Under the Great Barrier Reef Marine Park Authority management arrangements, certain zones are closed to fishing including trochus harvesting.

Evidence of effectiveness of management

These measures are considered partially effective. Managing on the basis of catch records means management measures lag behind the effects of exploitation on the resource.

For example, the 1990 catch of 611 t is considered too high and attempts will be made in 1991 to reduce the catch nearer to the approved 500 t. However, the impact of the higher catch in 1990 has already been incurred.

Management problems include:

- lack of respect for size limits;
- illegal harvesting and black marketing;
- operators with offshore Commonwealth Government licences may in fact be harvesting in State waters;
- instability of vessel usage and Master Pearler arrangements;
- removing operators from the fishery for reasons other than poor catch performance is very difficult i.e. for alleged illegal activities;
- pressure for entry to the fishery or increased quotas.

Aquaculture

Queensland has no aquaculture facility for trochus and no plans exist.

Other issues

The most up-to-date study on the biology and fisheries of trochus in Queensland is the 1985 report by Warwick Nash (Aspects of the biology of *Trochus niloticus* and its fishery in the Great Barrier Reef Region. Qld Dept. of Primary Industry and Great Barrier Reef Marine Park Authority).

[1] In 1990 and 1991 increased pressure for entry to the East Coast trochus fishery has been exerted by aboriginal communities on Cape York, as well as a number of European residents of mainland Queensland. In addition, the Island Coordinating Council in the Torres Strait has strenuously sought increased quota—largely through greater access to the East Coast fishery.

A research project to be undertaken in 1992 and funded by trochus inspection fees is now being formulated to cover issues such as stock assessment, recommended total allowable catch for the Torres Strait and East Coast fisheries.

Other issues that may be studied include:

- review of the 8–12.5 cm size limits,
- distribution along the GBR,
- potential closures,
- survival out of water,
- potential for restocking,
- natural recruitment,
- logbooks,
- prevalence of *T. niloticus* in Commonwealth waters, and
- assessment of *T. pyramis*.

A Management Plan for Queensland's trochus fisheries is almost ready for public comment. Our Minister has indicated his intention not to make major changes to the Plan until 1993 (after the research project in 1992).

Resource statement – Western Australia

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Introduction

Trochus is found in several areas along the Western Australian coastline. Off-shore it is found at Rowley Shoals, Browse Island, Scott Reef, Seringapatam Reef, Ashmore Reef and Cartier Island (Jones, 1983). Trochus is found along the northern reef platforms in King Sound where the Bardi Aboriginal Community hold the only collecting licence in Western Australia.

King Sound is occupied by a network of around 120 islands. The outer area is known as the Buccaneer Archipelago. The waters here are dominated by 11 m tides which produce rapid currents between the islands. Reefs surround many of the islands, and reef flats exposed during low tides can extend several kilometres. Trochus collecting in this area is unique in that only exposed reef flats during low tides are dry picked. No submerged collection of trochus occurs. Trochus collecting is undertaken by at least 60 of the community members throughout the year during spring tides.

Harvests

Trochus collecting has occurred in King Sound over parts of the last century. There is little information available on the fishery prior to 1979 when a full-scale commercial trochus fishery commenced. During the period of 1979 to the present, monthly records of the total catch per person have been collected. This provides information concerning total production and total effort (in terms of number of collectors).

The total annual production (Figure 1) has varied considerably over the last ten years. The annual production was very high during 1980 at 135 tonnes. The lowest annual production was recorded in 1983 at 9 tonnes. The annual production has since increased and stabilised around 50–70 t.

Socio-economic background

Trochus collecting is a significant income to many members of the Bardi Community who are based at One Arm Point on the western side of King Sound.

Processing and marketing

Shells are taken to the mainland after collection where they are boiled in 44 gallon drums filled with sea-water and the flesh tapped out. This processing is done by the collectors. The shells are then ready to be sold. Until recently the shells were sold to the Community Council where individuals received A$ 7 per kg of dry shell and the council then sold the shells to two overseas buyers for A$ 9 per kg.

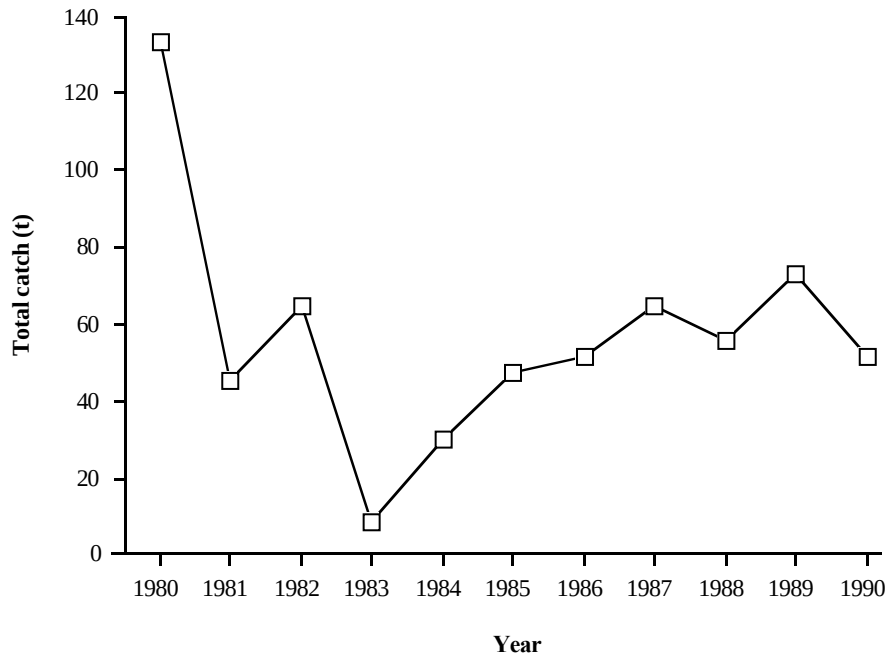

Figure 1
Total annual production of trochus at One Arm Point (1980–1990)

In April 1991 the community decided to give the trochus industry a formal business structure to be managed by a group of local administrators. This placed decisions regarding trochus collecting, value adding and management, as well as day-to-day operations, in the control of the Bardi Algni Management Group (Algni is Bardi for trochus). The future of this enterprise is uncertain, as the profit margin of A$ 2 is unlikely to cover operation costs with the present level of exploitation.

Introductions

The stocks of trochus in Western Australia are endemic and no introductions have taken place in this area. There is interest, however, in the feasibility of transplanting adults to reefs in Indonesian waters to decrease the amount of illegal trochus fishing by Indonesians in Australian waters.

Stock assessment

There have been no attempts at stock assessment in King Sound. In 1991 the community decided to fund a three-year research programme which will encompass stock assessment. Regular monthly sampling of the abundance and size distribution of trochus in fixed quadrats is being considered.

Management

The only legal management requirements currently in place are size limits of 65–100 mm (maximum basal diameter) which were introduced in 1984. These limits resulted from discussions between the collectors and the Fisheries Department of Western Australia. In the years prior to 1984 the minimum legal size limit was set at 2.5 inches (63.5 mm) in 1970 and 76 mm in 1983.

There are several initiatives taken by the collectors to preserve trochus stocks; such as leaving reefs with small shells for a period of time to allow shell growth and avoiding situations where several collectors work on the same reef. Additionally, four reefs have been closed to harvesting for the next three years to coincide with the research programme which commenced in September 1991.

These management measures are becoming less effective as stocks decline due to harvesting. Additionally, there are collectors that choose to ignore the legal size limits. There are several issues to consider in addressing trochus management. Firstly, the relevant trochus biology and resulting management models to determine size limits and yields. Secondly, the human aspect of regulating the fishery, particularly educating collectors on the necessity of implementing management procedures but also considering management principles that will suit community lifestyle.

Aquaculture

A research station has been constructed at One Arm Point. The station consists of a small laboratory with microscopes, five plastic tanks and a diesel pump to provide seawater through plastic pipes. This facility will be used to study the reproductive and larval biology of trochus in the area. It will also be used to hold shells for tagging and will provide education within the community specifically on a trochus hatchery, but also on hatchery principles generally that can be applied to other animals.

This facility is not intended as a full-scale hatchery. Further studies regarding size specific growth and mortality rates need to be completed before a hatchery can be considered as a suitable management method or a source of trochus. The cost effectiveness of establishing a hatchery has not been investigated.

Research

A three-year research programme to study the population biology and ecology of trochus in King Sound commenced in September 1991. The Bardi Aborigines Association are providing funds and assistance for the research to be completed by a doctoral student at the University of Western Australia.

The aims of the research are:

- To determine abundance and size-specific distribution patterns of trochus. To investigate size-specific rates of growth, fecundity, recruitment and mortality.
- To consider variation in abundance, size distribution and demography with respect to temporal and spatial scales.
- To construct a reasonably complete life history of *Trochus niloticus*.
- To establish suitable fisheries management principles.

A report discussing results from pilot studies and the history of the fishery over the last 10 years is being written.

References

JONES, H.E. (1986). Marine Resources Map of Western Australia. Part 1. The Resources. Report No. 74. Fisheries Department of Western Australia.

Trochus resource assessment, development and management in the Cook Islands

Patricia N. Tuara

Ministry of Marine Resources, Rarotonga, Cook Islands

Background

Trochus niloticus is found on 11 of the 15 islands of the Cook Islands in various populations. However the island of Aitutaki, an 'almost atoll', 200 km north of Rarotonga is the only island which has economically productive stocks. The focus of this report is, therefore, on this island, where the Ministry of Marine Resources has concentrated effort on stock assessment, development and management.

Trochus introductions

Trochus was first introduced to the Cook Islands in early 1957, with one shipment of 300 mature adults (greater than 6 cm basal diameter) from Fiji to Aitutaki (Powell, 1957). The population was allowed to establish itself, being protected by the disinterest of local people, rather than legislation. There is no written record of a monitoring programme linked to the introduction of the animals. However, following the first harvest season, surveys of the stock have continually been carried out.

Since the late 1970's a series of attempts have been made to introduce trochus to other islands in the Cooks group. Initial trochus introductions to the short bench reefs of the 'Makatea' islands in the South were largely unsuccessful. A lack of suitable habitat for trochus (on the bare, low relief reefs), and poor recruitment levels (with heavy larval run-offs) are likely to have prevented stocks establishing themselves.

In the atolls of the Northern group, the introductions have been more successful, with large adult trochus being found on Manihiki over two years after release. Table 1 is a depiction of the efforts to introduce trochus to the islands of the Cooks group.

Socio-economic background

The trochus industry is one in which all members of the Aitutaki island community (population 2,400) participate. Before a harvest is carried out, details concerning the price and management of the operations are discussed between the buyer, the Island Council, fisheries officers and the local community. The harvest is carried out by the men of the seven village communities.

The live trochus are brought to a central depot for inspection, cooking and packing by fisheries officers, members of the Island Council and selected public servants.

The harvest price of trochus has increased substantially from NZ$ 0.85/kg in 1984 to the present price of NZ$ 7.00/kg for A-grade shells. The sale of trochus has therefore contributed a significant proportion of the income of the local people.

Apart from adding to household income, earnings from trochus sales have also assisted in financing the island's community projects. Aside from the NZ$ 7.00/kg collected by the people, an amount of money is allocated to the Island Council for projects.

Table 1: Trochus introductions in the Cook Islands (Sims, 1985)

Island	Reef type	Year	Number introduced	Current status
Rakahanga	Fringe/atoll	1985	690	–
Penrhyn	Atoll reef	1985	400	–
Manihiki	Atoll reef	1985	400	–
Palmerston	Atoll reef	1981	2 000	Abundant
"	"	1982	1 000	Abundant
Mitiaro	Bench reef	1982	300	Rare/extinct
Manuae	Fringe/atoll reef	1981	500	Uncommon
Aitutaki	Atoll reef	1957	40	Economically productive
Mauke	Bench reef	1983	300	Rare/extinct
Atiu	Bench reef	1982	300	Rare/extinct
Rarotonga	Barrier/fringe reef	1983	200	Rare/extinct
Mangaia	Bench reef	1983	300	Rare

The implementation of the Individual Transferable Quota (ITQ) has assisted in ensuring a more equitable distribution of harvest earnings. This is an improvement over the past system when trochus was harvested by a minority group of interested fishermen.

At the present time, the entire community is involved in the trochus industry, either directly through the harvest and processing of shells, or indirectly through receipt of earnings. A decline in harvests or prices would minimise the level of income and employment available to the island community.

It is likely that less people would become involved in the industry over time. Added to this, support for a trochus management system would probably decline, leading to the harvesting of illegal size stock and over-harvesting. The end result would be a continued reduction of stock which would inevitably lead to stock depletion. The people of Aitutaki would feel the primary effects of a decline in harvests and prices. The wider Cook Islands community would be affected by the decrease in exports and national earnings.

Harvests

It was not until 1981 that the first harvest season on trochus was declared, after the Island Council complained that previously abundant stocks of the local turban snail (*Turbo* sp.) had decreased with the proliferation of trochus (Sims, 1984).

The harvest level for 1981 was an estimated 200 t or more over a 15-month period. Stocks were allowed to recover until 1983 when another season was declared. To guard against the over-exploitation of 1981, the harvest period was reduced to 3 months. The next harvest season was from November 1983 to February 1984 and resulted in 35.7 t of trochus being taken, a marked decrease over the previous harvest.

In 1985 and 1987, the harvest period was further reduced to 3 consecutive days and two separate periods of 24 hours, separated by a one month interim. The 1990–91 harvest was over a period of 5 days. The harvest for this period was approximately 33 t. Progressively better predictions of total harvest returns have been obtained over time.

The present information on the exploitation of trochus stocks is gathered by the Ministry of Marine Resources through pre- and post-harvest surveys.

Stock assessment

Recently obtained survey reports from years before trochus stocks were fished provide some information on the establishment of the pioneer population on Aitutaki.

Estimates of standing stock derived from these surveys show a dramatic increase in trochus abundance over a five-year period, from 35,000 trochus in 1974 (Masters and Wichman, 1974) to 470,000 trochus in 1979 (Dashwood, 1979). The 1974 estimate is likely to be a gross underestimation, but no description of the methodology used is provided. The 1979 figure is obtained by standard belt transects, and may be taken as accurate.

Trochus stocks on Aitutaki were initially overfished during the 1980–81 and 1984 harvests when stock assessment work was limited, and management measures less than fully effective. The stocks appeared to recover as seen in estimate figures to 1987 shown in Table 2 (Sims, 1988). The latest stock estimate from a survey undertaken in June 1990 was 300,000 individuals. This table was used as a basis for the 1990–91 harvest quota which is discussed in the section on management.

Table 2: Trochus abundance and harvests on Aitutaki, 1980–1987 (from Sims, 1988)

	1980–81	1983	1984	1985	1986	1987
Stock estimate	470,000 (1979 est.)	336,000	339,000	305,000	360,000	385,000
Quota (tonnes)	30	20	20	20 (est. TAC)	no harvest	40 (est. TAC)
Declared duration	3 months	3 months	3 months	3 days	no harvest	2 days
Actual duration	15 months	3 months	12 days	3 days	no harvest	2 harvests of 24 hrs
Licences number	?	42	300	250	no harvest	Day 1: 190 Day 2: 233
Harvest (tonnes)	200 (estimate)	35.7	45.7	27.0	no harvest	Day 1: 12.0 Day 2: 33.1
Harvest ratio	No accurate harvest data	31.0%	49.8%	26.5%	no harvest	Day 1: 11.5% Day 2: 36.0%
CPUE (kg/man/day)	No accurate harvest data	7	13	36	no harvest	Day 1: 63 Day 2: 141
Remaining stock	?	232,000	170,000	224,000	360,000	217,000

There are essentially two survey techniques used in trochus stock assessment. The first technique is the free-swimming search used for the pre- and post-1983–84 harvests. Free-swimming searches were conducted in the back reef (leeward) and centre- or open-shelf (windward) zones where most harvesting occurs.

Results were expressed as number of trochus observed per diver-hour, which together with rough estimates of area covered per hour allows translation of this relative abundance figure into trochus density. However, gross anomalies amongst these data, and comparison with density data obtained using belt transects, proved the unsuitability of free-swimming searches as an indicator of trochus density, and use of the method was discontinued (Sims, 1985).

The second technique is the belt transect used in later pre- and post-harvest surveys. A transect line is laid perpendicular to the reef front, across the entire width of the reef shelf, at 12 stations around the island (see Figure 1). The transect is divided into l0 m lengths, and the number of trochus 2 m either side of the transect line are recorded. The total width of the reef flat band surveyed along the line ranges from 4 to 6 m. The l00 m line transects are divided into 40–60 m^2 quadrats, and the total area covered in a line transect ranges from 600 to 800 m^2.

Stock assessment has provided figures for stock numbers, density distribution, size-class distribution and the impacts of harvests and natural disasters (such as cyclone damage) on stock. Figure 2 depicts the density of trochus based on surveys carried out in January and June 1989, and February 1990 using the transect method (Zoutendyk, 1990).

Management

Management of trochus has developed as an outcome of trial and error. Size restrictions, establishment of reserves, harvest seasons, quota limits, and other strategies have all been applied with little knowledge of the dynamics of trochus populations, and with minimal monitoring of the response of stocks to such regulatory practices (Sims, 1985).

The management of the fishery has been based on the use of harvest quotas and short harvest seasons. The quota is set from surveys of stock abundance, and harvest duration is determined by the estimated time to attain the quota. The system proved ineffective while continuous harvesting was allowed, but a shift to a series of twenty-four-hour pulse harvests appears to have successfully restricted quota overruns.

Size regulations of between 8 cm and 11 cm basal diameter have been applied. There is a requirement that all harvested trochus be kept alive until approved by an inspector. This is one method of enforcing size regulations and preventing out-of-season poaching and stockpiling of shell. Licensing of divers is a requirement under current law. A breeding reserve is in force over a 3 km stretch of the windward reef of Aitutaki (Sims, 1988).

The recent December – January 1991, 5-day harvest which implemented the Individual Transferable Quota (ITQ) as a management tool has proven to be the most successful harvest to date. Prior to the harvest the following formulae were used to estimate the harvest quota (Zoutendyk 1990):

Trochus standing stock estimate (N) = 300,000

Percentage of trochus in legal size range = 58 %

» Number of trochus in legal size range = 174,000

Harvest percentage of legal size range = 60 %

» Size of legal harvest = 104,400

Average weight legal trochus shell = 0.25 kg

» **Shell quota = 26.0 t**

Average weight of live legal size trochus = 0.33 kg

» **Live trochus quota = 34.5 t**

By basing the quotas as above on conservative standing stock estimates, and 60 per cent of those in the legal size range, the aim is to maintain the trochus population at its maximum sustainable yield. As an outcome, it may be possible to have annual harvests. The percentage of those in the legal size range to be harvested may be increased or decreased, as future data dictates, to maximise commercial yield.

The ITQ was calculated using a population census of Aitutaki conducted by the Island Council in May 1990. The Island Council decided that all individuals, regardless of age and actual ability or desire to participate, shall receive the rights to an equal share of the trochus harvest. To determine the ITQ the following formula was used:

Live trochus quota = 34.5 t

Population of Aitutaki = 2250

» **ITQ = 35,000 kg / 2250 ≈ 15 kg**

Each individual was therefore entitled to harvest 15 kg of trochus upon obtaining a licence. Once issued the licences could be bought and sold before the harvest and such transactions were done through the Island Council which administered the harvest (Zoutendyk, June 1990).

An assessment of the 1990–91 harvest showed that the ITQ was an effective management tool. Success was achieved in sustaining stock levels, enforcing the quota set, harvesting a high quality of shell, minimising the taking of illegal size shells, and spreading the income of earnings across the community. It is likely that the ITQ will be used in the next harvest.

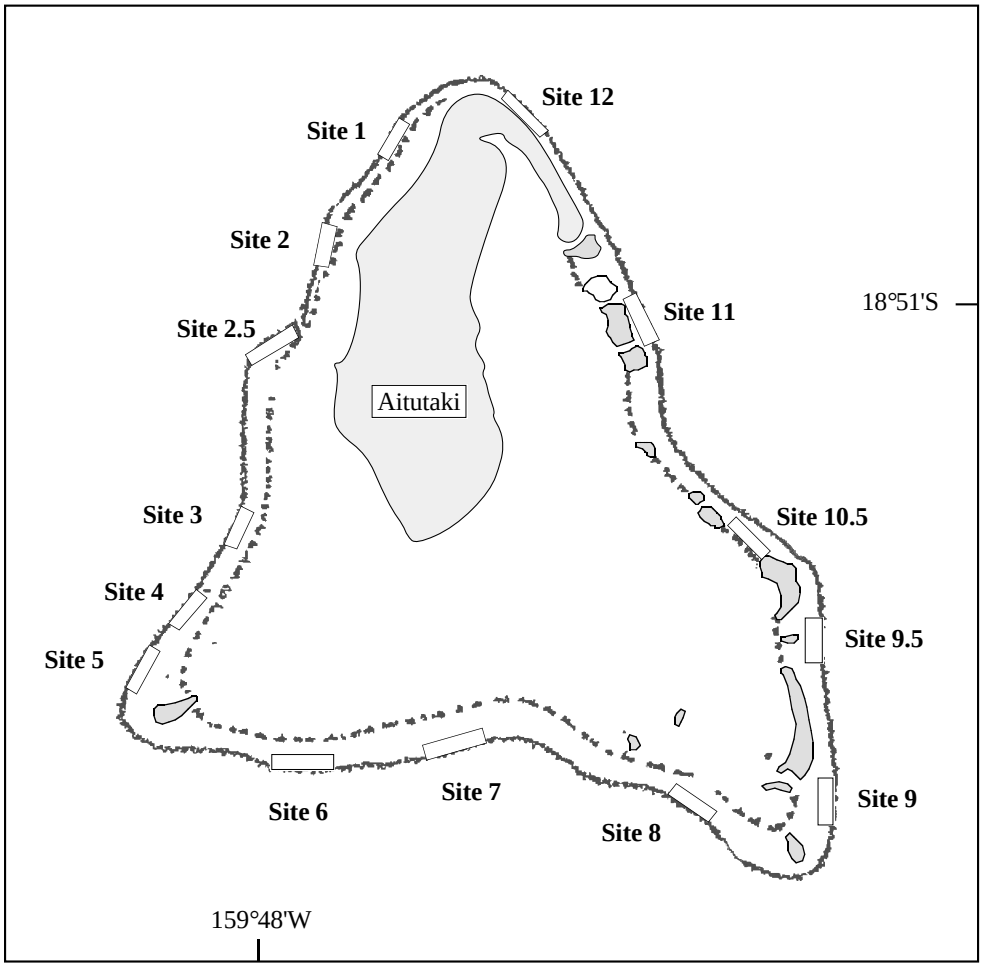

Figure 1
Map of Aitutaki showing survey stations

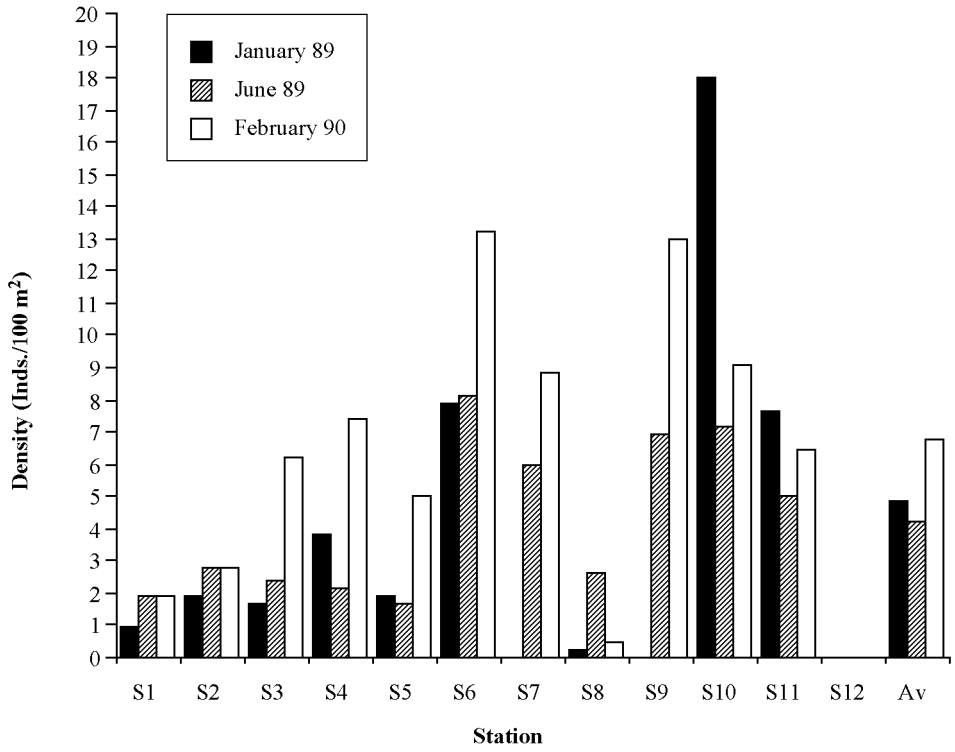

Figure 2
Aitutaki trochus density for Jan. 89, June 89 and Feb. 90 reef flat surveys (from: Zoutendyk, 1990)

Processing and marketing

After the trochus are harvested and transported to the central depot, they are inspected for size limits and quality. Trochus are then boiled to kill the animal and allow easier removal of the meat. The cleaned and dried shell is weighed and then sold to the buyers who ship them overseas for processing into button blanks and for use in jewellery or inlay work. A small factory on Rarotonga currently utilises a portion of the local pearl shell production in the manufacture of jewellery and tourist items (Sims, 1988).

At the present time there are two local buyers of trochus shell in the Cook Islands, both being from Aitutaki. At each harvest there has only been one buyer who has worked closely with the Island Council and the Ministry of Marine Resources. Prices for trochus shells have continued to increase from NZ$ 0.85/kg to NZ$ 2.00/kg in 1984, NZ$ 3.00/kg in 1988 and NZ$ 7.00/kg for A-grade shells in 1991 (Sims, 1988; Tuara, 1991).

Attempts have been made to locate local markets for edible trochus meat. A number of restaurants on Rarotonga which have been sent samples have shown interest. One of the restaurants has offered to pay NZ$ 4–5/kg. None of the restaurants contacted have any experience with trochus meat, and will need to experiment and develop dishes. Letters have also been sent to a possible buyer in Okinawa, Japan, but no response has been received. It has been reported that trochus meat fetches up to US$ 33.00/kg in Okinawan markets (Zoutendyk, 1990).

A market survey letter was sent to button blank manufacturers in Japan, Korea and Fiji. Two from Japan have responded and been sent samples. Both responded and said that Cook Island shell is thicker and thus inferior in quality to that of other countries.

Because of this, the highest price offered was only US$ 5,500 per tonne FOB for shell 6.5–11.5 cm. Response from Fiji has been better, with one button blank manufacturer there offering US$ 6,000 (approx. NZ$ 10,000) per tonne FOB for the same sized shell. Fiji, therefore, is a potential export market for Cook Islands trochus shell.

Aquaculture

At the present time, there is no aquaculture facility for trochus in the Cook Islands. The reproductive predictability and short larval life of trochus makes them most suitable for hatchery culture. However, according to Sims (1988) large-scale hatcheries for trochus do not appear to be commercially viable.

Sims (1988) believes intensive culture would simply not provide sufficient returns at current prices. Although recruitment supplementation has been suggested, with juvenile trochus released from the hatchery onto the reef, significant juvenile mortalities appear to occur in the wild, and the practical benefits of such a programme are doubtful.

Other issues

Research has been carried out to find an alternative method (to boiling) of trochus meat extraction. Trials have shown the use of a steel spring coil (similar to a corkscrew) to be an easy way to extract whole trochus. In one trial it took about 5 minutes to extract the meat from 12 shells. If the coil is used, care has to be taken to wash out possible trochus remnants to avoid unpleasant odours in the shells, and this may prove too tedious for the Aitutaki harvester who must clean approximately 500 trochus during a harvest. A local patent of the coil quoted the price of NZ$ 60.00 per coil which if supplied to all harvesters would prove to be quite costly.

Conclusions

Much progress has been made in the assessment, development and management of trochus in Aitutaki. Improvements in stock assessment have led to the formulation of an effective quota management system. At the same time, there is an increasing awareness and support which has developed in the community for the need to ensure the sustainability of trochus stocks.

The local people have come to recognise the role that the trochus industry plays in providing income and employment. The aim of the Ministry of Marine Resources is to play a decreasing role in the management of the industry. It is hoped that the local people will take on the responsibility of managing their resources on a sustainable basis with the Ministry providing research and technical expertise.

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Status of trochus exploitation in Chuuk State, Federated States of Micronesia

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Introduction

Trochus was introduced to Chuuk Lagoon by Japanese workers before World War II. The Chuuk Barrier Reef, surrounding a lagoon over 40-miles across, has an established population of trochus, as do some of the fringing and patch reefs within the lagoon.

The Chuuk State Department of Marine Resources employs local conservation officers who are responsible for managing marine resources, with trochus as one of their main concerns. The conservation officers survey trochus stocks annually, recommend to the State Governor whether to open trochus seasons in accordance with FSM laws, and monitor sales of trochus.

Although seasons have officially been closed many years, harvests continue illegally and many trochus are simply killed for subsistence consumption. This may explain low numbers of trochus seen in surveys of prime habitats (and even designated trochus sanctuaries) in recent years.

Extensive surveys during 1987, where divers were towed behind dinghies, found that even in the optimum habitats for trochus on the barrier reef, the densest populations averaged only 37 trochus per hectare. The Marine Resources (formerly Truk Maritime Authority) surveys in subsequent years are being conducted in permanently-marked transect areas of major trochus harvest and sanctuary sites, and show fewer and fewer stocks.

The State Governor has repeatedly sought advice and assistance in establishing a small hatchery to re-seed trochus in Chuuk Lagoon and in outer islands of the State.

Status of trochus exploitation in Pohnpei State, Federated States of Micronesia

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Introduction

Trochus were introduced to Pohnpei Island in 1939. As they are also found in large numbers in Sapwuahfik and Mwokilloa Atolls, they may have been introduced there during this period.

In June, 1989, 500 trochus were introduced to 2 atolls (Nukuoro and Kapingamarangi) from trochus sanctuaries on Pohnpei Island. These trochus were transported in a Yamaha dinghy hull on the deck of the field trip ship. Periodic changes of salt water were supplied from the ship's salt water system (used for fire fighting). Some aeration was provided initially on the trip although the air blower heated excessively and was turned off after one day. Survival was excellent, with only three trochus dying during the trip (blamed on rough handling). Follow-up monitoring has shown that the trochus have survived with few dead shells encountered. No juvenile trochus have been seen in either atoll to date. Further transplantings are expected during summer 1991.

In summer 1990, about 3,000 juvenile trochus were planted on Pingelap Atoll. The survival of the trochus has not been monitored, although an assessment is planned for summer 1991.

Aquaculture

Pohnpei has a small trochus and clam hatchery located on Lenger Island in the Pohnpei lagoon. To date, trochus output has been small (about 6,000 animals). This has been due to lack of adequate food for the young animals due to algal competition, and lack of tank space. Work is under way to enlarge the hatchery and use more intensive culture techniques introduced to Pohnpei by an Okinawa-trained Japanese Overseas Cooperative Volunteer.

It is planned to use the trochus output from the hatchery to perform monitored transplanting in Pohnpei and Pingelap islands. The trochus seed previously grown were quite expensive (greater than US$ 0.50 per piece). Trochus reef restocking is considered experimental but appears to be easier for many people to accept than stringent management (such as quotas).

Stock assessment

Stock assessment is conducted using SCUBA gear, counting trochus along a 100 m transect at 3 m and 5 m depth intervals. Trochus size is also measured by marking the diameter of the shell when placed on the clipboard. While average densities of trochus per square metre are reported, the large variances between samples makes it difficult to estimate the total population size. The size data to date has not yielded much information concerning year classes.

Trochus harvest

Harvesting of trochus was a major fishery in Pohnpei following WW II until 1965. Statistics on trochus harvests are very different from year to year due to factors such as procedural changes for managing a trochus season, overfishing of the resource and fluctuations in the price per pound for trochus shell. There is little interest in harvesting trochus when prices are low.

The level of harvesting of trochus has been reduced for the years 1990 and 1991 due to the new procedures and season length. Last year (1990) the length of harvesting was reduced to 24 hours of harvesting and this year, it was reduced further to 8 hours. Every trochus season, Police and Conservation Officers were deployed in the field before and during the harvesting period and patrolled the sanctuaries. During last year and this year's season, the sanctuary patrol was well established.

Inspection of trochus harvests has been conducted by the Department of Conservation and Resources Surveillance immediately following the harvest closure. During the inspection, undersized and dead trochus were sorted out and each fisherman was issued with a receipt for their catch. These receipts are useful for the final inspection just before the buyer purchased the trochus from the local fishermen. The information recorded during harvesting and from interviews of fishermen during inspection are totally different in gender composition. During the harvest it was observed that almost half of the fishers were female, but from inspection interviews the apparent number of female harvesters appeared to be much lower. It is recommended that next season the number of fishers is obtained from those actually participating in the harvest.

Socio-economic background

The trochus resource brought a large amount of money into the Pohnpei economy, mainly from Japanese and Korean buyers who are partners with local people. For example, copra exports in 1988 were valued at

US$ 128,000 compared to US$ 649,000 from trochus harvesting. This resource was controlled by the State Marine Resources Division as well as management.

The decline in the trochus harvest during the last two seasons was due to the short harvesting period and the lower price for trochus. The price of trochus is affected by the number of the buyers. Last season (1990) there were about six buyers, so there was competition between them and the highest price paid was US$ 2.75 per pound.

This year, 1991, there were only two local buyers, and the price also dropped accordingly. Decline of harvest has also affected the local processors.

Processing and marketing

Two processing plants are now buying trochus shells for making buttons. These plants are the only buyers who purchased trochus this last open season. Buying of trochus only took place during the marketing period. In 1988 and 1989 there were four buyers, three local people in partnership with Japanese partners and one local who owns a processing plant. During the 1990 season there were six buyers, five local businessmen in partnership with Japanese partners and again one owner of the local processing plant. In 1991 only the two owners of local button plants were buyers of trochus.

From 1988 to 1990, about 80 per cent of the trochus shell was exported to Japan for processing. Only 20 per cent of the shells were processed locally as there was only one processing plant. The shells processed in Pohnpei are mainly used to make buttons and handicraft jewellery.

Management

Some regulations and laws have been set up by the government which include season, size limits, restricted areas (sanctuaries) and permits. These help the resource from becoming depleted.

The Director of Conservation and Resources Surveillance has the power to designate seasons for harvesting trochus. The designated season will not exceed 60 cumulative days per year. This will depend on the trochus survey that is always conducted before the harvesting season by the Division of Marine Resources.

During the open season, the size limit, sanctuaries and harvesting methods form the focus for trochus resource management. No trochus shall be taken whose shell is less than three inches in diameter at the base. By law there is no upper-size limit. Inspection has to be done after the harvesting period using a board with a three-inch hole on it.

Checking includes dead shells, live undersize shells and stink shells (shells with the putrefying remains of the trochus still inside). Undersized shells are sorted out and placed back on to the reef. Last season (1990), there were 45,000 live shells that were undersized and taken back to the reef, this year only a few were found.

Restricted areas or sanctuaries have been designated on the reef where fishermen are prohibited from harvesting trochus. These areas are commonly patrolled throughout the year, mostly during open season. SCUBA diving is prohibited when trochus harvesting.

There are still problems that need to be solved before trochus season. People start collecting trochus during the day and at night before the open season is announced. This can be proven due to stink shells found in their catches.

Status of trochus exploitation in Yap State, Federated States of Micronesia

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Introduction

Trochus niloticus is a native marine species of Yap and is considered to be one of the most valuable marine species present in the State. It is harvested annually when the suitable stock size allows for marketing and consumption of the meat. However, trochus was introduced to Ulithi and Ngulu (outer islands of Yap) by the Japanese between 1930 and 1940 (McGowan 1958). The Japanese also attempted to introduce trochus from Yap proper to Woleai, Iflik and Sorol. These attempts were unsuccessful because the trochus died before arrival.

In 1983 Marine Resources Management Division also tried to transplant trochus to Woleai and this also failed due to bad weather and the irregular scheduling of the ship. Additional seeding trials were later made and they were successful. Between the years 1984 and 1986, trochus were transplanted to Woleai, Fechaulap, Ifluk, Eurpik, Elato, and West Fayu. The trochus that were transplanted to the outer islands were taken from Yap proper.

The objective of transplanting trochus seed was to establish self-sustaining populations of trochus in the outer islands of Yap State. If seeding of trochus is successful and self-sustaining populations are established, then trochus harvesting can be initiated in the near future. This will provide cash income opportunities for the outer islands where such opportunities are scarce.

Follow-up surveys of the outer islands that were seeded have been carried out. The aim of these surveys was to document the status of trochus seeding trials in the Yap outer islands. This information will be used as the basis for future transplanting, and possibly harvesting.

Follow-up seeding trials will be initiated later this year (1991) since federal funding has been approved. Re-seeding stock will have to come from Ulithi or Woleai, since those are the only islands with enough trochus for re-seeding, and are closer to the other outer islands than Yap proper.

Present harvesting level

The Yap State Governor has recently established a Trochus Harvest and Protection Review Committee to review all aspects which are related to trochus harvesting in the Yap state. The Committee is to accomplish the following:

- review restrictions and procedures used in the past for harvesting and protection of trochus,
- review all regulations which involve the harvesting of trochus,
- recommend improvements in the laws and regulations governing harvests and marketing of trochus, and
- review procedures utilised for enforcement, etc.

The catch has fluctuated widely during this period, as it did between 1915 and 1956, with a range from less than 10 t to over 70 t (mean = 28.4 t) (McGowan, 1958). For the seven years in which trochus was harvested between l979 and 1990, the catch averaged 26.3 t.

Socio-economic background

There were two buyers in 1990. The Asung company purchased live trochus for US$ 1.25 per pound and the TOA Threading Company purchased trochus for US$ 0.40 per pound. The TOA Threading company also purchased trochus from the Ulithi for US$ 1.50 per pound. Both of these buyers were from Japan.

They made arrangements with a local person to be their middle man and liaise with the harvesters. It seems that the demands on trochus are increasing year after year. The average price of trochus before 1990 was US$ 0.25 per kg or US$ 0.11 per pound. However, even though the price in the years before 1990 was low, village fishermen still continued to harvest trochus.

Processing and marketing

The two Japanese buyers mentioned earlier purchased 88,482 pounds of live trochus in 1990. The TOA Threading company purchased 20,976 pounds of live trochus from Ulithi. It is assumed that 80 per cent of this total live weight is the weight of shell.

Stock assessment

Trochus stock assessment is usually conducted at least three months before the harvesting season opens. There are thirty-two sites around Yap-proper which have been selected that are to be surveyed every year. The follow-

ing survey methods listed below are used at Yap-proper and on the outer islands:

- A 100 m transect line is anchored at about 5–10 m under water, parallel to the reef.
- Two divers swim the length of the transect line counting and measuring all trochus found within 2 m on each side of the line (an area of 400 m^2). Size is measured at the widest base diameter.
- On land, the data is used to determine the mean trochus density, size frequency distribution and also to estimate the total harvestable stock.

Management

Without an adequate stock of trochus there can be no viable trochus fishery. To maintain a sustainable fishery, some control is required on the harvesting of trochus. The following regulations were followed during the past harvest seasons:

- The minimum base diameter size was set at three inches. This is slightly larger than the size at which trochus begin to reproduce.
- The maximum base diameter size limit was set at four inches. The larger shells are needed to provide the brood stock to replenish the trochus population.
- Only live trochus are accepted and any under- or oversized trochus are returned to the reef alive.
- The use of SCUBA was forbidden as it would have given an unfair advantage to those who have access to it.

After the 1990 harvest, it became evident that the trochus harvesting and monitoring system in Yap needed reviewing and amending. The following rules were adopted to govern the 1991 harvest season:

- All trochus harvesters must register with MRMD prior to collecting trochus shell.
- The harvester's permit must be carried at all times during harvesting. It is non-transferable. Any boat, raft, etc., must have at least one permit holder present while collecting or in possession of trochus shell.
- Only FSM citizens can collect trochus shell.
- Only trochus shells that are three to four inches across the widest part of the base can be collected, be in people's possession or be sold.
- All trochus must be brought to the inspecting station alive to be inspected and weighed.
- The harvester's permit must be presented to the inspectors by the permit holder for the trochus shell to be weighed.
- An inspection receipt recording total whole weight and allowed selling weight of cleaned trochus shell will be issued after weighing.
- No SCUBA equipment can be used in the harvesting of trochus shells.
- Permit holders must provide MRMD inspectors at the inspection stations information on the number of collectors, how many hours they spent collecting and the general area from which they collected.
- This permit and all inspection receipts must be presented by the permit holders to the inspectors at the time of selling.
- Meat from trochus can only be sold locally.
- Radio announcements will be made advising details of when the season will open and close, where and when inspection, weighing and buying will occur. Harvesting and selling is only permitted during the open season.

Reference

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Status of trochus in Fiji

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Introduction

Fiji is comprised of 300 inhabited islands scattered along 176°E to 178°W longitude and 15°S to 21°S latitude. Volcanic islands are surrounded by barrier reefs and lagoons. Fiji barrier reef is the second largest in the world and provides a suitable habitat for trochus.

Trochus harvesting has a long history in Fiji and, together with beche-de-mer, provided the basis for prosperous fisheries in Fiji in the past. The trochus fishery was very prosperous in the seventies.

The turban top snail (*Trochus niloticus*) is a reef-associated marine snail which occurs naturally all over Fijian reefs. *Tectus pyramis* is closely related to *Trochus niloticus* and is very common in Fiji but is not utilised commercially. The valuable green snail (*Turbo marmoratus*) does not occur in Fiji.

Trochus is a very important fishery to the native Fijians, especially people living along the coast. Since trochus shells do not require preservation and are a non-perishable commodity, they are well-suited to the village situation.

Harvests

Trochus are collected by hand, usually by walking on reef flats at low tide or by free diving. The shell is usually boiled to extract the meat which generally comprises 15 per cent of the live weight. The meat is eaten as a subsistence item and is a delicacy to the native Fijians.

As with other countries, production for export in recent times has fluctuated markedly in Fiji, from as high as 547 t in 1973 down to 166 t in 1979. The low production trend continued during the 1980s and average yearly production was estimated to be around 250 t/yr. In 1988, production was around 400 metric tonnes but fell drastically to around 200 t the following year (1989) despite high prices offered by local shell buyers. Even with high prices offered in 1990, production remains low (around 200 t). Figure 1 shows the weight and value of trochus exports from Fiji between 1981 and 1990.

Socio-economic background

In the seventies, exploitation of the trochus resource was entirely carried out by the village communities. The animals were collected from reef flats by women at low tide and men collect them from deeper places by free diving. This changed in the 1980s when several commercial companies were established. Some of the companies employed divers using SCUBA gear to collect trochus.

By the beginning of the 1990s the trochus resource was being over-exploited and this was felt by all sections of the fishery. Two button factories in Fiji have closed and the remaining two are on the verge of closing down. People in the village have now turned to other resources

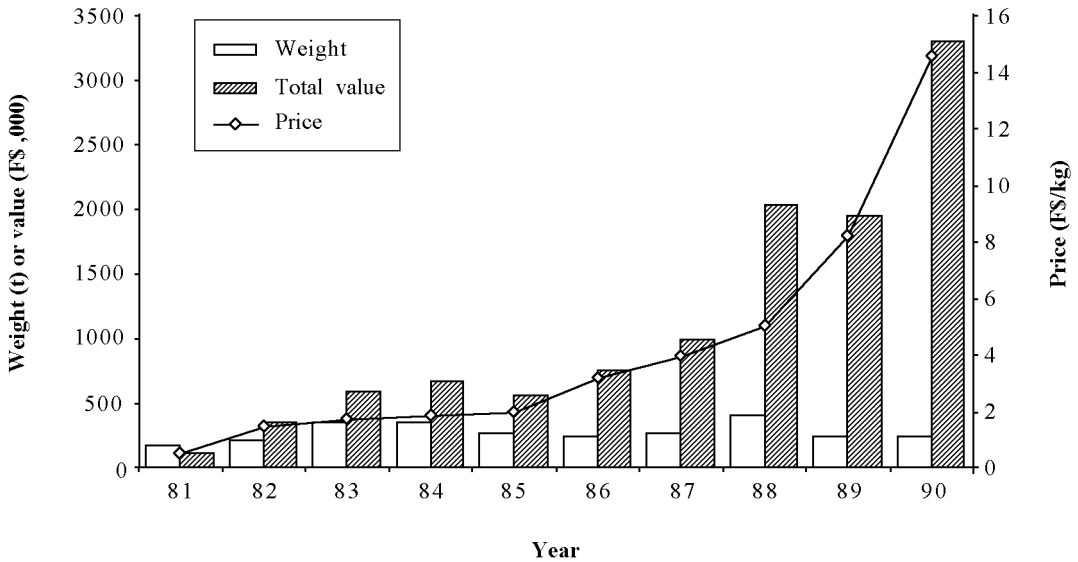

Figure 1
Fiji trochus shell exports, 1981–1990

and there is very little interest in trochus at present. As a result, the price for trochus has dropped significantly in the last few months.

Processing and marketing

Trochus shell is collected for the production of quality buttons and other ornamental purposes. When collected from the reefs, the animals are boiled to extract meat, which is eaten as a subsistence item.

In the manufacture of buttons, blanks are cut from the shell and later buffed and polished. The residual shell still has value and can be further processed to produce chips for ornaments.

During the 1980s in Fiji, there were eight exporters of trochus shell and four companies were engaged in button processing. To date only two raw shell exporters continue to trade and only two factories continue button manufacture. Most companies have closed down their operations due to insufficient supplies of trochus shell.

Stock assessment

Fiji Fisheries has not carried out any assessment of the trochus resource. This is mainly due to lack of expertise in stock assessment methodology. As trochus hide in crevices and under rocks, it is difficult to develop a method of quantifying the population.

Examination of export and local market figures suggest that the trochus resource has been depleted or over-fished throughout Fiji.

Management

Fisheries regulations prescribe a 3.5 inch (≈ 89 mm) minimum harvest size. Exports are required to be licensed and are subject to inspection. There are currently no other restrictions.

We believe that the 3.5 inch minimum size restriction is not a very effective management measure. The reason behind this is that button factories absorb all sizes and process the under-sized trochus shell immediately to avoid fisheries inspections. Once the under-sized shells are processed into blanks, it is very difficult or impossible to know their size. Some fishermen sell bigger sizes to raw shell exporters and sell under-sized shells to button factories.

Since it is ineffective to enforce size restrictions, other means of management should be formulated soon. Options are as follows:

- Implement export quota (e.g. 100 t/year);
- Introduce pulse-harvesting—e.g. ban fishing for three years and allow fishing every fourth year;
- Aquaculture—for reef-reseeding and commercial operation as well;
- Ban export of blanks.

Aquaculture

Makogai Mariculture Station carried out two spawnings of *Trochus niloticus* in November 1989. An estimated 90,000 fertilised eggs were produced by each trochus. High mortalities were experienced in the early stages of development and very few survived to the juvenile stage. *Trochus niloticus* juveniles from these spawnings are now used in our giant clam culture tanks to graze on algae and clean the tanks. The main objective of these spawning experiments was to produce small size trochus for this purpose.

Conclusion

There is an immediate need for trochus resource assessment to be carried out in Fiji. Since suitable assessment methodology is yet to be developed, it is hoped that following the Trochus Workshop in Port Vila, participants from Fiji will have learned skills to carry out extensive field surveys throughout Fiji. It is also hoped that the participants from Fiji would also learn from the trochus culture facility in Port Vila so that a trochus hatchery could be established if approved by the Fiji Government.

Status of the trochus resource in French Polynesia

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Background

Trochus *(Trochus niloticus)* is not endemic to French Polynesia. This species of shellfish was introduced in November 1957 from Port Vila (Vanuatu) when 40 surviving specimens were sown in the lagoon of the Tautira district of Tahiti. The purpose of this introduction was to counteract the gradual depletion of pearl shell stocks in French Polynesia.

In 1962, the Government Council introduced regulations prohibiting the collection, transport, farming and sale of this shellfish with the exception of imported trochus shell.

From 1963 to 1972, 7,912 trochus from two Tahiti lagoons were transplanted to the Society Islands (5,800), the Tuamotus (1,129), Gambiers (400) and Australs (583) (see Figure 1 on page 33).

In 1970, the Territorial Assembly decided to regulate trochus fishing in French Polynesia. These regulations provided for:

- a permit to be issued by the Director of Fisheries before commercial fishing could commence,
- demarcation of fishing grounds and reserve areas,
- stock protection measures, such as size limits and quotas, and
- trochus preparation and marketing procedures.

Not until 14 years after its introduction to French Polynesia, in November 1971, did trochus harvesting begin on Tahiti.

The resource was exploited every year from 1971 to 1985, for a total of 1,618 t from the Society Islands, except in 1984 when fishing was suspended as result of the 1983 cyclones.

In order to avoid over-exploitation of the stocks, trochus harvesting was banned from 1985 to 1989, during which time fishing regulations pertaining to all lagoon species were comprehensively reviewed.

In 1988, the Territorial Assembly adopted a resolution on the protection of marine and freshwater animal species belonging to the natural heritage of French Polynesia, in which regulations currently applicable to trochus in French Polynesia were included. This shellfish is now a protected species and its collection, transport, storage, marketing and consumption are forbidden.

However, the Minister responsible for the sea may waive this rule for research and development programmes, and also for commercial fishing, subject to strict compliance with quotas and fishing seasons laid down by him in conjunction with the supervisory committees of the districts concerned.

Under the 1988 regulations, trochus fishing was authorised in 1990 and a total of 380 t harvested—284 t in the Leeward group of the Society Islands and 96 t in the Tuamotus.

Stock assessment

The assessment method developed by B. Salvat in 1967 involves marking out a 2 m-wide strip of reef—called a transect—at right angles to the shore, and counting the number of trochus within this zone.

The transect is divided into sections 2.50 m in length, thus forming successive observation stations each 5 m^2 in area.

Before commercial fishing started in 1971, the trochus population of Tahiti Island was estimated at 10 million individuals or approximately 2,500 t. The Tahiti stock is believed to have dropped to 605 t in 1984.

At the present time, no estimates are available as to the trochus stocks of the various islands of French Polynesia.

Stock exploitation

Two types of harvesting may be identified:

- commercial fishing subject to prior authorisation, and
- uncontrolled fishing for subsistence consumption of trochus flesh, the local handicraft industry and commercial export.

Only the former activity is monitored and the known statistics are as follows:

- from 1971 to 1983 : 1580 t
- in 1985 : 38 t
- in 1990 : 380 t

The uncontrolled kind of trochus collection is illegal and contributes significantly to stock depletion.

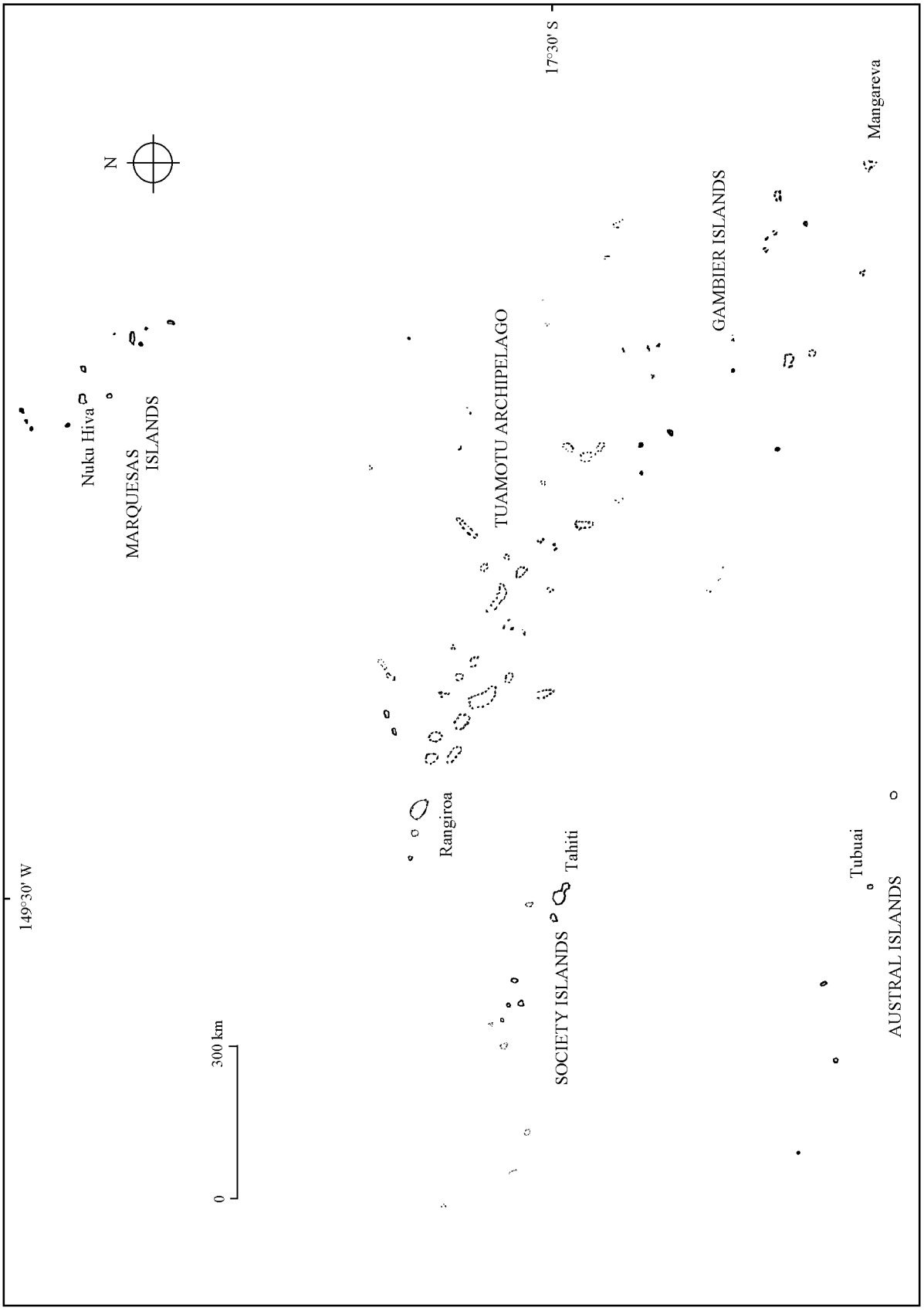

Figure 1. Map of French Polynesia

Socio-economic context

Commercial trochus fishing involves three main types of economic operators:

- Administration: responsible for organising collection, monitoring and marketing of trochus stocks in conjunction with the supervisory committees of the districts concerned.

- Fishermen: fishermen supplement their income considerably with this activity. In 1985, a kilogramme of trochus (with the animal inside) was sold for 160 CFP francs (1 US$ = 103 CFP francs as at April 1991). In 1990, the price oscillated between 450 and 550 CFP francs per kilo for prime-grade trochus depending on where it was fished. The 1990 harvest generated a total income of approximately 135 million CFP francs paid directly to 2,000 fishermen, many of whom, especially in the Tuamotus, have accumulated capital in this way for the purpose of funding their own fishing and pearl-farming activities.

- Buyers: in the absence of a local processing industry, the buyers (approximately ten) are primarily exporters with a marketing network overseas.

In 1990, 355 t of trochus shell were exported, of which 237 went to Singapore, 45 to Japan and 40 to Australia.

However, two projects to construct local button factories using pearl oyster shell *(Pinctada margaritifera)* trochus shell *(Trochus niloticus)* and green snail shell *(Turbo marmoratus)* are on the drawing board.

Protection and management

The resource protection and management measures provided for in the regulations are as follows:

- fishing is authorised only during specific periods and under the supervision of staff of the territorial administration, occasionally the police force, or of the municipal districts concerned,

- collection of trochus under 8 cm and over 11 cm is prohibited, to ensure adequate reproduction of the species,

- fishing quotas per lagoon have been set,

- sanctuaries have been established in parts of the lagoon,

- scientific organisations can obtain special permission to collect trochus specimens for resource monitoring purposes,

- supervisory committees have been set up to make proposals regarding protection and exploitation to the Minister responsible for the sea. These committees, composed of representatives of the technical and administrative authorities and of the fishermen are decentralised think-tanks, one for each municipal district, that ensure more rational management of marine resources.

Conclusion

The trochus stocks of the island of Tahiti have gradually been eroded, particularly as a result of uncontrolled fishing.

However, the commercial fishing authorised in 1990 produced indications that large stocks still exist in French Polynesia and in the Tuamotus in particular.

Rational and regular exploitation in the islands of French Polynesia will require at least some prior scientific assessments, as a basic for more informed decisions on the issuing of fishing permits, a greater awareness in fishermen of the need to protect their own resources, and stricter compliance with the regulations in force.

Trochus resource exploitation in Okinawa – Japan

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Harvests (production)

Statistical data on production fluctuates by years depending on the market demand. In the early days of the 1950s, shells were one of the important export products from Okinawa and the trochus formed most of the exported shell. The greatest volume exported was 950 t in 1955, but there was a gradual decrease in later years (914 t in 1956 and 689 t in 1958) associated with the introduction of other fisheries such as tuna longline, skipjack pole and line, trawl fisheries, etc.

The production of trochus in Okinawa is closely related to the market demand for the shells rather than the meat for the local market. Production increased steadily from 1980 until 1986 when landings peaked at almost 600 t. Since 1986, landings have declined gradually, which may be related to over-harvesting, although the market demand has continued to increase steadily.

Total revenue from the sales of trochus were highest in 1985 with a value of ¥ 19 million, which contributes only 1.2 per cent of the total fisheries production revenues in Okinawa.

Socio-economic background

The total population of Okinawa Prefecture in 1990 was 1,179,000. Of this total population, only 0.9 per cent or 4,500 persons were fishermen. Only a small number of fishermen, 2.8 per cent of the total fishing population, were engaged in shell harvesting, some professionally and others on a part-time basis.

Most of the shell collection is conducted in the area where the reefs are large enough to foster the shells. However, the fishing grounds can only support a limited number of professional fishermen.

Processing and marketing

Trochus and the green snail have been highly valued from ancient days for their shells, which are utilised for jewellery and inlay. Okinawan fishermen have even explored trochus resources in the South Pacific Islands and adjacent areas. The highest production in 1955–1956 was made not only from local waters but also from other foreign waters, reefs and lagoons.

There is no trochus shell processing firm in Okinawa. Meat is consumed locally and highly valued at a price of ¥ 2,500–3,000/kg at a remote island, where the meat is salted and packed in different sized bottles and sold. But if the meat is sold for fresh consumption, the price will be ¥ 3,000–7,000/kg because it is highly prized in local society. The trochus shell market at one time declined markedly when the button materials were replaced by cheaper plastics.

Now, however, because of high market demands, mainly at the trochus shell market in Japan, prices have increased. According to the Japanese Government statistics, imports of shell were about 2,000 t until 1986 and then dropped to around 1,000 t. The exporters of shells to Japan are Indonesia, Papua New Guinea, Solomon Islands, Philippines, Fiji, New Caledonia, Micronesia and Vanuatu.

As the price of trochus increases, the more shells are exploited, thus leading to over-harvesting. Declines in the landings will result in higher prices for trochus. The ex-vessel price per kg for trochus was ¥ 720 in 1989, but it has been raised to ¥ 800–900/kg since 1990.

The shells harvested by fishermen are mostly marketed through fisheries cooperative associations to which the fishermen belong. The fisheries cooperatives then consign the sale of shells through the Okinawa prefectural federation of fisheries cooperatives to the dealers on the Japanese mainland.

Introductions

The trochus is endemic to Okinawa waters; no shell has been introduced from a foreign country.

Stock assessment

No stock assessment study has ever been conducted in Okinawa. The biological study started in 1987 when a reef-farming project was initiated. In order to obtain representative indications of the shell abundance, natural juvenile trochus was surveyed once a month from June to October 1988. Juveniles in intertidal zones were smaller than those found in deeper waters; 89 per cent of juveniles under 6 cm in diameter were found in shallow water from mean tidal low water to extreme low water spring tides.

Adult shell surveys were also conducted from June to October 1988. 9.3 cm sized shells were mostly observed at the depth of 4–30 m at the rate of 0.8 individuals/100 m^2. This number of individuals is not enough to support the estimated potential yield.

Management

Okinawa Prefecture's conservation measure on trochus is restricted to size regulation on collection of shells less than 6 cm across the base. More strict regulations can be established by fisheries cooperative associations. One of these, Onna Fisheries Cooperative Association, declared stricter regulations than the prefectural guidelines for harvestable size, and established a no-fishing zone throughout the year. The shells collected in the reefs under Onna Fisheries Cooperative control are maintained at an average size of 111.7 ± 15.6 mm. However, the average size of shells in Kumejima, an isolated island about 100 miles from the Okinawa mainland where the fishing intensity is lower than the Onna Fisheries Cooperatives managed reef flats, was 112.7 ± 17.5 mm. The density of trochus at Kumejima is also much greater than on the reefs controlled by the Onna Fisheries Cooperative.

Aquaculture

Seed production study on trochus was started in 1987, as one of the technical development projects of the coastal fisheries development programme. The project was developed into a 5-year project beginning in 1988 with the financial assistance of National Government. The project was shared by both the Fisheries Experimental Station and the Sea Farming Center.

The staff of the Experimental Station concentrate on the ecological study of natural trochus stocks and development of release techniques to ensure high survival of trochus juveniles. The Farming Center engages in mass production and juvenile rearing methods to obtain proper size of the released stock. The seed production techniques have been successfully developed to produce more than 1 million 2–3 mm sized juveniles. Further technical development is necessary in order to produce the seeds efficiently with less manpower involvement. However, the present techniques are sufficient to produce several million juveniles.

The grow-out method of juveniles up to releasing size is under way, both in tanks on land and cages in the ocean. In the tanks, the juveniles are reared on the surface of polyvinyl chloride corrugated plates covered with a diatom film (*Nitzechia, Navicula)* which are placed in the tanks as a settlement substrate for larvae and feed for juveniles.

Between 110–180 thousand juvenile shells of about 10 mm size have been released every year, but the survival rate of these cultured juveniles was very poor. Intensive ecological studies are under way in parallel with the identification of proper sites for release and grow-out.

We are trying to maintain a mass production rate of 7,000–26,000 (average 18,000) trochus per m^2 by increasing the water flow necessary to keep the juveniles alive. On the other hand, we are also trying to develop cage culture of the juveniles in the ocean to grow to the proper release size in order to save running costs. The data obtained from the field studies are not yet sufficient to make comparisons with those from the grow-out in the tanks.

Country statement – Marshall Islands

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Introduction

Information contained in Asano and Inenami (1939) and McGown (1958) indicates that the Japanese brought trochus *Trochus niloticus* to the Marshall Islands from the Eastern Caroline Islands on two occasions in the 1930s. The authors specifically mention that the trochus was implanted at Jaluit, Majuro, Ailinglaplap, and 'other areas', which presumably included Arno, Kwajalein and Enewetak. Kay and Johnson (1987) state that trochus was introduced to Enewetak by the Japanese around 1935. The most recent trochus survey conducted in the Marshall Islands was in 1989, by the Regional Fishery Support Program (FAO/UNDP) and the Marshall Islands Marine Resources Authority. This survey was limited to Enewetak and Bikini Atolls. A summary of the survey and the subsequent recommendations are attached with this statement.

Since 1990, the Marshall Islands Marine Resources Authority (MIMRA) has been taking steps to gather information about trochus harvesting in the Marshall Islands. Previously, the only involvement of MIMRA in this fishery was in seeking Cabinet approval for a proposed harvest season. Otherwise, there has been no management, monitoring, or development and expansion in exploiting this resource on the many other atolls and islands within the Marshall Islands. Essentially, the potential of this fishery was not recognised until recently.

In the 1960s, local people harvested trochus only for subsistence purposes. It was not until the 1980s that commercial activities began. By that time the trochus population in the center of Majuro was already depleted, and in other areas it had greatly declined due to lack of management.

At present there are no records on the size of the trochus resource in the Marshall Islands. There may have been a couple of resource surveys done in the 1980s but records are not available from these surveys. It is the aim of the MIMRA Office to seek assistance from the regional programmes to conduct surveys in the Marshall Islands.

Summary of the results from the 1989 trochus survey of Enewetak and Bikini Atolls

- During a two-week period in February and March 1989, a survey was conducted of the trochus resources of Enewetak and Bikini Atolls in the Marshall Islands.
- Trochus were successfully introduced to Enewetak about 1935, and at the time of the survey they were found to be moderately abundant there.
- Local fishermen have harvested trochus from Enewetak for three-month periods during each of the last two years. In 1987, local sources indicated that an estimated 100 t of trochus were harvested and in 1988 the harvest was estimated to be 150 t.
- There is no record of an introduction of trochus to Bikini Atoll, and no trochus were located there during this survey.
- At Enewetak, trochus were found on the reef flat in the surf zone and in the passages between islands where strong currents are prevalent.
- Based on a limited number of transects, densities of commercial-size trochus in the inter-island channels were estimated to average 556 per hectare (0.06/m^2). On the reef flats to seaward, trochus were estimated to average 962 per hectare (0.10/m^2).
- Large variability between samples, as a result of a clumped distribution of the live shell in different habitats, means a relatively large number of transects would be necessary to make a more accurate estimate of the present density of trochus at Enewetak.

Recommendations

- It is recommended that a minimum size for the harvest of live shell from the reefs of Enewetak be set at three inches (≈ 76 mm), and that a maximum size be set at five inches (≈ 127 mm).
- It is also recommended that the season for the harvest of shell at Enewetak remain at three months and start with the commencement of the calm season in June or July.
- MIMRA, in collaboration with the Enewetak Council, should be responsible for setting the dates for the start and finish of the season.
- It is recommended that a quota of 100 t be set for the annual total harvest of trochus from Enewetak Atoll.
- MIMRA should investigate the current pricing policy offered by buyers for shell at Enewetak.

- To assist in maintaining the value of the resource to atoll residents, it is recommended that a permanent reserve, where all harvesting is banned, be established between two islands on the eastern or northern reef rim of the lagoon.

- It is recommended that MIMRA work closely with the Division of Revenue and Taxation to more closely monitor the export of shell from the Marshall Islands.

- To assist with this it is recommended that all traders in marine resources in the country pay a license fee and register with MIMRA.

- It is recommended that exports of marine produce from the country should only be made through registered traders.

- Traders should supply MIMRA with information relating to the source, quantity, destination and value of the product prior to export approval, and the product should be inspected to ensure that there is no breach of legislation relating to the exploitation of that organism.

- It is also recommended that MIMRA utilise the services available through regional and international fisheries organisations to assist with monitoring the trochus fishery on the atolls.

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Country statement – New Caledonia

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Developments of the trochus fishery since the beginning of the century

New Caledonia, which is surrounded by one of the world's biggest lagoons, possesses a major Pacific trochus resource. The mother-of-pearl forming the shell of this large marine gastropod is considered to be one of the strongest, thickest and most beautiful available on world markets. Commercial interest in this species began in New Caledonia in around 1907. Angot (1958) wrote: 'at that time, all one had to do was walk out on the reef flat at low tide and collect the many shells lying in the hollows in the coral, sometimes with a shovel or a rake.'

Figure 1 shows the trends in shell exports since that period. The wide fluctuations in the curve can be correlated with the vulnerable nature of the stock of trochus, which is easy to harvest, especially by divers. Commercial fishing was significantly interrupted twice, firstly for the duration of the Second World War and secondly in what is commonly referred to as the 'nickel boom' in the 1960s. The wars and the 1973 slump in the mining sector were followed by record trochus exports after the resource had been left undisturbed for an extended period.

The vulnerability of the stocks was swiftly realised by scientists working in New Caledonia early in this period. In 1930, Professors Risbec and Gruvel asked the territorial authorities to take conservation measures to stop harvesting, which they thought excessive.

Various regulations were introduced:

- Since 1916, the fishery has been closed for six months annually (and once for a full year in 1956–1957).

- Minimum size limit: 8 cm basal diameter, increased to 10 in 1957, then again reduced to 8; present regulations permit harvesting of specimens 9–12 cm in basal diameter.

Since there was no method available for appraising stock dynamics at that time, it is difficult to evaluate the real impact of these measures, which were probably beneficial from the strict point of view of species conservation, but not necessarily helpful from a fishery management standpoint.

Recent developments in the fishery and relevant regulations

Trochus fishing once offered an income-generating activity to many people affected by the mining slump, which began in about 1973. The equipment available (boats, diving gear) has become extremely efficient and has con-

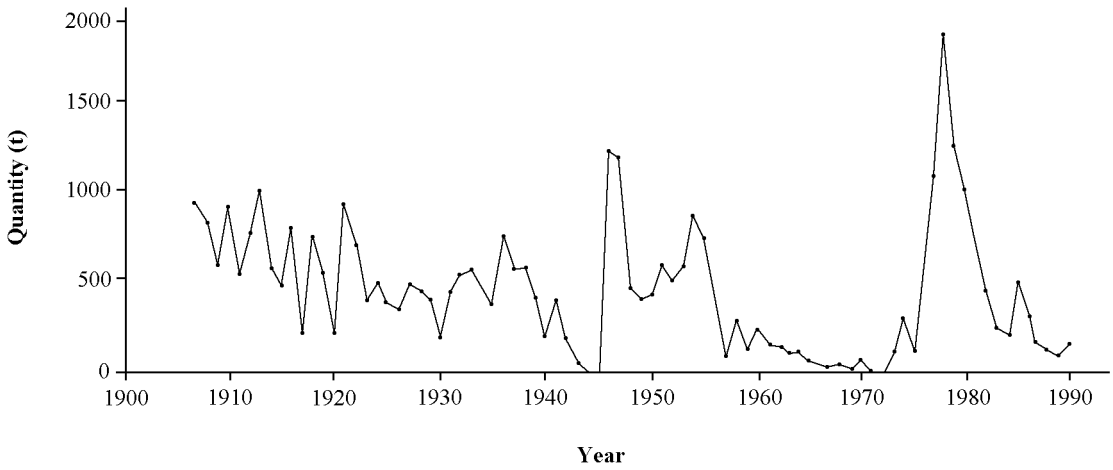

Figure 1
Trochus shell exports from New Caledonia

tributed to the sharp rise in shell export tonnages. If to these two factors is added the single applicable regulation setting the minimum size at 8 cm, it is easy to understand the rapid drop in harvests which succeeded the record 1915 t exported in 1978, i.e. approximately one-third of world production at that time. Recent statistical data demonstrate that, having exceeded 500 t in 1985 and 300 t in 1986, exports have never risen above 200 t since 1987.

Data on trochus growth and stocks gathered by ORSTOM in 1982 made it possible to take the following conservation measure in 1983: harvesting is authorised for sizes between 9 and 12 cm. The trochus, which reaches maturity at approximately 7 cm, can therefore breed for approximately two seasons before being harvested; large trochus ($\geq$ 12 cm) have a commercially less valuable shell but nevertheless form a still active breeding stock.

The size limit on trochus is accompanied by control of the number of authorised harvesters who, in addition to the fishing licence required by all professional fishers, need special permission to harvest trochus. This method makes it possible to estimate the evolution of fishing effort. There were 18 licensed fishers in 1985, 22 in 1986, 12 in 1987, 10 in 1988 and 1989 and 13 in 1990.

The reef areas mainly colonised by trochus, when the substrate is favourable, are formed of shallow flats, often dry at low water, as well as the first few metres of the reef slope; this distribution influences the harvesting methods used, which is either on foot or by diving (without an air supply).

The animal is separated from the shell after cooking, which detaches the retractor muscle. Another technique involving a spiral-shaped blade with a pointed end has been tested. Although it requires special dexterity, this is a worthwhile method because it makes it possible to extract the animal fresh with as little damage as possible. The unworked shells are then delivered to two or three local exporters who freight the merchandise to Asia (mainly Japan) and Europe (chiefly Italy).

Resource management

Trochus is a good example of the kind of living resource which is perfectly suited to the economies of Pacific Island countries. Trochus exploitation has the following advantages:

- no sophisticated equipment is required;
- the important product is the pearl shell, a non-perishable renewable resource, the flesh is a by-product, but also an additional source of food for fishers;
- the shells can be exported and earn foreign exchange on an international market where demand is very high;
- small shell-processing workshops provide employment and yield significant added value;
- the area populated by natural stocks can be extended through transplanting to reefs with small or non-existent trochus populations.

On the other hand, this resource requires strict fishery management because the stocks are vulnerable and can be slow to regenerate.The main management options are as follows:

Size limits

These regulations are easy to enforce at the shipment stage. The minimum size must not be under 8 cm in order to avoid seriously disturbing the production of juveniles. It may be accompanied by a maximum size of 12 or 13 cm in order to leave breeding stocks on the reef with less valuable shells but high potential fertility.

Catch quotas

A quota can be set for the fishery as a whole or for large segments of it, or indeed per fishing boat. All these options require fishery catch and effort statistics covering a fairly long period in order to determine realistic quotas. Surveillance and enforcement work normally leads to counter-productive bureaucratic delays. Nash (1985) recommended an overall quota of 500 t for the Great Barrier Reef off Australia; Bour and Hoffschir (1985) consider that a 400 t quota could be set for New Caledonia, to follow a period of lower quotas enabling the biomass to revive to its optimum level, estimated at 4000 t (fishing mortality F = 0.10 and natural mortality M = 0.10).

Closure of the fishery

A fishing ban may be imposed on a rotating basis between various areas or for a particular period of the year. Experience shows that it is pointless to hope to enforce such bans or closures 'on the ground'; also, stopping production altogether is harmful for an export-oriented resource.

Sanctuaries

Heslinga et al. (1984) recommended the establishment of totally protected areas (sanctuaries) which would act as sources of spawning stock for adjacent reefs. These zones would have to be selected on a scientifically valid basis and monitoring work would need to be especially efficient there. Management methods are therefore mostly difficult to implement and monitor. The solution probably lies in the production of spawn using aquaculture techniques in order to reseed over-exploited reefs.

Aquaculture trials

The advantages of producing trochus in ponds

Research by Heslinga and Hillman (1981) showed that juvenile trochus could be bred in ponds without any sophisticated equipment and that juvenile mortality did

not rule out spawn production aimed at reseeding reefs from which the natural population had been wiped out. The above authors reared young trochus until the age of one year but did not, to our knowledge, attempt to transplant them into the natural environment.

Various trials were carried out in New Caledonia in cooperation with IFREMER for the purpose of exploring this kind of stock regeneration prospect.

A reef where the trochus population was too sparse would probably not be able to attain a level of recruitment adequate for stock maintenance, which in the longer term would leave the field clear for colonisation by other species. The introduction of a small population on a particular location on a reef, at a density providing normal breeding conditions, can be the starting point for complete recolonisation of the reef through dissemination of larvae during the planktonic phase.

To the above idea it could be objected that merely transplanting adults from a populated reef to an over-exploited reef flat would be a quick way of achieving the same objective; this solution is possible for small and not too distant reefs. In the particular case of New Caledonia, however, the solution would be costly and hazardous because of the fact that the stocked reefs lie a long way offshore (east coast) as do those for reseeding (west coast).

Trials carried out in New Caledonia

In March 1986, approximately three million eggs were laid by three females placed with males in a breeding pond at the Saint Vincent Aquacultural Station, i.e. a million eggs per female. After three months, 12,000 juveniles still survived. They measured between 2 and 3 mm in diameter. Figure 2 shows the growth curve observed on a sample of 296 specimens. When compared to the curve published by Heslinga (1981), very similar growth over the first six months is observed, followed by significant divergence. The constant temperature of the warm waters of Palau in Micronesia where Heslinga's experiments took place probably explains this fact.

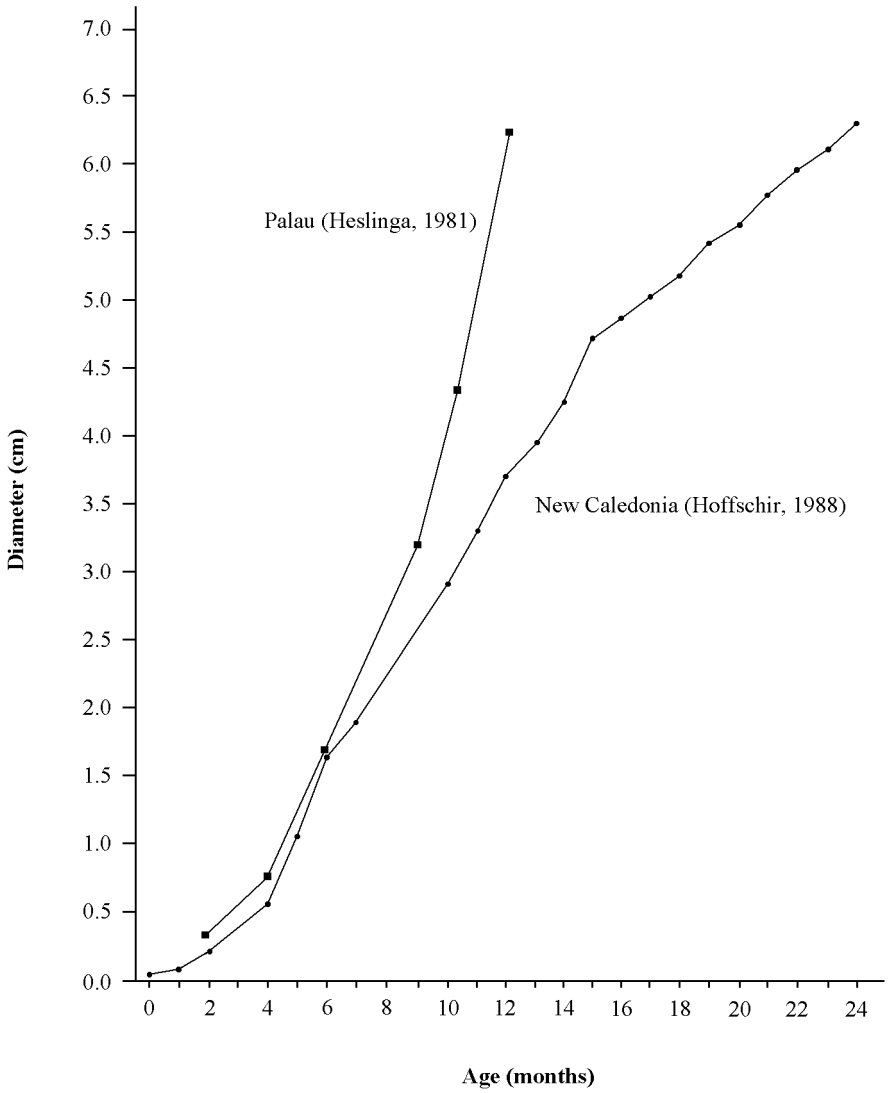

Figure 2

Growth curve for juvenile trochus in rearing pond

Transplanting juvenile trochus into the natural environment

An attempt was made to establish a stock of trochus by seeding reefs off Lifou in the Loyalty Islands, where this species is absent, using spawn produced by aquaculture. Of 5,700 juveniles measuring 19 mm and 11 months old on average at the time of introduction, 19 were recaptured one year after introduction. Their average size was 64 mm, with the smallest measuring 49 mm and the largest 74 mm. Most had reached their 'size at sexual maturity', 60 mm on average in New Caledonia, and it can therefore be considered that these specimens could form a stock of potential breeding animals.

During this year of life in the natural environment, the mean annual growth was 45 mm, much more than the results obtained in the rearing pond over the same period (33 mm). Despite the low number of recaptures, no doubt due to the fact that they were scattered far and wide by bad weather conditions (disruptive cyclone

two weeks after transplanting of the juveniles) and the difficulty of surveying extensive areas of reef, the growth obtained augurs well for the adaptation of trochus juveniles to the reefs of Lifou.

This experiment therefore demonstrates that the transplantation of trochus produced by aquaculture and introduced into the natural environment is possible and that the repopulating of reefs favourable to this species is feasible. These aquacultural activities may be a solution to the overexploitation of this resource and thus permit the production of an original form of raw material with a very promising future.

Benefits of SPOT satellite imagery

The type of mapping we are concerned with is known as 'thematic' because it is necessary to distinguish between environments which are homogeneous, or considered to be so; each environment identified is a 'theme', which often corresponds to specific associations of fauna and flora encountered in a particular ecological setting.

The general principle of thematic processing is to classify the pixels of the scene in order to reduce the original mass of data and obtain a useable map. Classification is based on three concepts:

- the way it is decided to classify each picture element;
- similarity between elements of the same class; and
- separability between classes.

The mathematical tools used to resolve these problems are conventional statistical methods, with the advantage of being able to visualise the result on the image when the calculations are complete.

Natural habitats and objects which can be detected by the satellite give selective responses on the three colour channels; the art of classification is to define 'boxes' on each channel in which to place the pixels considered as belonging to the targeted theme. For this purpose, work will first focus on a part of the image whose geographical and/or topographical characteristics are known (through field studies and/or aerial photographs).

The computer is then asked to distinguish between all the pixels of this small area on a cross histogram whose axes could, for example, be the first two channels. The classification of the pixels, including the demarcation of the cluster of dots on the histogram into thematic groupings, is done using conventional statistical methods (for example the method of maximum likelihood). The term used is 'supervised classification' because it is the field knowledge of the person processing the data which will enable him or her to accurately sort pixels into boxes, the edges of which (in terms of radiometric levels) provide what we call the spectral signature of the themes.

The visual result of this classification will be a simplified map of the small area studied, called an experimental zone, where a single and completely arbitrary colour has been assigned to all the pixels of one theme. This initial thematic map will take the form of a mosaic of colours identifying the targeted theme.

As far as possible, this first stage should be followed by ground-truthing work to refine the classification if necessary. When the match between the reality and the map of the test zone is considered satisfactory, it is possible to apply the selected classification to all pixels of the SPOT scene. The thematic map of the scene as a whole then concerns an area of several thousand km^2. Here again, ground truthing is needed before the final thematic map can be produced.

Thematic mapping through the analysis of remotely-sensed images provides the possibility of greatly reducing one of the main sources of statistical error in estimation of abundance in trochus stocks by conventional quadrat or transect methods. That is: the difficulty of estimating the geographical area of habitat suitable for trochus to live.

There is little point in expending a large effort on replicating trochus survey transects to produce accurate density estimates, if the resulting estimate of total stock abundance is flawed by the poor estimation of total habitat area that is possible from most current charts. Shallow-water coral areas are amongst the most poorly-mapped habitats on the planet, but these reefs are probably the most amenable to analysis by remote-sensing of all marine habitats.

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Country statement – Palau

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Introduction

The archeogastropod, *Trochus niloticus*, is an endemic resource and a highly-valued commercial export from Palau. In the last ten years, many tonnes of trochus were sold, generating millions and millions of dollars in revenues for the fisheries industry. Unfortunately management programmes, including seasonal harvests, size restrictions and sanctuaries, have had short success and there is now a national concern over the decline in trochus populations.

Recently a three-year moratorium on the harvest of trochus has been imposed by the Government of Palau in an attempt to allow the densities of natural populations to increase to former levels. In the past, unplanned moratoriums on trochus harvesting occurred during World Wars I and II. Immediately after each war there were substantially higher harvests of trochus. However, within a few years the amount harvested dropped precipitously to low levels.

It is important that we determine the existing densities of trochus on Palau's reef, the potential carrying capacity of the reefs and the maximum sustainable yield of this fishery. Unless we determine these basic tenets for setting up a fisheries management programme, trochus management programmes will continue to have short-lived success because of over-harvesting.

Processing and marketing

There is national concern over the decline in trochus populations in Palau. Because of this, a three-year moratorium on the harvest of trochus has been imposed by Palau in an attempt to restore the natural population densities of trochus on the reefs.

In the past years, there were between five and seven trochus buyers in Palau. Trochus shells were cleaned and sold to Japan for making buttons and jewellery. About 100 to 200 t of trochus shells were exported out of Palau each year.

Stock assessment

There has been some work conducted on the stock assessment of trochus in Palau but this was carried out during rough weather. Results of this study are thus not accurate but may be used to give an initial rough estimate of natural stocks.

The survey teams used counted trochus along a 100-metre transect line. Two divers carefully searched the substrate two metres on each side of the transect line. They used an underwater writing board to measure and record the number and size of specimens.

Harvest

The trochus harvest levels until today ranged from 100 to 200 t annually. These figures came from reports based on total shell landing at different dock sites in Palau.

Other information obtained from professional fishermen indicates that catch per fisherman at present is much lower than 20 years ago.

Aquaculture

There is a trochus hatchery in Palau but it does not have operational funds to conduct programmes. The facility is intended to serve as a seed-production centre where juveniles can be produced and distributed to all depleted reefs around Palau as a means of population enhancement. However, at present, the viability of population enhancement through restocking with cultured juvenile trochus is still being studied, and is not yet an established approach to resource management.

The cost-effectiveness of such projects has not been determined but is required so that later research can be conducted accordingly.

Management

Awareness of the decline in the trochus population has generated concerns about improved management of the resource. However, these management measures have not been implemented due to financial constraints. The Palau Government has also initiated research programmes in the hope that results can be used to draft conservation measures. However, these measures will be ineffective without enforcement.

Country statement – Papua New Guinea

Department of Fisheries and Marine Resources
Research and Surveys Branch, Kanudi, Papua New Guinea

Introduction

Papua New Guinea (PNG) has an estimated population of four million people (1990 census). Fourteen per cent of these people live on the coast of the mainland and the island groups. Most of these coastal and island communities depend largely on sea resources to support their livelihood.

The country has approximately 10,000 kilometres of coastline and an estimated five million hectares of shallow coral reef in waters of less than 30 m depth. According to a preliminary habitat survey conducted in 1988, 1989 and 1990 an estimated eight per cent of the reef area is suitable habitat for *Trochus niloticus*.

Following World War II the islanders and coastal people have been harvesting trochus for consumption of the meat and commercial sale of the shell. In 1951 PNG exported 1030 tonnes, the highest annual production. From 1980 trochus exports have increased from 320 t to 850 t by 1989. Since 1980, PNG has exported a total of 4,200 t of trochus valued at an estimated 10 million Kina (K 1.00 = US$ 1.05 in 1991). This earned the country K 0.5 million in export tax for the same period.

The taking and processing of trochus shell is administered and regulated under the Continental Shelf and Natural Living Resources (CSNLR) Act. The exporting of any marine organisms is regulated by the 1953 Fish Export Regulations. There is a trochus management regulation currently in force, however it creates problems in the management of the fishery. In June 1989, and again in 1990, a Trochus Management Plan was submitted to the Government to be regulated under the CSNLR Act. The plan has yet to go to the National Executive Council (NEC) for approval.

A PNG trochus potential yield of 800 to 1000 t per year was estimated by the 1989 UNDP Fisheries Sector Review. Although the current export figures are below the estimated potential yield, signs of localised over-harvesting are becoming apparent in the island provinces of North Solomons, Manus and New Ireland, which are major producers of trochus (see Figure 1 on next page).

Trochus shell purchase data and shipment records are currently being collected in order to verify these observations,. At the same time, surveys are being planned for the areas concerned to provide an assessment of the level of exploitation of trochus stocks in New Ireland, Manus and West New Britain Provinces.

Harvests

The extensive areas of shallow reef support a range of sedentary resources which are harvested for food and commercial use. The trochus are found as deep as 15 m and are commonly collected during the day. However, in areas where resources are starting to decline, fishermen are frequently operating at night, collecting shells with the aid of torches. Fishing at night is becoming a common method in the main producing areas such as Manus, New Ireland and West New Britain.

Shell exports from PNG between 1980 and 1990 are shown in Table 1, and Figure 2 shows the evolution of catch, value and price of trochus exports from 1980 to 1990. The main sources of information are the Department of Fisheries and Marine Resources (DFMR) Inspection Export Register and the National Statistic Centre (NSC).

It is believed that the current volume of exports are under-declared by approximately 30 per cent, which sug-

Table 1: Weight and value of Papua New Guinea shell exports, 1980–1990

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Trochus											
Weight (t)	327.4	187.9	278.3	357.2	310.0	450.7	535.9	426.6	437.0	568.6	305.4
Value (,000 K)	309.6	148.9	248.8	372.8	379.0	664.3	952.3	986.8	1,322.3	2,619.2	1,875.8
Green Snail											
Weight (t)	27.7	17.3	36.4	27.5	21.4	11.7	13.1	16.9	14.8	20.0	8.6
Value (,000 K)	148.0	57.7	117.0	106.6	379.0	67.6	41.4	69.4	40.4	560.0	184.5
Mother of pearl											
Weight (t)	8.4	5.0	1.9	13.4	6.5	4.7	5.0	19.9	22.7	30.0	23.4
Value (,000 K)	12.7	8.5	3.0	23.5	8.7	9.4	10.2	53.9	115.0	180.0	119.9

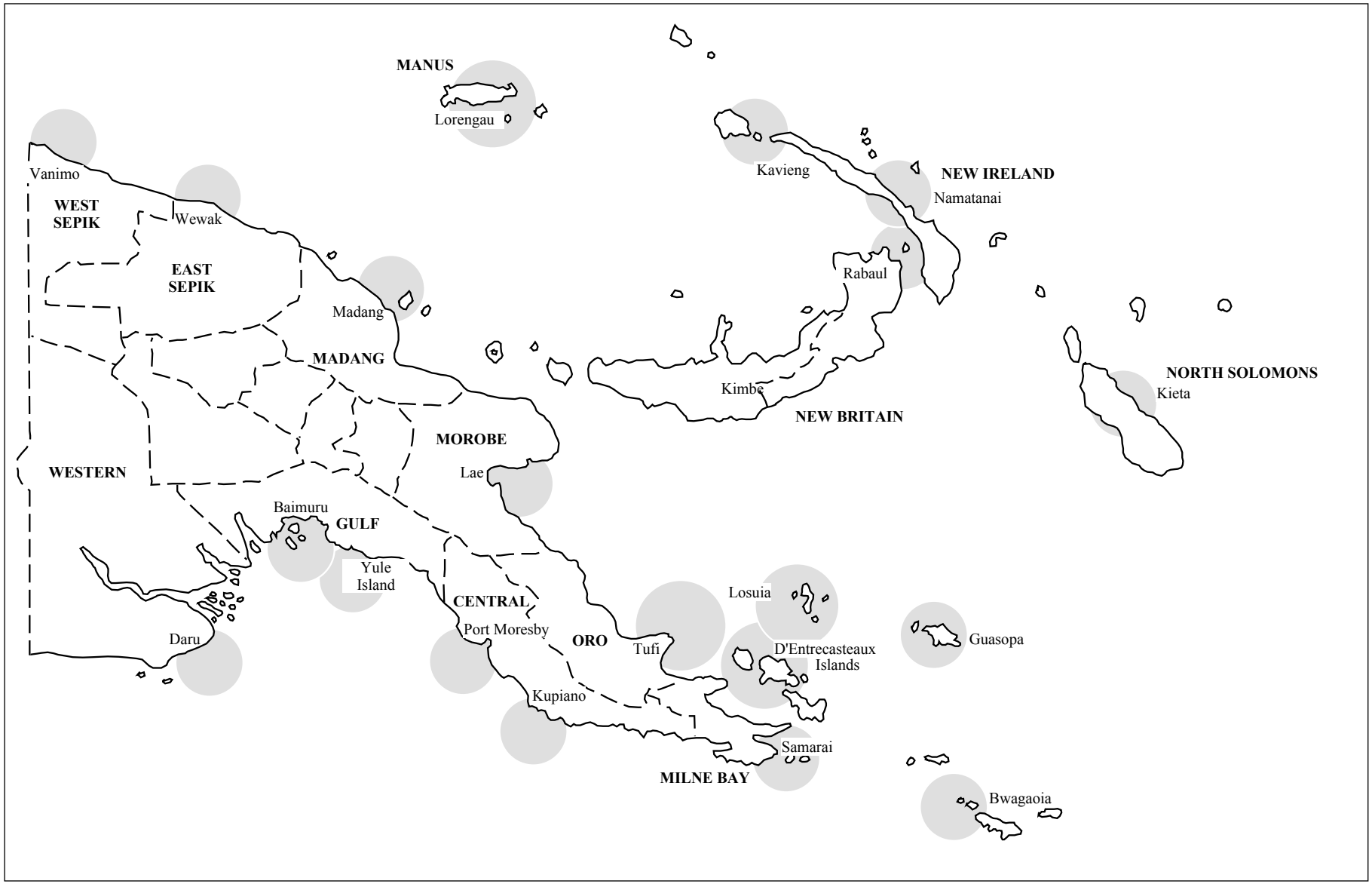

Figure 1. Map of Papua New Guinea showing some major trochus production areas

gests that speculation about over-harvesting in Manus, New Ireland, West New Britain and North Solomons Provinces may be a genuine concern.

Processing and marketing

Since 1980 over 40 exporting companies have applied to DFMR for permission to export sedentary marine organisms. Although during 1985 the world market price for trochus increased, a rapid decline in production was experienced in North Solomons, Manus and New Ireland Provinces during the following year. However, a large number of Asian businessmen entered the country at this time, going from island to island arranging for export of large quantities of shell. This continued until 1989, offering stiff competition for the small locally-based exporting companies. By 1990 only 22 exporting companies continued in the industry, and of these six are currently the major exporters of raw trochus shell. There are also an estimated 30 local trochus shell buying companies throughout the country, acting as company agents to the exporters.

The exporting agents buy cleaned shells from fishermen and sell to the exporting companies. All 22 exporting companies are located at five major and three smaller export ports throughout the country. The raw shells are bagged in 50 kg units and exported in containers. Most of the country's trochus shells are exported to Japan, a major importer, followed by Korea and, more recently, Singapore and Hong Kong. Germany, Spain and the United Kingdom are also occasional importers. The export FOB value of trochus shells varies from one importing country to another. Since 1980 the price for trochus exported to Japan has increased from K 1,020 per tonne to K 6,100 per tonne.

Socio-economic background

Trochus are harvested year round by the rural coastal and island people. Records show that one of the three trochus shell buyers in Manus had dealt with 3,000 fishermen in 1989 and 4,000 in 1990. In this country people often fish in family groups but only one of the family members would go to the urban centre to sell their shells. This arrangement strongly suggests that the actual fishing effort is certainly higher than the number of fishermen selling. During the 1989 and 1990 fishing season over 4,000 fishermen were likely to have been involved in harvesting trochus shell in Manus, representing an estimated 20 per cent of the rural population of the Province. The combined harvest of an estimated 200 t (from all 3 buying outlets) valued at an estimated K 0.9 million (hence an average buying price of K 4.50/kg) were recorded for the same period.

These economic benefits are likely to be similar in New Ireland, North Solomons (except for the insurgency period), West New Britain and Milne Bay Provinces, however mean buying price offered to fishermen for these provinces ranged from K 1.50 to K 3.00 per kg. Where there is no active beche-de-mer fishery the number of fishermen likely to be involved in harvesting trochus shell may range from 14 to 20 per cent. The employment benefits may certainly be considerable because of the general depression in the prices of agricultural commodities such as copra and cocoa.

The price incentive has resulted in increased fishing effort for trochus causing some localised over-harvesting. As a short-term benefit, this has a positive impact on the rural income per capita. In the event that the stock becomes over-harvested, the fishermen would turn to

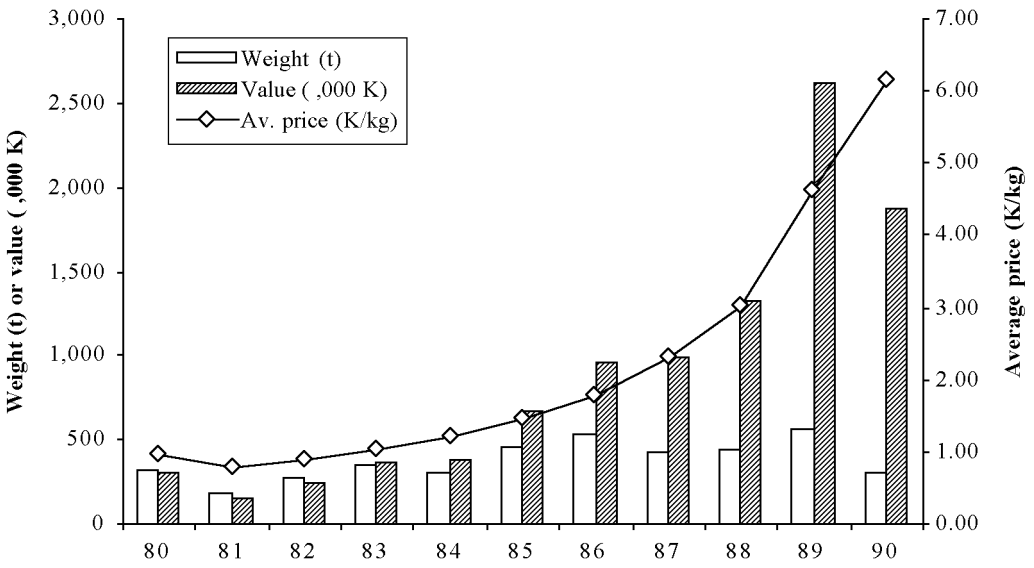

Figure 2
Papua New Guinea trochus shell exports, 1980–1990

other forms of fishing, targeting beche-de-mer or shallow water finfish. The real impact is likely to be felt by the smaller exporting companies and some of the shell buyers, who may be forced out of business. This trend has already become evident where major exporters are starting to increase their buying price, causing heavy competition, although the world market price is starting to drop.

Stock assessment

The DFMR has a Fisheries Research Station located at Kavieng, New Ireland Province. The station is chiefly responsible for sedentary resources stock assessment. This project began in 1988, employing three fisheries biologists responsible for work on commercial bivalves and gastropods, commercial holothurians and the setting-up of effective data-collection systems and improvment of information reporting for all commercially-harvested coastal marine organisms.

In the last three years, three resource assessment surveys have been conducted in six different locations in New Ireland Province. The survey used transect methods to determine species occurrence, depth and geographical distribution. By using these methods, the percentage of various reef habitats were determined. The results of these surveys (Tenakanai, in prep.) showed a density range of 32 to 77 trochus per hectare for the six islands surveyed with a mean of 45 trochus per hectare. Trochus were found as deep as 15 metres, and habitat suitable for trochus formed between 3 and 18 per cent (mean = 8 per cent) of the total shallow reef area to the 15-metre isobath.

This year (1991) three provincial surveys have been planned for Manus (April), West New Britain (July) and New Ireland (October). The South Pacific Commission (SPC) have assisted with the Manus survey by contributing K 2,000.

The activity of shell buyers in Manus and New Ireland is being monitored, as are the movements of shell from province of origin to various ports of export in the country. All trochus shell exports are monitored through Customs and Fisheries Inspection export documents. In 1989, 22 per cent of the trochus shells exported out of New Ireland were below the current minimum size limit of 80 mm, while about one per cent were larger than the maximum of 130 mm (Figure 3). Over this period the mean shell weight was 262 g and the mean shell basal diameter was 97 mm.

Potential yields of trochus are difficult to estimate for PNG due to the lack of detailed bathymetric charts, poor information on reef habitats and the cost of surveying the extensive reef systems throughout PNG.

Management

The taking and processing of all sedentary organisms are administered and regulated under the Continental Shelf and Natural Living Resources Act. The main management problem with this Act is that the regulations are very loose and penalties are limited to K 200. Enforcement is minimal on physical inspection and declaration of actual quantity harvested, resulting in poor data collection and the control of the harvesting and pro-

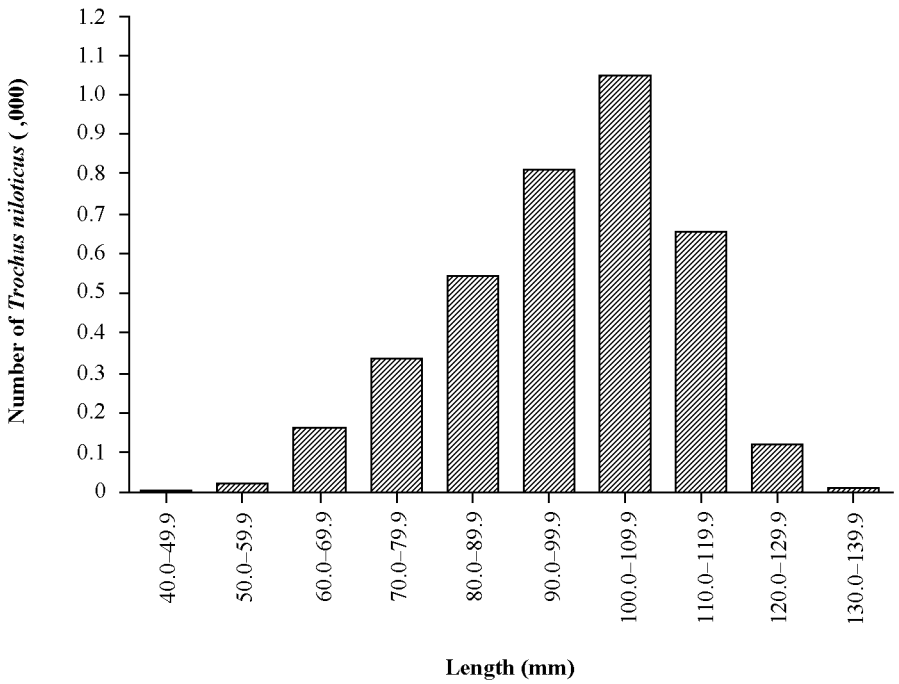

Figure 3
Diameter of trochus niloticus shells from New Ireland, 1989

cessing. To minimise this problem, DFMR propose a management plan involving minimum and maximum size control (80–130 mm) for *Trochus niloticus*. No fishing should be carried out during the night (18.30–05.30 hrs) and it is forbidden to use SCUBA and hookah apparatus for the collection of live animals.

For the purpose of maximising local participation, it was suggested that all the buying activities be restricted to Papua New Guineans whose grandparents are of PNG origin and the harvesting be reserved only for the resource owners and any clan members authorised by the resource owners. In 1990 this management plan was resubmitted to the National Fisheries Council (NFC) meeting and was finally endorsed and recommended to the NEC for approval, enactment and finally to be enforced. It is taking a little while, however it is anticipated to be approved and gazetted before the end of this year.

The only other legislation, which is about to be implemented at the same time as the management plan, is the Manus Provincial Government's 'Marine Resources Protection Act' adopting the same regulations as the management plan. It is likely that this Act will be in place by July, 1991.

One other piece of legislation that should be noted is the 1953 Fish Export Regulations which only applies to trochus shells once it has been declared for export. Its main function is the regulation of quality, quantity, grading, price control and other administrative procedures related to export.

Aquaculture

Papua New Guinea has no immediate plans for trochus culture. It would become necessary as a management tool only when the wild stocks are in danger of non-recovery.

Other issues

In 1988, plans were being developed to study the biology of *T. niloticus* and *T. pyramis*. The main problem with the implementation of this project was the difficulties of tagging animals for growth studies and of finding a technique to extract trochus meat for a gonad development study to determine spawning periodicity and fecundity counts. These tasks have been shelved until manpower problems have been solved and cost-effective techniques have been developed.

In 1989 and 1990 the data collection system of the project found it difficult to conduct resource mapping of shallow reef areas in waters of up to 30-metre depth. A plan was designed to explore the possibility of using remote sensing for habitat mapping to a depth of 30 m. Technical assistance was sought from the South Pacific Commission. Three sites were proposed in New Ireland, Manus and West New Britain Provinces. Funding again became the main constraint and the project was shelved.

The current reporting of trochus shell buying from fishermen, movement of product from province of origin to various ports of export, export declaration by exporters, product grading and physical inspection and entry of correct export information on the DFMR Export Register are not being properly enforced. One of the tasks of the sedentary resources project is to improve data collection and improve information reporting.

During 1991 the project has developed a number of forms which will be tested between May and July. If these forms are found to improve data collection then they will be implemented for use in 1992. Database programmes are being designed to handle the information once these data forms start to accumulate.

Trochus assessment, development and management in Solomon Islands

John Leqata

Fisheries Division, Ministry of Natural Resources
Honiara, Solomon Islands

Introduction

Exploitation of trochus in the Solomon Islands is presently at an all-time high. We have already received reports from the provinces that there is evidence of over-exploitation in some areas. Recently, the rate at which our valuable marine shell resources are harvested and exploited is alarming, and should be brought to government's attention immediately. If Solomon Islands continues to export raw shells, the resources will be depleted within five years or less. Also, trochus supplies to local factories are beginning to decrease, and the existing machines and manpower are not being fully utilised.

The relative value of trochus has increased dramatically over the last four years, providing an incentive for village divers to harvest more trochus. Since there is no proper monitoring of area where trochus is harvested to assess its availability, it is impossible to determine the productive capacity of a given area. Although we have statistics for the total weight and value of trochus exports from the Solomons, we lack information on the quantities, grades, size and quality produced in different areas of the country.

Present information on exploitation comes from export statistics and processors. Trochus production in the Solomon Islands has ranged between 250 and 660 tonnes from 1972 to 1989 (Table 1). I doubt whether large declines in production such as in 1974 and 1978 can be wholly attributed to over-exploitation. Rather they may result from the influence of the price of agricultural commodities such as copra and cocoa.

Socio-economic background

Trochus harvesting is a small-scale artisanal occupation and involves boiling the mollusc to remove the meat which is locally consumed. The people in the villages harvest trochus by reef walking and free-diving. No-one has yet used the modern SCUBA diving equipment in order to increase their harvests. When the price of trochus is high, people may harvest more. However, this is not always the case. When the price of copra increased simultaneously with that of trochus, people favoured copra as an income earner, as it is easier to collect and process, thus diminishing the supply of trochus shells to buyers and exporters.

Trochus is an income earner for Solomon Islands villagers, but as harvesting is easy, consisting of collecting the shells at a depths of up to five metres, the exploitable stock is very vulnerable, and in recent years there has been a distinct decline in the tonnages harvested. The establishment of a facility utilising trochus meat in the Solomon Islands is hampered by the large geographical area over which the animal is harvested.

Processing and marketing

A number of local companies are involved in the export of raw marine products, and trochus shell accounts for the major part of raw marine shell exports. More than 40

Table 1: Export of Solomon Islands trochus shell, 1972–1989

Year	Weight (t)	Value (SI$)	Average price (SI$/kg)
1972	562.13	80,831	0.14
1973	460.86	92,160	0.20
1974	244.65	63,128	0.26
1975	514.40	150,473	0.29
1976	566.50	181,519	0.32
1977	400.58	167,712	0.42
1978	265.98	136,141	0.51
1979	308.51	169,521	0.55
1980	369.72	209,833	0.57
1981	399.79	309,992	0.78
1982	340.21	272,829	0.80
1983	392.97	313,808	0.80
1984	468.70	533,967	1.14
1985	499.90	768,232	1.54
1986	662.34	1,008,911	1.52
1987	445.22	2,045,169	4.59
1988	460.07	3,814,538	8.29
1989	371.70	4,541,445	12.22

Note: In 1991, SI$ 1.00 = US$ 0.38

establishments have been issued with Fish Processing Establishment Licences. There are 40 buyers of unprocessed marine shells plus two button blank processing factories.

Up to the end of 1990, trochus shell was mainly processed overseas for the production of buttons, shell jewellery and artefacts. A feasibility study for the establishment of a trochus processing plant was conducted in 1988. It concluded that the establishment of such an industry would be both feasible and profitable for Solomon Islands. The first factory, Daido (SI) Ltd was established in 1989 and is expected to utilise 150 t per year when operational. A second factory, Solko Co. Ltd, with a potential to process 400 t per year was commissioned in Honiara in 1990.

Trochus is the most important non-finfish marine resource in terms of export earnings for the Solomon Islands. Apart from an unknown amount harvested for subsistence, trochus shell is either exported or sold to the two local button factories. In 1983, the Solomon Islands was the second biggest source of trochus for the Japanese market.

Exports in the 1980s have ranged between a low of 280 t in 1982 and a high of 660 t in 1986, with exports averaging 440 t per year. Exports of trochus in 1990 amounted to 372 t worth $US 1.9 million. Trochus exports show a decline towards the end of the 1980s following a peak in 1986 (Figure 1), which cannot be attributed to the local button factories absorbing harvests.

The followings market information on trochus was supplied by Daido (SI) Co. Ltd:

- 1 t of raw shells yields about 200 kg of button blanks
- 1 t of button blanks is valued at SI$ 100,000 (in 1991, SI$ 1.00 = US$ 0.38)
- Raw materials introduced into the factory during 7 months = 25 t
- Export value of 25 t = SI $ 375,000
- Processed button blanks = 5 t
- Export value of 5 t of processed button blanks = SI$ 500,000
- Factory capacity requires 15 t of trochus monthly

For a continuous supply of raw shells, the two button-processing companies must pay SI$ 14–15/kg to rural fishermen or divers to continue collecting trochus and other commercial marine shells.

Japan and Korea are dominant in importing and processing of trochus, both whole and in the form of button blanks, although traditional button manufacturing centres are also to be found throughout Europe.

Management

Current legislation states that fishermen may not catch or retain, sell or expose for sale, buy or export any trochus shell under 2.5 inches or 6.4 cm basal diameter. This is to encourage the establishment of viable trochus processing factories in the country. Some measures of protection for this industry may be provided by the restriction of

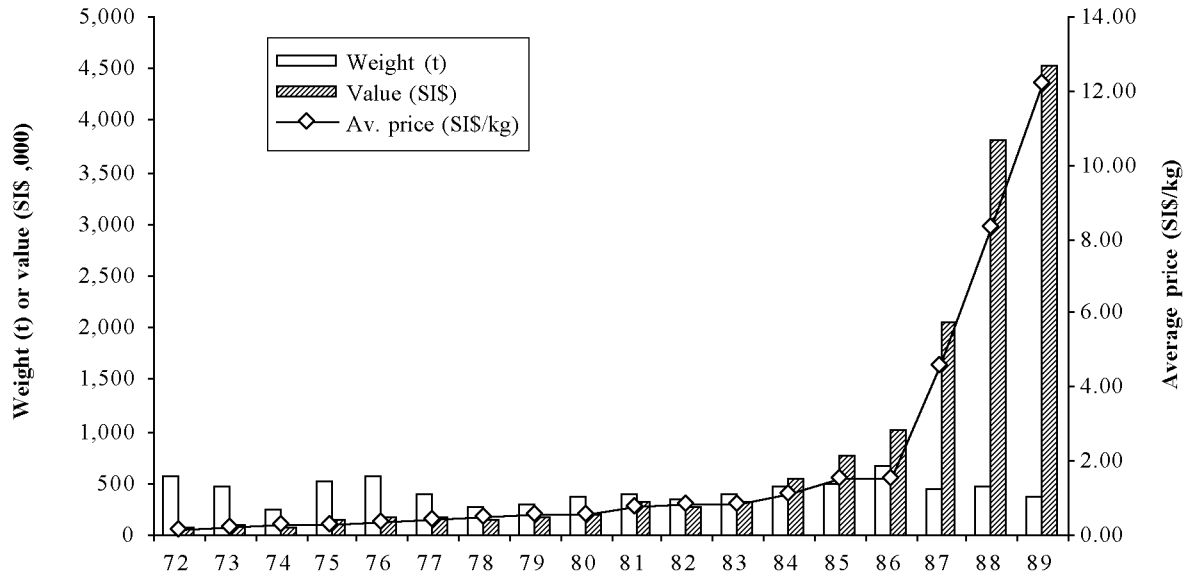

Figure 1
Solomon Islands trochus shell exports, 1972–1989

exports until local demand has been met. At present, export duty has been increased from 10–15 per cent by value of raw shell.

In the Solomon Islands, the size limit was increased from 6.4 cm to 8 cm basal diameter. The minimum size limit of 8 cm was chosen because a greater percentage of the trochus population will be sexually mature than at the former limit of 6.4 cm. The current size limit is probably too small to allow viable breeding in the wild. Other South Pacific countries have minimum size limits ranging from 6–9 cm basal diameter. A maximum size limit of say 12 cm could be imposed to protect the older, more highly fecund individuals.

The older, larger shells are often of low value anyway because of worm holes. If necessary, other stock controls can be introduced such as a national annual quota, closed seasons and/or areas, but the latter with some difficulty due to the problem of hoarding. The best upper size limit would be in the range of 10–12 cm basal diameter. No catch quota has been enforced yet but the equal production quota for the two button-processing companies was placed at 150 t per year. Careful monitoring and regulated expansion of domestic trochus processing should remain a high priority.

Care must be taken that the capacity of such facilities, in conjunction with raw shell export, does not exceed the sustainable yield of the resource. This is probably no higher than 450 t per year for the areas currently fished. In order to ensure availability of trochus shells in the long term, it is recommended that the level of annual production be set at 300 t annually and that the export of raw shells or unprocessed shells be banned in order to ensure that supply of raw shells be made available for processing. Also, the number of button blank factories from marine shells be presently restricted to the established two companies.

It is the wish of the Solomon Islands Government to allocate export quotas for each company according to their most efficient capacity. In this way, consistent export quantities can be continually maintained, rather than giving the companies a free hand. There is no merit in continuing export of trochus shells while two button factories have been established to undertake local processing of shells. If the export of raw shells is continued, the resource will be depleted within five years or less.

Some management recommendations warranting considerations are:

- A minimum size of 8 cm basal diameter and maximum size of 12 cm basal diameter should be placed on commercial fishing. The maximum size should also cover subsistence food fishing if it is to be effective, although this will be difficult to enforce.

- Provisions should be made for a number of sanctuary areas that are spread throughout the main fishing areas, and are easily recognisable to fishermen.

- A publicity campaign to inform the general public of the regulations and of their rationale should be mounted.

- As trochus is a sedentary animal, adapted to the coral reef biotope, it would appear that trials to breed trochus juveniles in a hatchery, with a view to reseeding reefs, might be a way of conserving this resource.

Aquaculture

Presently, no aquaculture facility for trochus has been established in the Solomon Islands and future plans for such a facility are not anticipated due to lack of funds and manpower. Restocking of juveniles is envisaged, such as trials to breed trochus juveniles in a hatchery to reseed reefs, especially in areas where over-harvesting threatens or has already caused economic extinctions of this important resource. Cross-breeding exercises can be helped to develop the best shell shape for the country, starting at 8 cm basal diameter.

Other issues

No biological or other research on trochus has been undertaken in the Solomon Islands. But data on export figures and prices from both export companies and the two button blank factories in the country have been monitored and analysed by the Fisheries Division. Future research plans for these important commercial marine shells have not been anticipated due to lack of funds and manpower.

Trochus resource in Tuvalu

Ministry of Natural Resources and Development
Fisheries Department, Funafuti, Tuvalu

Introductions

Trochus niloticus does not occur naturally in Tuvalu. Adult trochus brought in from Fiji were introduced for the first time to Funafuti in 1985 (181 inds.) and 1987 (200 inds.). Subsequently two air-drops of trochus shells were conducted to introduce trochus to the outer islands of Tuvalu. These air-drops were organised with the kind assistance of the FAO/UNDP Regional Fishery Support Programme and the Royal New Zealand Airforce. For the first air-drop in April 1988, 4,852 trochus were brought from the Cook Islands and introduced to the islands of Nukulaelae, Nukufetau and Funafuti. The second air-drop was carried out in July 1989, and trochus were brought from Aitutaki in the Cook Islands and introduced to the islands of Nui (1,000) and Nanumea (1,200).

Stock assessment

Underwater visual surveys have recently been carried out on Funafuti, Nukulaelae, Nukufetau, Nanumea and Nui. Live adults trochus were found at all islands where they were introduced except at Nui. It is possible that the trochus have not survived at Nui, because the second air-drop operation was not very successful, as it is thought that most of the animals were crushed on the reef when they landed. Alternatively, they may have survived but were not detected by the survey.

It is hoped that these introduced stocks breed successfully (as has been the case in Aitutaki and a number of other Pacific Islands) and that in five or ten years, numbers will have built up sufficiently to allow harvesting as the basis of a valuable cottage industry for Tuvalu people. There are encouraging signs that there has been some recruitment to the original seeded population on Nukulaelae.

Management measures

Tuvalu is serious about protecting these valuable animals to allow them to breed unhindered and build up their numbers. A policy has been established which states that anyone who removes any trochus shells from their habitat is liable to a fine of up to A$ 1,000 or a maximum term of six months in jail. However, the resource at present has not reached the harvestable stage. The aim of this exercise is to develop a small-scale export industry in Tuvalu in the future.

Country statement – Vanuatu

Department of Fisheries
Port Vila, Vanuatu

Introduction

Vanuatu Archipelago is composed of 80 islands with a land area of 14,800 km^2. The Archipelago extends 875 km on a North–South axis between 13 and 21°S. Her exclusive economic zone, extending to 200 n.mi. from the shore, encloses an area of 848,000 km^2 of ocean. The islands are surrounded by narrow fringing reefs and beyond the reef slope the shelf may descend steeply into deep water.

Fisheries research in Vanuatu should be easy for those so motivated to carry it out. In most seasons the climate is amenable for work and a marine resource investigator could be satisfied for many years on almost any shore. Collection of scientific information on marine organisms has only recently increased rapidly, reflecting the changing attitudes of the Government to exploitation of marine resources.

In keeping with the objectives of the workshop, this paper will summarise the history and present status of the trochus resource in Vanuatu.

Harvest

The resources of the commercial top shell (*Trochus niloticus*) in Vanuatu are relatively small compared to other Pacific countries. Scientific assessments of the respective trochus populations within the fringing reefs of each island in the archipelago and maximum sustainable yields have not been conducted, and hence accurate information on the potential long-term annual harvests is not available.

Trochus harvesting in Vanuatu for other than subsistence purposes has a long history. Trochus resources have been harvested mainly for export purposes, since the beginning of the 20th century. It is a mature fishery, not a recent development like the deep-slope fishery. The trochus populations on the reefs within the archipelago have been influenced by long-term sustained exploitation as well as natural phenomena. Fishing data are scarce. There are no available figures on the rate of harvest which would indicate appropriate levels of exploitation.

From trochus harvest records collected between January 1976 and May 1982, there were significant annual variations in levels of trochus harvested from different regions within the archipelago and for the country as a whole (see Table 1 on next page). These yearly fluctuations may have resulted from factors such as: depressed trochus prices offered to the fishermen, switching from trochus to copra harvesting if the copra price is more attractive, or bans or taboos on trochus harvesting enforced by island councils or chiefs. It is important to account for such factors when drawing conclusions on the level of trochus harvests in Vanuatu.

Though there has not been a strategic assessment on the level of trochus harvests in Vanuatu, information obtained from confidential figures supplied by certain factories indicates that the level of trochus harvest in Vanuatu has reached a peak and is now undergoing a steady decline. This is reflected in the level of exploitation of the resource.

Socio-economic background

The top shell (*Trochus niloticus*) has been harvested by the locals in large numbers as a source of protein since prehistoric times because of its tasty flesh, large size and ease of capture.

The harvest of trochus is a small but significant source of revenue and employment in Vanuatu (David 1985). This activity has been stimulated by the steady increase in demand for the trochus shells on the world market, which in turn affects the market price for trochus (Nash 1989; T. Cyran, S. Bourdet, pers. comms.).

The trochus resource is exploited by at least four sectors of the population. They are: fishermen, reef owners, village communities and foreign small-scale fishermen (mostly Koreans).

Harvesting of trochus has recently become a leading source of income for rural area and outer island dwellers. The prices offered per kilogramme of trochus shells compared to that offered for copra are very appealing. Copra buyers are paying VT 15/kg for hot-air-dried copra and VT 10/kg for smoked copra (in 1991, VT 100 ≈ US$ 0.9).

Other resources could be a source of revenue for outer island dwellers, for example, fin-fish. However fishing as a career only attracts interested and motivated individuals. Further, the expenses of buying, hiring, or leasing a boat and maintaining it, is a burden for those not so well-off financially. Fish can be caught by various methods but following capture there are problems with keeping it fresh enough during transportation to Vila or other urban centres for sale. Other island dwellers cannot buy the fish, either because they do not have money or because it would seem strange to pay for fish, when they themselves could catch it for their own consumption.

Thus trochus has become a very popular resource to harvest as it is easy to capture, the flesh can be consumed as

Table 1: Weight (kg) of trochus harvests from different islands of Vanuatu (1976–1982)

Island	1976	1977	1978	1979	1980	1981	1982
Ambae	718	4,889	510			329	404
Ambrym	81	12,286	848	445	405	182	
Anietyum	3,108	268	1,285		1,243	156	75
Aniwa			2,056	42			
Banks	2,195	6,728	3,128	754	5,952	816	
Efate	480		92	116			
Efate Z.		904	2,997	315	2,194		438
Epi		521	521	2,024	4,805	4,524	2,723
Erromango		6,785	1,166	3,229	662	1,354	
Futuna	1,195				226		
Maewo		1,169					
Malekula	919	8,990	7,040	5,775	6,858	7,571	4,153
Paama		2,288		58			829
Pentecost	82	262	78		710	837	80
Santo	82	385	8,023	520		23	
Shepherds	1,324		89		1,229	2,319	726
Tanna		629	450	761	1,473	451	1,544
Total	**10,184**	**46,104**	**28,283**	**14,039**	**25,757**	**18,562**	**10,972**

Note: These figures were compiled from the files of the Vanuatu Cooperative federation chartered boats that were transporting shells from January to May each year

Table 2: Weight and value of raw trochus shell exports (1969–1984) and value of button blanks exports (1985–1990)

Year	Weight (t)	Value (VT ,000) of raw trochus	Value (VT ,000) of button blanks
1969	2.0	n. a.	
1970	7.0	n. a.	
1971	31.0	n. a.	
1972	71.0	n. a.	
1973	56.0	n. a.	
1974	88.0	n. a.	
1975	170.0	n. a.	
1976	213.0	n. a.	
1977	98.0	3,580	
1978	26.0	13,110	
1979	37.0	2,010	
1980	58.0	1,210	
1981	49.0	4,440	
1982	77.0	12,028	
1983	19.0	3,319	
1984	37.0	2,010	
1985			18,708
1986			15,780
1987			13,149
1988			21,054
1989			41,960
1990			43,858

Source: Statistics Bulletin of Vanuatu

a source of protein, and the shell can be sold to the buyers for an attractive price.

Pricing

The prices offered to local fishermen or to any other group of collectors for raw shells range from VT 150–200/kg depending on quantity and sizes.

Processing and marketing

There are three shell factories operating in Vanuatu, all located in Port Vila. They are: Melanesian Shell Products (MSP), Hong Shell Products (HSP) and Vanuatu Coral Shell Processing Factory (VCSPF).

Another shell factory was located in Santo, Vanuatu's second largest urban centre, operated by Melane-sian Shell Products. This factory ceased operating recently, mainly due to insufficient stocks of trochus shells to process.

Following the closure of the Santo shell factory, all commercial harvests are sent to Port Vila by a network of buyers distributed throughout the islands. Within each island where trochus shells are harvested, the shell factories establish a buying agent. Each factory offers its own buying price. VCSPF and HSP tend to offer prices ranging from VT 150–200/kg. This means that they offer VT 150/kg for trochus shells with basal lengths ranging from 11–15 cm or greater and VT 200/kg for trochus shells with basal lengths ranging from 9–10 cm or less. MSP offers VT 200/kg for all trochus shells with basal lengths starting from 9 cm and upward.

Data collection and monitoring of the trochus resources should be possible, given the centralisation of processing in Vanuatu. However, it has been very hard for the ORSTOM Fisheries Research Unit to obtain first-hand information from certain shell factories, since the present fisheries legislation does not compel the factories to cooperate with the fisheries officers in the collection of data.

Data collection from the shell factories depends on the goodwill of the factory managers. The manager of MSP has been very cooperative with the fisheries officers in supplying information. However, this information is supplied in confidence. There has been some cooperation with the VCSPF, but no figures are given. In the case of HSP, there has been no cooperation with the fisheries officers. Thus the scale of operation of VCSPF and HSP is unknown.

Although trochus has been exported from Vanuatu since the beginning of the 20th century, there is not a complete record of the export statistics. Trochus exports in 1921 were approximately 60 t, (Dunbar 1981). Later trochus export statistics extend between 1950 and 1958, and are available from 1969 to the present. Table 2 gives the amount of trochus exported from Vanuatu between 1969 and 1990.

Processing trochus shell for commercial button manufacture in Vanuatu is viable given a sufficient supply of raw material. It is estimated that a small factory will require between 60 to 100 t of raw material per annum for it to remain profitable and pay internationally competitive prices for its raw materials.

Button blanks are semi-processed products of trochus shell. These are produced after the shell rings are cut using a special machine with a diamond cutting ring. Once the blanks are produced, they are sorted for blemishes. It is estimated that a factory will need 10 t of raw shell to produce one tonne of button blanks. One tonne of raw shell will produce approximately 200,000 button blanks.

Marketing

The marketing of commercial shells differs according to individual shell types. All trochus shells are processed into buttons for the high-quality garment industry. Japanese companies are the leaders in this sector and set the price trends for these products.

Vanuatu shell factories export their processed products to: Japan, Italy, France, Hong Kong, Singapore, Taiwan, Korea and Mauritius (Indian Ocean).

Introductions

Introduction of the trochus has never taken place in Vanuatu. *T. niloticus* is a species endemic to Vanuatu.

Stock assessment

In view of the small area of suitable habitat, trochus stocks are limited in Vanuatu and thus prone to intensive fishing.

The first trochus stock survey was carried out by L. C. Devambez of the South Pacific Commission in 1959 (Devambez 1959). The survey was concentrated on trochus habitat in the Central and Southern groups of Vanuatu (known then as the New Hebrides) at the request of the Condominium Government, to determine whether trochus fishing, closed early in 1958, could be re-opened.

The survey was divided into two parts, the first covering the central group, the second covering the Southern group. For the survey the following islands were visited to obtain estimates of trochus population: Emae Island, north Efate, Kulivu in the Maskelyne Group, south-east Malekula, Tutuba, south-east Espiritu Santo and Aneityum, the southern-most island of the archipelago.

The results of this survey indicated that most of the populations (98.91%) were molluscs aged three-years-old or older, and the proportion of young shells under three-years-old was extremely low (0.87%). The density of trochus on the reefs was noticeably low (the average take per diver-hour was 7 trochus, with extremes of 10.3 for Emae Island and 3.3 for Aneityum).

Devambez proposed three possible factors which might have contributed to the scarcity of trochus on the reefs:

- Indiscriminate removal of trochus of all sizes.
- Removal of worm-damaged trochus by fishermen who believed that this would benefit future stocks and lead to better harvests. Most of these worm-damaged trochus were large (> 10 cm) specimens.
- Over-fishing caused by high prices of trochus shells between 1952 and 1958.

In 1961, Devambez was requested by the Condominium Government of the New Hebrides to conduct a supplementary survey (Devambez 1961). Islands visited were: Aneityum and Erromango in the southern group; Emae, Kulivu (Maskelyne Island), and Tutuba in the central group.

Results of this second survey showed a higher proportion of trochus between one and three years of age; 8.2 per cent increase in Kulivu, 50 per cent increase in Tutuba and 100 per cent increase in Aneityum. The density of trochus on the reefs visited showed considerable improvement. The average harvest rate was 7 trochus per dive-hour in 1959, while in 1961 this had increased to 24.1 trochus per diver-hour.

Since 1961, no other stock surveys were carried out until 1990 when the ORSTOM Fisheries Research Unit initiated a three-year Trochus Stock Assessment Project. Funded by the USAID funds allocated for technical assistance, the Project was set up with the following study objectives:

- History and monitoring of collection by business.
- The analysis of data on the production and exportation of trochus, supplied by the processing factories. This will provide information on exact quantities of trochus collected according to the size and island.
- Determination of biological parameters of trochus.
- Study of the growth rate.
- Tagging of trochus on different reefs in the group. This will provide a better understanding of the growth rate of trochus in various parts of the group.
- Study of age of achieving maturity. This study will enable the ORSTOM Fisheries Research Unit to measure the time between the onset of sexual maturity and growth to a size of 9 cm. The results will permit setting size limits for different islands in Vanuatu.
- Analysis of trochus stock in Vanuatu.
- Structure analysis by population size and movement.
- Evolution of trochus catchability. The objective is to examine the changes in trochus catchability throughout a lunar month. The results will show when the catchability of trochus is easiest.
- Quadrats and sampling of size groups.
- Analysis of the stock movements to be carried out on various representative reefs, to be able to calculate whether fishing activity is compatible with the production potential of the habitat.

The results obtained in the first year of the Trochus Stock Assessment project have not yet been released. The results are still confidential.

Survey methodologies

a. 1959 survey method

Devambez (1959) marked out reef areas into quadrats of 50 m x 25 m. These quadrats were sampled by a team of three to six divers. The divers recovered all the shells they could find in the marked out quadrats in a time span of one hour. All the trochus found, including dead shells, were taken, measured and returned to the reef. In addition, whenever possible, boulders and slabbed areas on the reef table were searched at low tide in an attempt to discover juvenile specimens. Measurements were taken along the greatest diameter across the base of the shell.

b. 1961 survey method

The method followed by Devambez during the 1961 survey was not exactly the same as that used in 1959. First, the increase in shell populations was so evident in most cases that it was felt preferable to extend the stations or to multiply them rather than to perform systematic work as was done during his first survey. Secondly, the unfavourable weather conditions repeatedly prevented any search for juvenile trochus on the reefs at low tide. Nevertheless, study sites established on checked areas during the first survey were re-visited for comparison of results. As in 1959, the shells were measured along their greatest diameter across the base.

c. 1990 stock assessment survey method

The methodology used in this stock survey adopted the use of quadrats. According to Nash (1988), this method is more suitable for the distribution of trochus on the reef, since it makes it possible to estimate the number of trochus visible over a chosen area. Quadrats of 900 m^2 were established, and a search time of 30 minutes was allocated for each diver (i.e. 2 divers in each quadrat). At the end of the 30 minutes the number and size of the trochus collected were recorded. Each area of 900 m^2 was therefore explored for a total time of 60 minutes.

On each of the reefs studied, the location of the quadrats was decided upon the basis of the fishing habits of the local fishermen. The quadrats were located on the areas which were heavily fished.

Management

Trochus fisheries can be managed by a variety of methods. These methods include size limits, limited fishing seasons, quotas, trochus sanctuaries, closed seasons and export criteria.

Closed seasons

This management option has only been operated once in Vanuatu. In early 1958 the Condominium Government of the New Hebrides declared a halt to trochus fishing. Prior to the cessation of harvesting in 1958, no legislation was drafted to protect the resource either by establishing a size limit or a closed season. Any shell over 5 cm (basal diameter) was fished. The ban on trochus fishing implemented in 1958 remained in force till 1962 when the fishery was re-opened.

Quotas

In Vanuatu the trochus resource was previously managed by an export quota of 75 t (whole shell weight) per year for the entire country, set by the Government. This system ceased to operate in 1984, when a policy was introduced by the Government to prohibit the export of whole trochus shell from the country to encourage the processing of shells into button blanks prior to export. No quota system of any kind operates for trochus in Vanuatu at present.

Size limits

The only management tool that operates for trochus resources in Vanuatu is minimum size limit. This management measure was introduced in 1983 by the Government. The minimum size limit is set at 9 cm (basal diameter).

Studies of maturation indicate that the onset of sexual maturity generally occurs at sizes between 5 and 8 cm maximum shell diameter. Setting the minimum size limit at 9 cm allows the individual trochus to breed several times before entering the fishery. The minimum size limit is thus essential in minimising the effects of overfishing.

Aquaculture

Trochus hatchery

Trochus aquaculture in Vanuatu has experienced a series of problems. The Vanuatu Fisheries Trochus Hatchery was established in 1985, funded by the French Government. The immediate objective then was to develop techniques necessary for trochus seed production and juvenile rearing. The long-term objective being to determine whether re-seeding of exploited trochus populations with hatchery-reared juveniles is a practical tool for management of natural stocks.

Since the establishment, the hatchery encountered problems related to seed production and juvenile rearing. The suspected cause then was water quality. The hatchery experiments were terminated when the facility provided by the French Government was destroyed by Cyclone Uma on 7 February 1987.

The Fisheries Department requested the South Pacific Regional Aquaculture Development Project (SPRADP) to provide a consultant to identify the existing problems in the hatchery and to review the facilities. SPRADP commissioned an Australian consultant, Mr W. J. Nash to review the existing aquarium facilities in January 1989. The consultant recommended the replacement of the water pump and the piping system. This equipment was identified as the cause of the poor water quality in the tanks.

Without sufficient funds to meet the consultant's recommendations, the Fisheries Department again approached the SPRADP to provide funds for the replacement of the equipment. In September 1989, the replacements were made under the supervision of Mr R. Foscarini, (Associate Professional Officer to the SPRADP). The existing hatchery continues to be funded by SPRADP.

The first successful trochus seed production was realised in 1990. A total of 3,500 juveniles are now being reared in the hatchery. The hatchery now concentrates on meeting its long-term objective, which is to determine whether re-seeding of reefs with hatchery-reared juveniles is a practical management strategy.

Until now, no re-seeding experiments have been conducted. However, it has now reached a stage whereby the hatchery-reared juveniles are of a reasonable size to be experimentally re-seeded on a reef flat.

Wild stock enhancement with hatchery-reared juveniles

History has shown that *Trochus niloticus* are sensitive to intensive fishing. There are a variety of management options for trochus resources. One of the options, is the re-seeding of exhausted reefs with hatchery-reared trochus juveniles. This option unlike other options, may increase the wild stock beyond its natural size.

The Fisheries Department recognises the economical aspects of this management option, should it lead to a successful re-stocking of an exploited wild stock. Enhancement of trochus with hatchery-reared juveniles cannot be seriously considered as a practical tool for managing wild fisheries at present. It has yet to be demonstrated experimentally that this is an effective strategy for enhancing wild stocks.

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Trochus resource of Western Samoa

Department of Agriculture, Forests and Fisheries
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Introduction

Western Samoa consists of four islands, Upolu and Savaii (the two largest islands), together with Manono and Apolima. Most of the coastline is fringed by narrow coral reefs which drop rapidly into very deep waters. Extensive barrier and patch reefs are found along the northern and western coastlines of Upolu. The land area extends over 1,100 km^2, supporting a population of 170,000 people.

Historically, Samoans were highly dependent on locally-caught fish as a protein source. Because of its limited continental shelf area and modest offshore tuna resources, Western Samoa's export potential is limited. Development of small-scale commercial or artisanal fisheries to supply Apia with fresh fish began in 1976 through a United Nations boat-building project.

Canned fish, turkey tails and mutton flaps are also consumed to supplement the Samoans' protein intake, particularly since the supply of fresh fish can not satisfy present demands (Zann, 1990). The imported foods are now preferred because they are cheaper than locally-caught fresh fish. Increases in fish price's reflect the amount of fish available. As the amount of fish caught decreases, the prices they fetch increases.

Lagoon and reef fishery resources of Samoa are very heavily exploited (Helm, 1992). A recent assessment of the inshore fishery (Zann, 1991) documents that almost half of all rural households go fishing each week in inshore waters of less than 5 m depth.

Catch data from bottomfish and pelagic species indicate a decline in catches in the recent past, due mainly to sustained fishing pressure. Ease of accessibility of the fishing grounds and the use of destructive fishing methods (dynamite, poison, etc.) have also contributed greatly to the reduction in the reef and lagoon production. In addition, Samoans are also well noted for their ability to utilise any marine organism of any size. Coupled with this kind of fishing mentality, targeted fisheries are vulnerable to pressures beyond the resources' capabilities to cope.

Gastropods, such as *Trochus* spp. and *Turbo* spp. are no exception to the Samoan appetites. Locally, these shells are caught for their meat. The village-fisherman usually catches trochus as a by-catch which generally constitutes his meal or, when in excess, is sold on the roadside or at the municipal market. Two trochus species are found in our local waters, *Tectis pyramis* and *Trochus niloticus*, the latter being an introduced species. Trochus, like other inshore fisheries, are now becoming scarce in the fishing grounds.

Although not a major fishery, the persistent subsistence fishing pressure has resulted in the slow disappearance of the gastropod from the lagoons of Western Samoa.

Fishing ground ownership was and still is the responsibility of the titled chiefs (matai) of the villages. The council of chiefs oversee the general protection of the village-owned land extending from the mountain ridge down to the lagoon and reef fishing grounds. Traditionally, curfews on fishing days, fishing hours and restrictions put on particular fish species were amongst the rules implemented by the council.

Village fishermen were commonly restricted to their own fishing grounds and forbidden to fish in nearshore waters belonging to neighbouring villages. Nowadays, this is no longer practiced in most villages, and only a very few still implement restrictions. As inshore resources are declining, local fishermen are now focussing their efforts to the offshore areas.

Historically, trochus contributed to the protein intake of the local Samoans as the resource was plentiful and easily accessible. However, through indiscriminate fishing of the shells and the use of dynamite, poisons and chemicals, reductions in population numbers and shell size are evident. Further, much trochus habitat has been destroyed. Nowadays, few shells are harvested from the inner reef waters.

Harvest

The trochus resource of Samoa is disappearing from the shallow areas of the lagoon and reefs. In general women carry out 'gathering'-type fishing, targeting bivalves, gastropods and echinoderm species such as sea cucumbers and sea urchins. Trochus and turbo shells are mainly targeted when in abundance, however, harvest numbers from the last couple of years have shown them to decline, and they now hardly contribute to the catch. Less than 500 shells per week are sold at the market in Apia.

Socio-economic background

Rural villagers collect shells. Subsistence fishing is very important to the majority of rural dwellers (Zann et al, 1984). Fish and marine invertebrates provide people in rural areas with the greater proportion of their dietary protein. The local seafood provides 82 per cent of the protein requirement, with gastropods (including trochus) representing 9 per cent of this intake (Zann et al, 1984).

There is no major trochus fishery in Samoa. Harvested shells are small in size and very few in numbers.

Introductions

Early in 1990, a proposal was put to the FAO/UNDP Fishery Support Programme for the introduction of the *Trochus niloticus* to Western Samoa.

Mainly for the purpose of stocking our reefs and the economic value of the shell. The success of introductions of this species in other islands was also of interest.

The first batch consisted of 50 shells and was collected in Makuluva and from Suva reef of Fiji. These arrived on 19 September 1990, and were released on Namu'a Island off Aleipata, on the south-east side of Upolu. Another shipment of 62 shells, also from Suva reef, arrived later on 10 October 1990, and was released in the same area.

When the shell sizes from time of arrival to two months after release were compared, a clear increase in margin was noticeable, as was an interruption in shell growth at the time of shipment.

We are now looking towards the Cook Islands and Palau for shipment of shells. Preference will be given to the Palau stock, for the quality of the shell.

Stock assessment

With the introduced species, assessment and management studies will be used to closely monitor the trochus population. As for the local species, efforts are focused on controlling their harvest.

Aquaculture

With the arrival of the first batch from Fiji, 10 shells were left in the Fisheries aquaculture ponds. The shells were the largest of the shipment. During captivity they spawned spontaneously, however, this did not result in any juvenile being produced. Culture of trochus in Western Samoa is possible. Our aquaculture facilities are now under renovation, and one of the species we wish to culture is trochus—mainly for its economic value in the button industry.

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Other selected papers

Trochus shell and button industry in Japan

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Introduction

Shell button production started about 115 years ago in Nara Prefecture, not far from Osaka. The traditional Japanese garment is the kimono and does not require any buttons, however, with the adoption of western clothing in Japan, the button became a necessity.

By 1950, the shell button export had become an important industry in Japan and, by 1960, a large volume of shell buttons were exported to world markets, mainly to the USA as well as to major European countries. At one time, there were more than 120 shell button makers located near Osaka.

Hong Kong became a major importer of Japanese buttons when it became the world's garment manufacturing centre. However, when the polyester button was invented around 1955 in the United States, the market share of the shell button declined rapidly.

The Japanese button industry

In 1985 there were 286 button makers in Japan, employing 4,132 people, who exported buttons worth ¥ 44,636 million (US$ 323.5 million). In 1989, there were 271 registered button manufacturers, employing a total workforce of 4,343 people which generated exports worth ¥ 52,809 million (US$ 382.7 million).

About ¥ 10.8 million worth of buttons were exported in 1985 for every person employed in the button manufacturing industry. In 1989 about ¥ 12.2 million worth of buttons were exported per employee. This means productivity went up by ¥ 1.35 million (US$ 9,783) per person in the 5-year period.

It is very difficult to maintain such productivity in the shell button industry due to the fact that the material is a natural product, and most of the work must depend on human labour. One of the machine factories in Japan keeps trying to develop an automatic blanking machine, but has not been successful due to the fact that trochus shells do not have a uniform shape.

Presently there are around 40 shell button makers, including shell button blank factories. Shell button manufacture was traditionally a cottage industry.

The shell button industry depends on raw shell imports, and raw shell prices greatly fluctuate in a cycle, which presents the establishment of large scale enterprises. In 1989, the value of shell button exports amounted to US$ 18.34 million, which represents about 0.007 per cent of the value of Japan's exports.

Fifteen years ago the shell button industry in Japan obtained much of its button blank supply from Korea. Gradually, Japan has become dependent on importing shell button blanks from other locations such as Indonesia, Thailand, the Philippines, Fiji and, recently, the Solomon Islands.

The key limiting factor of button manufacture in Japan is the cost as well as the shortage of labour. I believe that it will be a natural course for our industry to ask the countries where trochus shell is available to produce shell blanks, and in the near future to produce finished shell buttons. Compare GNP per capita in 1989: US$ 23,202 in Japan, US$ 17,121 in Australia, US$ 4,968 in Korea, US$ 1,257 in Thailand, US$ 7,509 in Taiwan, US$ 450 in Indonesia, US$ 736 in the Philippines.

Another important factor is productivity. I personally believe the price for raw shell, especially the price of trochus shell, is overvalued on today's market. I also believe the price of finished trochus shell buttons hit its highest (from the demand point of view) in the spring of 1989, but on the other hand for the raw shell the peak was in the spring of 1990.

In the spring of 1989, there were very strong demands from world fashion for cotton and linen blouses. Trochus shell buttons match perfectly with these materials as well as silk fabrics. Starting from the spring of 1990, high-tech, man-made fabrics became more in demand in the fashion world and trochus shell button does not fit such fabrics. Thus the demand on trochus shell buttons has greatly declined. Today we are faced with the problem that finished trochus shell buttons cannot be sold in large quantities and the shell price is much too high.

Our company market, in 1992, size 18 (11.5 mm) trochus shell buttons for US$ 90.58/kg when the same size buttons fetch: US$ 3.30/kg for urea, US$ 5.07/kg for regular polyester, US$ 14.50/kg for better quality polyester, and US$ 22.54/kg for nylon.

Due to the fact that the cost of shell buttons became so high, user/garment factories or buyers of garments switched to imitation shell button mostly made of polyester resin. These imitation shell buttons can be sewn by automatic button feeders and can be dyed to match colours very easily.

The important three points to remember for trochus exporters: no dead, no sun-bleached and no worm-eaten raw shells should be included in shells to be exported overseas. For those who wish to start off producing the trochus shell blank we are in a position to help. It can be started with a very small initial investment.

Processing and trade of Melanesian Shell Products (MSP)

Melanesian Shell Products Ltd
P.O. Box 1133, Port Vila, Republic of Vanuatu

Introduction

Trochus shells are one of the main locally-available raw materials in Vanuatu. In the past, large quantities of trochus shells were exported without any processing. The Government of Vanuatu since 1982 has supported a policy of increasing the value added to its exports and is therefore interested in further development of button manufacturing. A ban on export of whole unprocessed trochus shells was put in place in 1983 by the Vanuatu Government.

Project background

Melanesian Shell Products (MSP) commenced its activities in 1983 when the company Trocas Vanuatu went into liquidation. At present MSP only produces trochus button blanks and decorative shells. The company was assisted by a French technical expert from Ets. F. Mercier, a French button manufacturer, in training local employees in the techniques of button manufacture. Initially, the company faced no difficulties in the provision of raw materials, until other factories were being established.

MSP was established in 1983 with the participation of the Government of Vanuatu, the Development Bank of Vanuatu and Ets. F. Mercier, France. Presently, MSP is 65 per cent owned by the Development Bank of Vanuatu, 34 per cent by Ets. F. Mercier, and 1 per cent by Mr Jimmy Simon, a Vanuatu national. MSP provides present permanent employment for 17 Ni-Vanuatu persons. In 1990, MSP expanded its operations to Luganville on the island of Espiritu Santo.

As one of the leading factories in the South Pacific region with trained and skilled personnel, MSP sent two of its workers abroad to give training to Solomon Islanders in 1989. It has also used its workers abroad as resource persons at shell processing seminars in Papua New Guinea, Solomon Islands and Palau. The company has also sent workers abroad with the help of the Government of Vanuatu to attend training courses on management, marketing, mechanics, arts and engineering. MSP also provides on-the-job training to the company's workers.

Market and plant capacity

Demand

Mother of pearl buttons are a high quality product and there is only a limited number of manufacturers worldwide. Demand for trochus button blanks is very high. The main buyers are big button manufacturers. The mother of pearl button has to compete with the plastic button, which is only one third of the value of the mother of pearl button.

Projected sales

MSP exports its products to France, Mauritius, Japan and South Korea. At present 80 per cent of trochus button blanks are exported to France and Mauritius. The company also exports to Japan and South Korea on a small scale. MSP's local sales are mainly decorative shells and jewellery products.

Production programme

Presently MSP produces 840,000–1,000,000 trochus button blanks per month. MSP uses 4 to 5 t of trochus shells monthly.

Plant capacity

The capacity of the present plant is 6 to 10 million button blanks per year.

Materials and inputs

Raw materials

Vanuatu trochus shells are of very good quality. In the past, most trochus shells were exported. In order to assure the regular provision of raw materials, the collection of shells has to be organised. MSP ensures that commercial shell collectors are fully briefed on the regulations governing trochus harvesting to avoid overfishing and to ensure a continued supply through recruitment. According to studies done by MSP, 100 kg of trochus shells (size 9–10 cm) yields 20,800 button blanks.

Auxiliary materials

For the decorative shells and shell jewellery the following materials are necessary: sulphuric acid, muriatic or hydrochloric acid, polishing cloth rolls, polishing paste, sandpaper belts, grinding stones and iron brushes.

Factory supplies

The factory supplies comprise packaging materials, tools, consumable tools and spare parts for the machinery. Tools and consumable tools are imported because they are not locally available. The factory has to maintain a considerable stock.

Utilities

Electricity, water and gas are locally available.

Location and site

MSP is situated on the main road between the airport and the centre of Port Vila. The building is owned by MSP and it is large enough for the present plant capacity.

Project engineering

Layout and scope of the project

From local raw materials, MSP produces button blanks, green snail cut pieces, trochus shell wastes (1st rim, 2nd rim, 1st centre, 2nd centre and blank mouths), and decorative shells and jewellery.

Technology

The technology presently used is considered appropriate. MSP technology, with the participation of Ets. F. Mercier, is now meeting European manufacturing standards.

Equipment

Present equipment consists of new and second-hand machinery. The machines are imported from Italy and South Korea. At present MSP has: 7 blank-cutting machines; 1 blank-sorting machine; 1 drying machine; 2 green snail cutting machines; 1 planing machine; 1 grinding and sandpapering machine; 1 diamond-saw machine.

Manpower

At present MSP has 17 employees: 1 manager, 1 accountant, 1 mechanic, 7 blank cutters, 3 sorters, 3 shell decorators and jewellers, 1 collector (Santo).

Problems currently faced by MSP

Presently, the MSP operation is facing difficulties. This is mainly due to the establishment of two new shell factories, Coral Shell Factory and Hong Shell Products, creating more competition in the buying of shells in the islands. This has led to the following problems:

- a decline in the local supply of trochus shells and illegal smuggling of trochus shells out of the country;
- the imposed quota of 70 t by the Fisheries Department being exceeded;
- some local businessmen storing trochus shells do not wish to sell to the factories, demanding a higher price per kg of trochus shells.

Recommendations

To safeguard the existing well-established MSP factory the following measures are recommended:

- the establishment of any new shell processing factories should be avoided;
- information must be given to every Ni-Vanuatu citizen about shell types and legal shell sizes to avoid overfishing;
- restriction must be placed on Ni-Vanuatu citizens and expatriates who go to the islands and exploit these marine resources;
- an halt to the illegal smuggling of shells must be stopped so that a better estimate of the total production can be made by the Fisheries Department;
- the imposed quota of 70 t by the Fisheries Department must be respected by all the established shell factories in the country;
- all shells collected by local businessmen must be sold to the existing factories;
- a fixed price for trochus shells must be set that all existing factories must use when buying shells from the islands.

Mass seed production and restocking of trochus in Okinawa

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General introduction

Okinawa has a long history in fisheries for the trochus (*Trochus niloticus*). Transplantation of this species to Micronesia was successfully tried by Okinawan people between 1920 and 1930. As the trochus is an important material for the manufacture of shell buttons, it has been intensively exploited. The Okinawa Prefectural Government has been trying to protect and manage the resources of trochus by adopting a regulation that prohibits the catch of trochus smaller than 6 cm in shell diameter.

However, due to an increased demand for the shell in recent years, the resources have been rapidly depleted. In some areas, depletion of this shell resource has been most obviously observed by the decrease in size of the trochus landed, and under such conditions, enhancement of the trochus resource had to be carried out by artificial seed production. The Okinawa Prefectural Government commenced research on the seed production of trochus at the Yae-yama Branch of the Okinawa Prefectural Fisheries Experimental Station, Ishigaki Island, in 1987.

From 1988, the research on seed production and stock enhancement of the trochus has been taken up as a five-year project (The Development Project on the Aquaculture Techniques for Local Species) which is half subsidised by the Central Government. In this research project, the Okinawa Prefectural Fisheries Experimental Station is in charge of the biological study on trochus fishery and resources and the development of seed-stocking techniques, and the Okinawa Prefectural Sea Farming Center is in charge of the development of seed production and intermediate culture techniques.

From the research work, it has become possible to produce up to one million trochus seed of 2–3 mm in shell diameter. More research is required to establish more efficient and labour-saving production techniques, although the necessary number of trochus seed could be produced with the present level of technology if facilities were available to cope with this production capacity. Experiments are in progress to establish intermediate culture techniques. In one experiment, young trochus are cultured on the surface of corrugated plastic plates placed in concrete tanks. Diatoms are grown on the surface of the plastic plates as a food source for the trochus. In the other experiment young trochus are cultured in baskets hung in the sea.

FAO started a project in the South Pacific region to enhance the resource of trochus. Trochus is an important fisheries resource for South Pacific countries, however, there is concern that these resources are being depleted. Our efforts in aquaculture research on trochus have attracted attention from FAO and they have kindly translated our reports into English. It will be gratifying if the work conducted in Okinawa can contribute to trochus aquaculture development in the South Pacific region. We would like to express our thanks to Mr Hideyuki Tanaka, Project Manager of the FAO South Pacific Aquaculture Development Project, for his efforts to produce the translation.

This report summarises the results of our research carried out until the end of 1990. The results discussed in this report are still tentative, as our research is still in progress. The results are obtained in latitudes of 24–26°N, which is somewhat further north than the countries concerned. Therefore, we are concerned that these results may not be directly applicable under the conditions prevailing in the South Pacific region. We hope, however, that this report will be of some help to the development of aquaculture of the trochus and other gastropods in the region.

Study on release of trochus seed

Introduction

The Okinawa Prefectural Fisheries Experimental Station has carried out the experimental release of trochus seed, using seed produced by the Okinawa Prefectural Sea Farming Center. The Station monitored the released seed, surveyed to select the optimum seed-release site, and carried out an ecological survey to maximise the survival rate of the released seed and related fisheries biological surveys.

Trochus catches

Figure 1 shows the trochus catches in Ihe-ya Village and On-na Village between 1982 and 1989. The trochus catches declined after the highest catch in 1983 of 8 t, valued at ¥ 4.8 million, in Onna Village, and after the highest catch in 1984 of 10 t, valued at ¥ 3.8 million, for Iheya Village. The price of trochus meat in Onna Village fluctuated monthly from 2,000–7,200 ¥/kg as shown in Figure 2. The price was lowest in May and June and highest in December. The price of raw shell was lower in Ihe-ya village than in Onna Village as shown in Figure 3, due to the longer distance and thus higher transportation costs to the place of processing. Figure 4 shows the shell-diameter distributions of trochus landed from four locations in Okinawa.

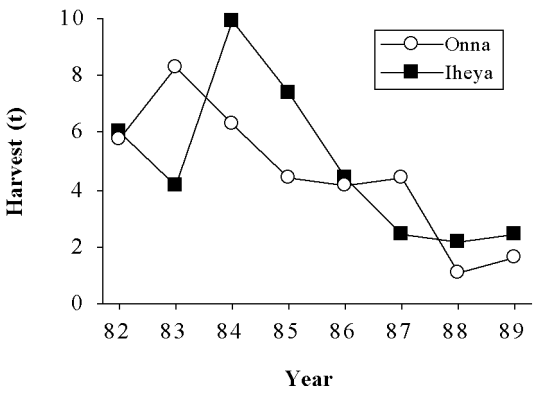


Figure 1

Amount of raw trochus shell landed in Onna and Iheya villages, 1982–1989

Ecological study of trochus

Training of fishermen in trochus resource management

Groups of young fishermen belonging to the Fisheries Cooperatives of Onna Village and Iheya Village were trained by staff of the Station in a method to establish closed areas for trochus fisheries, marking methods for young and adult trochus, methods to trace the released trochus, and methods of ecological survey. The ecological survey included the identification of predators by observing the shells of dead trochus eaten by predators, as well as observations of the habitat and distribution of larval, young and adult shells. Young fishermen also realised the importance of resource management through this training, and with their cooperation the closed areas (sanctuaries) were extended. Young trochus were transplanted from shallow places into the closed area to avoid collection by shore strollers and leisure divers.

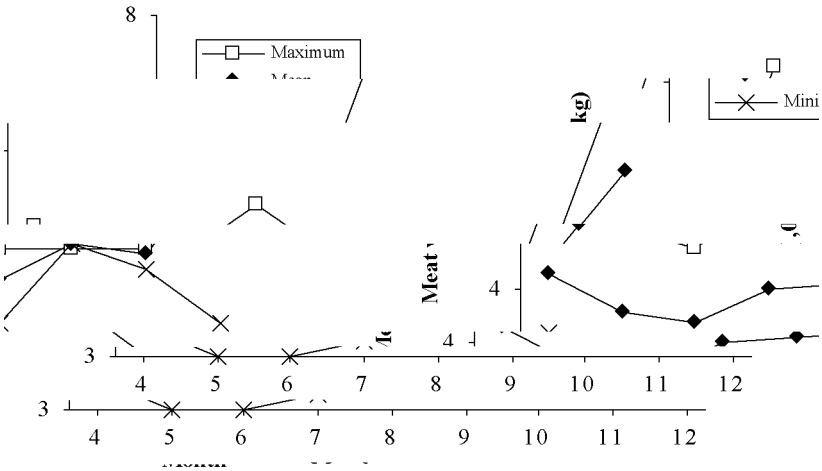


Figure 2

Price of trochus meat by month in Onna village

Survey on habitat of trochus

Collections of veliger larvae were carried out in an attempt to find the settling-out habitats of trochus larvae. However, as most of the veliger larvae collected were similar to each other in morphological characteristics, it was not possible to separate the veliger of trochus from those of other species.

Some young trochus (48 mm in average shell diameter) were found at the edge of coral reefs which are out of the water at low tide. However, it was not possible to draw conclusions on the habitat of young shells due to insufficient data.

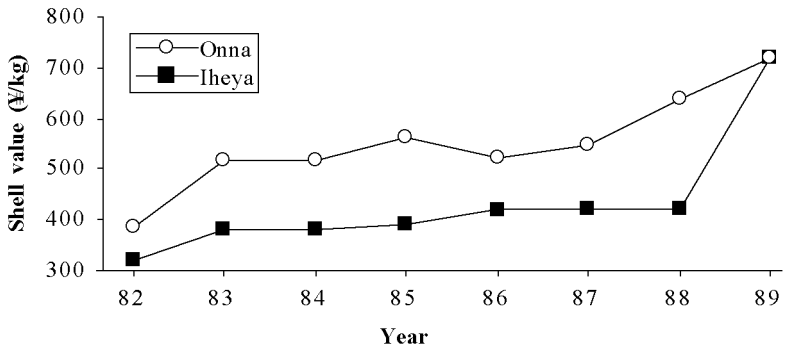


Figure 3

Value of raw trochus shell in Onna and Iheya villages, 1982–1989

In adult trochus habitat the algal community was dominated by brown algaes *Pocockiella variegata* and *Spathoglossum pacificum* which comprised 42 per cent and 18 per cent by weight respectively of the algae in the area. However, *S. pacificum* comprised 42 per cent and *P. variegata* 30 per cent of the weight of all the algal material observed in the alimentary canal of the trochus. The mature trochus (> 8 cm shell diameter) were observed to consume three times as much food as the immature trochus (< 8 cm shell diameter).

Survey on spawning season and spawning cycle

The gonads of trochus were examined throughout the year. Records were made of the histological features of the gonad, the ratio between cross section areas of the gonad and hepatic gland, and the egg diameter distributions of 640 trochus (Fig. 5). Eggs were separated individually by ultra-sonic treatment and randomly sampled for measurement of egg diameters under a microscope projector.

From June to August, 95 per cent of the observed eggs were fully mature, being 180–240 μ in diameter. The number of fully-matured eggs was highest in June. In April and May, about 20 per cent of eggs were immature and there was no mode of mature eggs. Eggs in these months seemed to be oocytes formed prior to the spawning season. In October and in March, some eggs were mature. However, a mode was observed at around 60 μ egg diameter. Therefore, gonads seem to be in a preparatory stage for the maturation in March and a shrinking stage after the maturation in October. In January and February, almost all eggs were immature. From the histological observations and changes in egg diameter distribution, the process of sexual maturation of the trochus can be summarised as follows:

- November – February: Resting stage
- March: Preparatory stage
- April – May: Beginning of spawning
- June – September: Peak of spawning
- October: Shrinking stage

Predators of released trochus juveniles

An experiment was carried out with 18 carnivorous animals to find out which species prey on young trochus. One to five individuals of each predatory species were placed in an aquarium together with five trochus of 6–8 mm in shell diameter. Whenever the trochus were eaten by the predators, new trochus were placed in the aquarium to replace the eaten ones. The 18 carnivorous animals are listed as follows:

Crustaceans:

- *Calcinus latens* Hermit crab
- *Pilumnus vespertilio* Crab
- *Thalamita danae* Swimming crab
- *Callapa hepatica* Calappa crab
- *Eriphia scabricula* Crab
- *Gonodactylus chiragura* Mantis shrimp

Gastropods:

- *Gutturnium muriciunum* Short-neck triton
- *Nassa serta* Francolina jopas
- *Mancinella tuberosa* Tuberose rock shell
- *Mancinella hippocastanum* Chestnut rock shell
- *Thais muricina* Prickly rock shell
- *Morula musiva* Rock shell
- *Morula spinosa* Spiny rock shell
- *Dorioconus textile* Textile cone
- *Dorioconus magnificus* Feathered cone

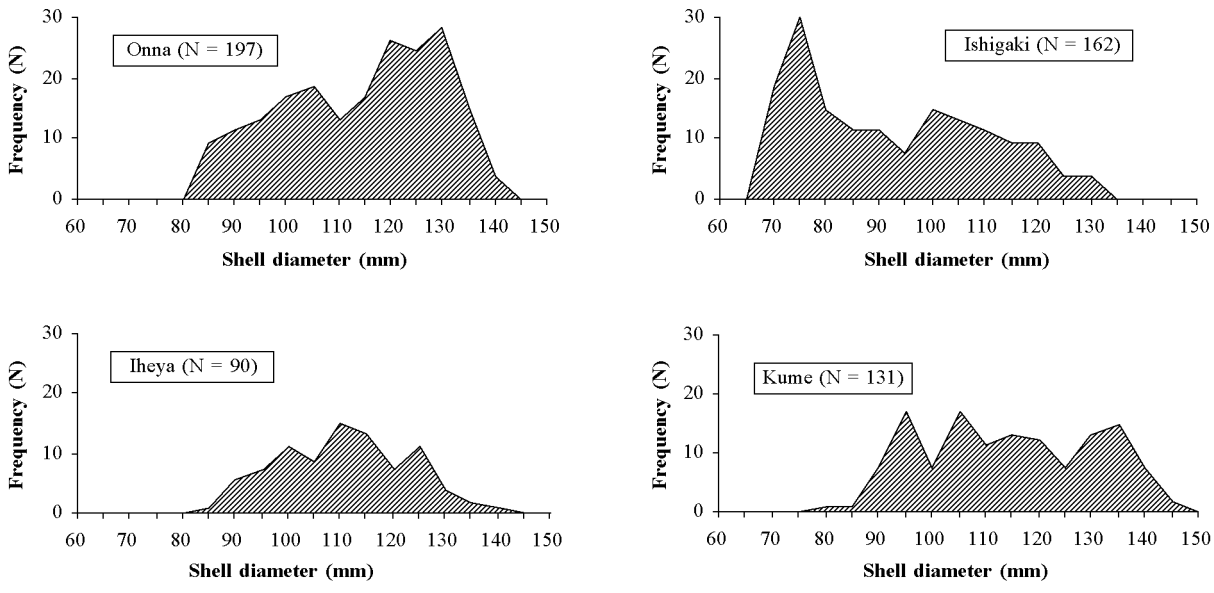


Figure 4

Shell diameter distribution in Onna, Ishigaki and Iheya villages, and Kume island

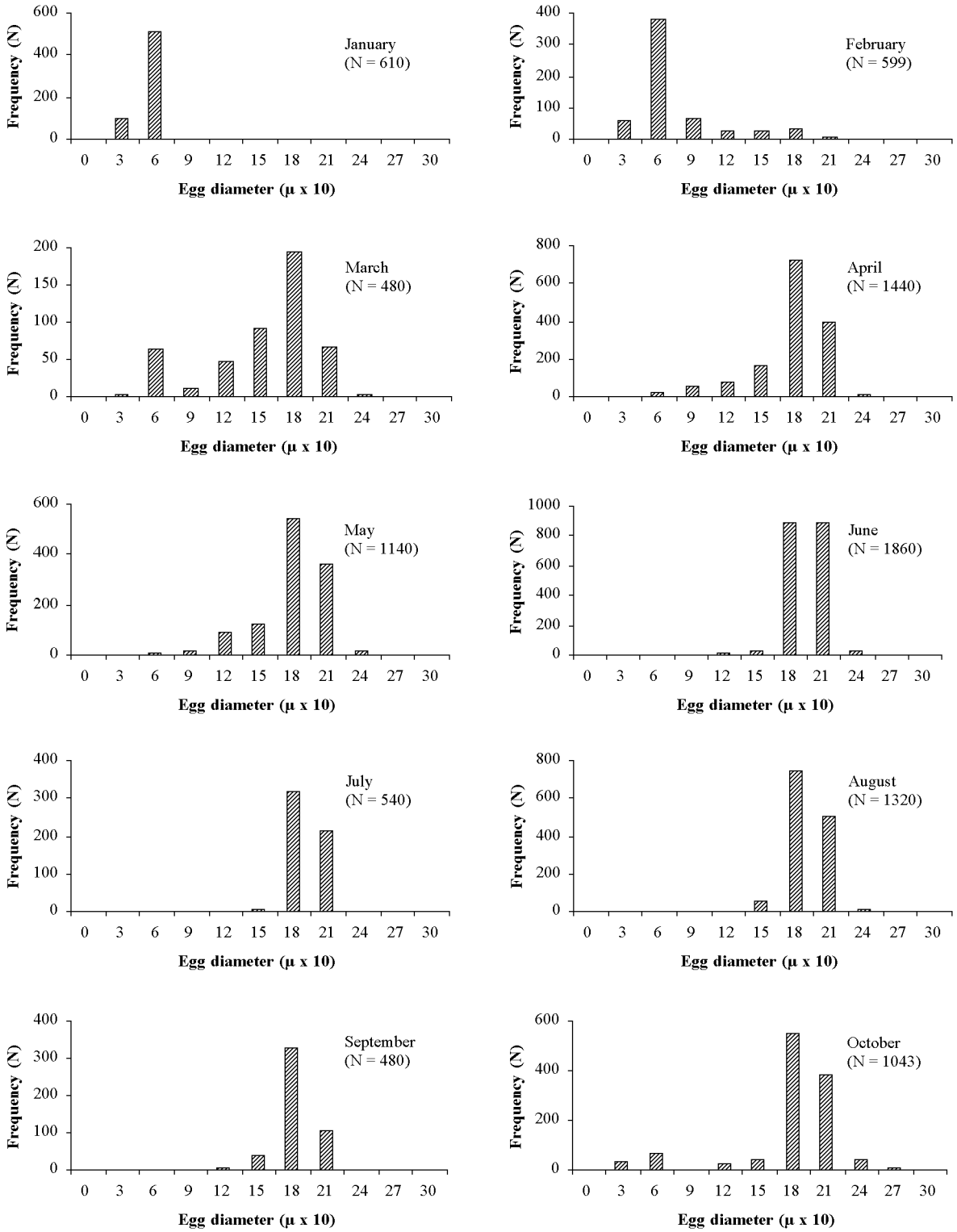


Figure 5

Trochus egg-diameter distribution, by month

Platyhelminthes:

- *Pericelis byerleyana* Flatworm
- *Planocera reticulata* Flatworm

Fish:

- *Diodon holocanthus* Porcupine fish

Table 1 shows the results obtained. Porcupine fish, *Diodon holocanthus*, consumed the largest number of young trochus in the experiment. However, as porcupine fish are not abundant in the trochus habitat, this fish may not play an important role as a predator on the young trochus in the sea. The flatworm, *Planocera reticulata*, was observed to attack the trochus at night. The flatworm is found under stones in the intertidal zone, and it may move actively at night to feed on small gastropods. The mantis shrimp, *Gonodactylus chiragura*, has a hard projection at the carpopodite of the raptorial leg, and can eat gastropods by breaking the shell using this projection. This aggressive animal, whilst in the aquarium during the experiment, sometimes broke the thermometer or hit the fingers of the researchers using this projection. In the tidal zone, it lives in holes in limestone around which scattered fragments of shell were observed, indicating that this animal is a frequent predator on young trochus. The crab *Pilumnus vespertilio* is a sluggish animal, and it could eat only a small number of trochus in the experiment as crabs could not climb the wall of the aquarium to where trochus were attached. However, there were observations in which they attacked gastropods in the sea. As they were found abundantly in the intertidal zone, they may be a major predator on the young trochus.

In the case of calappa crab, *Calappa hepatica*, only small individuals (13 mm in carapace width) ate the young trochus, while an adult callapa crab (33.5 mm in carapace width) did not consume any in the experiment. This crab thrusts its chelae into the mouth of the trochus shell in order to eat the meat, and therefore, adult crab with large chelae could not eat young trochus with small shell mouths. Since calappa crabs usually inhabit tidal pools with sandy bottoms where the trochus are rarely found, they may not be a significant predator of the young trochus.

Further experiments were carried out on the prey-size selectivity of the top five predators. Two groups of the trochus with average shell diameters of 10 mm and 17 mm respectively were used in the experiment. Five individuals from each group were placed in an aquarium of dimensions 18 x 30 x 14 cm, together with each predator animal and supplied with running water. The number of predator animals placed in each aquarium is shown in Table 2 (see next page). The number of trochus eaten by the predators was counted daily and any individuals consumed were replaced by the same number of live trochus.

The results of the experiment, shown in Table 2, indicate an interesting food-size selectivity by the predators. The mantis shrimp, *Gonodactylus chiragura*, ate about 15 times as many 10 mm trochus as 17 mm trochus. Crabs also demonstrated a higher taste for 10 mm trochus than for 17 mm trochus. By contrast, the tuberose rock shell, *Mancinella tuberosa*, ate twice as many 17 mm trochus as 10 mm trochus. It was concluded that the minimum releasing size of the trochus should be at least 17 mm to avoid excessive predator mortality.

Results of the experimental release of trochus seed

In 1989, seed trochus were released inside squares of 10 m x 10 m, fixed on the sea bed. Two methods of release were tried: direct release, and the release of trochus together with the substrata on which they were attached. Dead coral, shells of the giant clam and rocks were used as the substrata. Trochus were marked with colored glue before being released. Mortality (mortality plus the loss from the experimental site) rate and movement of the released trochus were studied by periodically counting the number of released seed. The experimental sites were situated at Miyuki Beach in Onna Village and Mabuni in Itoman City. The three sites at Miyuki Beach, called Sites 02 and 03, were situated on the coral reef, which extends about 130 m from the shore line to the sea. The average biomass (wet weight) of large seaweed in this area was 204 g/m^2, indicating that the productivity of the area was rather high.

The experimental site at Mabuni, called Site M, is situated on a coral reef area in which the red alga *Gelidiella*

Table 1: Number of young trochus eaten per day by predators in the laboratory experiment

Predator	Size of predator (mm)	Period of experiment (days)	Volume of aquarium filter (litre)	No. of trochus given per day	Size of trochus (mm)	No. of trochus eaten per day
Diodon holocanthus	210	3	500	10	16	10
Planocera reticulata	30	26	1	5	7	1.04
Callapa hepatica	33	21	1	5	7	0.89
Gonodactylus chiragura	36	26	1	5	7	0.54
Gonodactylus chiragura	69	26	1	5	7	0.73
Pilumnus vespertilio	31	26	1	5	7	0.31

acerosa formed dense colonies. Trochus of two different size groups were used in this experiment. The average shell diameter of one group was 8 mm and that of the other was 16 mm. It was expected before the experiment that the survival rate of the released trochus would be higher for larger individuals. However, as shown in Figure 6, the survival rate at Site M where 16 mm trochus were released was almost the same as the survival rates for Sites 01 and 03 where 8 mm trochus were released. It was concluded that survival rate is not related to size for trochus ranging between 8 and 16 mm. It is expected that the survival rate will be significantly raised by releasing trochus larger than 30 mm in shell diameter.

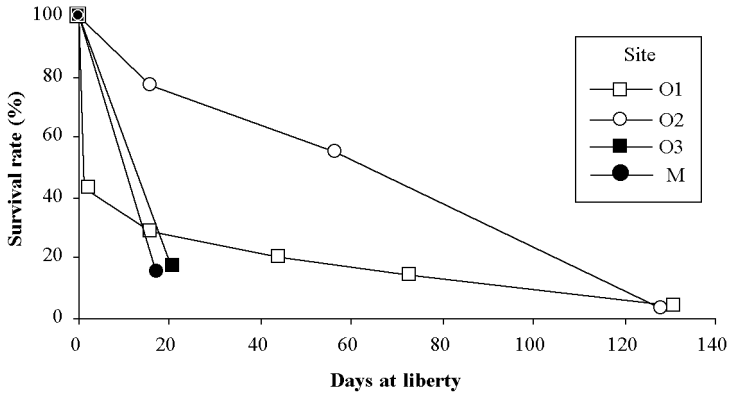


Figure 6

Survival rate of trochus seed released at Miyuki beach (Sites 01, 02 and 03) and Mabuni Beach (Site M)

All sites were situated in the tidal range between a high level of +106.5 cm and extreme low-water level at spring tide of –42.2 cm. This range is the natural habitat of young trochus and in this experiment, the position of the site on the tidal level showed no relationship to the survival rate of the released trochus. If, however, trochus are released at levels outside of this range, there may be some relationship between the position of release and the survival rate.

Table 2: Common predators and rate of predation in the laboratory experiment

Trochus size: 17.3 ± 0.8 mm

Predator	Size of predator (mm)	Period of experiment (days)	No. of predators	Total no. of trochus eaten	Rate of predation
Gonodactylus chiragura	TL 57.1	34	1	5	0.147
	TL 39.0	34	1	5	0.097
Thalamia danae	CL 36.3	31	1	3	0.097
Pulumnus vespertilio	CL 26.1	31	2	1	0.015
	CL 16.6	31	3	0	0.000
Mancinella tuberosa	SH 41.6	34	4	21	0.155
Planocera reticulata	TL 72.6	19	1	22	1.158
	TL 50.6	19	1	8	0.421

Trochus size: 9.6 ± 1.1 mm

Predator	Size of predator (mm)	Period of experiment (days)	No. of predators	Total no. of trochus eaten	Rate of predation
Gonodactylus chiragura	TL 57.1	34	1	55	1.618
	TL 39.0	34	1	36	1.059
Thalamia danae	CL 36.3	31	1	27	0.871
Pulumnus vespertilio	CL 26.1	31	2	37	0.597
	CL 16.6	31	3	0	0.000
Mancinella tuberosa	SH 41.6	34	4	9	0.066
Planocera reticulata	TL 72.6	19	1	22	1.158
	TL 50.6	19	1	4	0.211

An accurate assessment of the density of the predatory animals such as mantis shrimp *Gonodactylus chiragura* and crab *Pilumnus danae* which inhabit cracks and holes in the coral reef was difficult. To identify predatory animals and estimate the extent of mortality of released trochus caused by predation, all dead trochus were collected from the experimental sites and were compared with those obtained from the laboratory experiments mentioned earlier. The types of shell breakage were classified into nine categories as shown in Figure 7. Seven types of shell breakage were caused by the five predatory animals as indicated by the laboratory experiments, and two types of shell breakage caused by the two carnivorous gastropods which were found from field observations.

Figure 8 shows the frequency of shell-breakage types caused by each predatory animal observed in the laboratory experiments. The mantis shrimp breaks the shell by a strong blow to the body whorl of the shell, causing a longitudinal breakage of the shell. Only mantis shrimp can cause the shell fracture pattern of type 5. Crabs use their chelae to break the shell opening or to break the apex of the shell. Shell breakage of types 1-2C were caused only by the crabs. The porcupine fish crush the shell into small fragments with their fused, beak-like teeth. In many cases, shells broken by porcupine fish are difficult to separate from those badly broken by the mantis shrimp or the crab. The swiftest predation rate was observed for the porcupine fish. In the laboratory experiments, a hungry porcupine fish may consume up to five young trochus within a period of ten minutes.

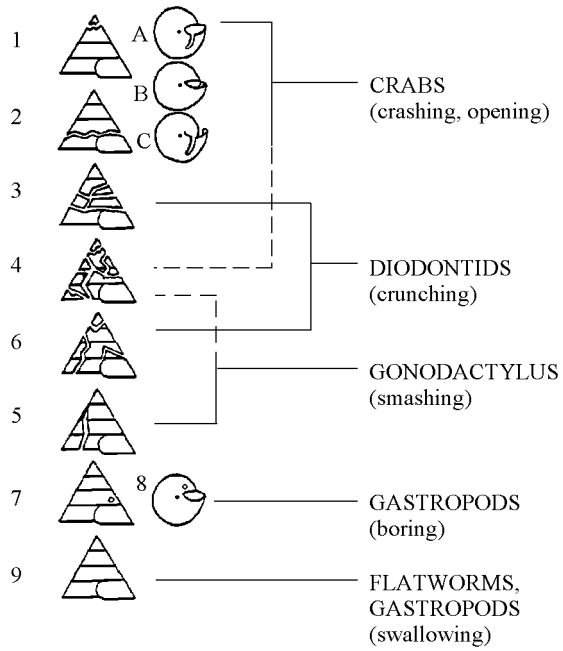


Figure 7

Patterns of trochus shell breakage by predators

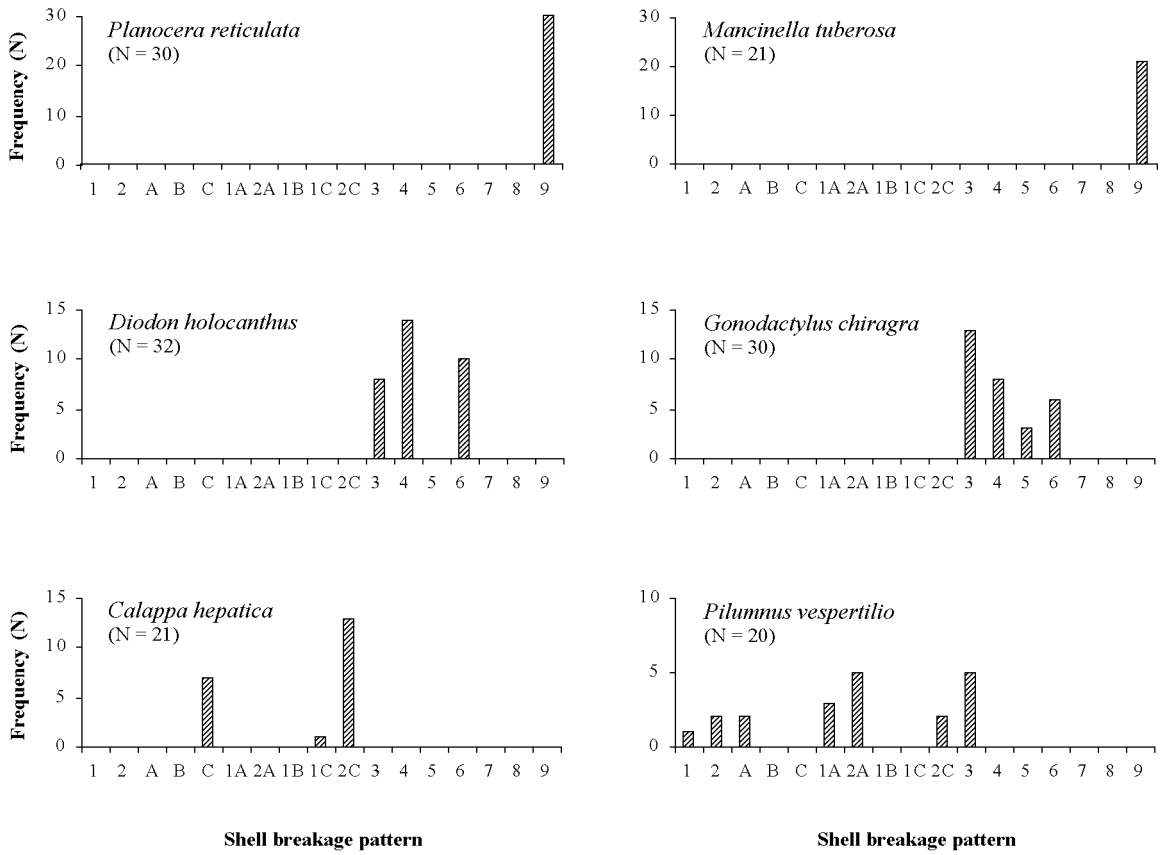


Figure 8

Distribution of trochus shell breakage pattern observed during the laboratory experiments

Figure 9 shows the frequency distribution of shell breakage types obtained for each site. The amount of dead shell was highest at Site M where trochus of 16 mm in shell diameter were released. The main cause of the mortality was thought to be predation. The most commonly occuring shell fracture at Site M was of type 9 followed in order by types 4, 3, 1-2C, 6, 7, 8, and 5.

Type 9 was caused by flatworm predation or by natural mortality. Type 1-2C were caused by crabs and their frequencies were almost twice as high as that of type 5 which was caused by mantis shrimp. The cause of shell breakage of types 4 and 3 have not been identified. Types 7 and 8 were caused by muricid shells. During the field experiment, attacks on young trochus by the muricid shell *Morulina granulata* were often observed.

Although the size of the released trochus at Site 02 was the same as that at Site M, the survival rate of the released trochus at Site 02 was much higher. An estimated 0.7 trochus per day were eaten by predators which was less than 10 per cent of that observed at Site M. The pattern of the frequency distribution of shell breakage types at Site 02 was similar to that at Site M with type 9 fractures having the highest frequency and type 1-2C frequencies being twice as common as type 5.

The pattern of the frequency distributions of shell fracture types was quite different at Sites 01 and 03 from those at Sites 02 and M. The highest observed frequencies were for type 5 fractures, followed by type 1-2C at Sites 01 and 03.

This might indicate that trochus of 8 mm in shell diameter were too small as a prey item for crabs. The results obtained in the laboratory experiments mentioned earlier supported this hypothesis. The mantis shrimp seemed to prey selectively on smaller trochus.

The result of the present experiment suggests that 8 mm trochus are most prone to predation by the mantis shrimp and 16 mm trochus by the crabs.

The reason for the large difference in the mortality rates between Site M and Site 02 was the difference in the condition of the sites during low tide. The area which included Site M became a tide pool 25 cm deep. This tide pool attracted many predatory fishes and crustaceans, particularly on cold nights during winter.

On the contrary, Site 02 was completely exposed to the air at low tide and not many aquatic predators could remain at this location under these conditions. The mantis shrimp forms a territory around its habitat and, if another mantis shrimp invades this territory, the larger one preys on the smaller one as observed in the laboratory experiment.

Therefore, the mantis shrimp does not move far from the tide pool, thus making the tidal pool habitat more dangerous for the release of trochus. It was concluded that trochus should not be released in an area where deep and wide tide pools are formed at low tide, since such areas tend to attract and concentrate many predators.

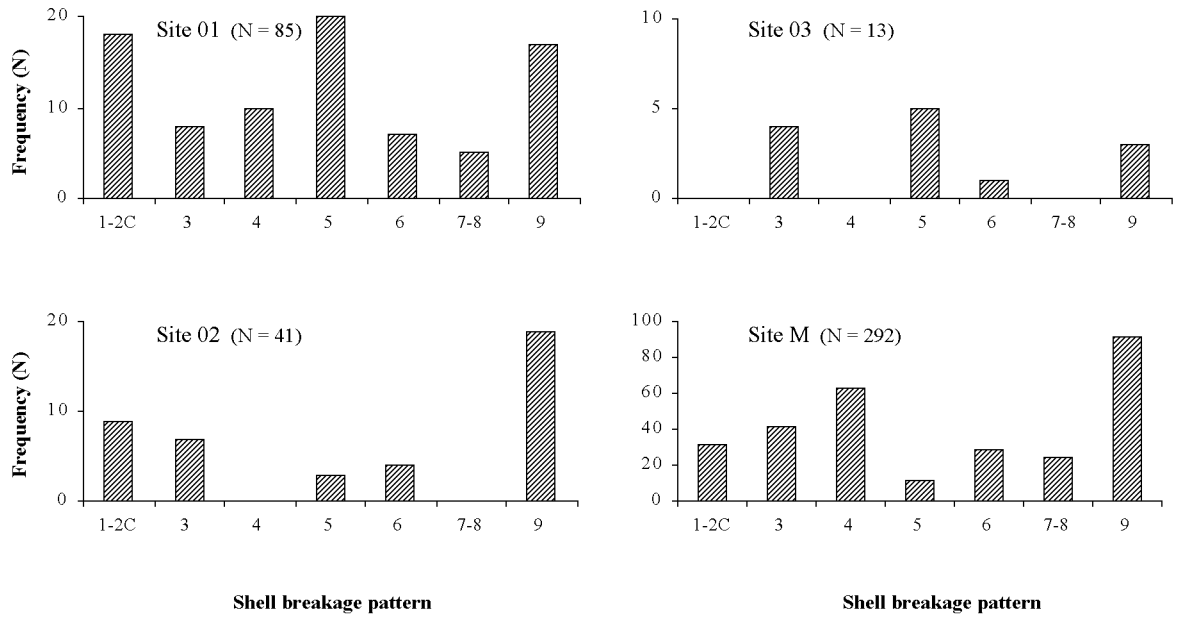


Figure 9

Distribution of shell breakage pattern in relation to the release site

Miyuki Beach is situated at the fringe of the coral reef and faces north to the open sea. At Site 01, the sea condition became rough 18 hours after the trochus were released and the northerly wind speed reached 10 m/s twenty-four hours after the seeds were released (Fig. 10).

Shortly after the rough weather, the released trochus were observed only at the centre of the Site 01 (see Fig. 11 on next page). The survival rate of trochus dropped to 40 per cent at this stage. These trochus which were grown under artificial conditions had poor adherence to the substrata under natural conditions and many trochus were removed by the turbulent seas and presumably suffered high mortality.

The released trochus dispersed gradually in the direction of the prevailing wave action following the rough weather (Figs. 11 and 12). This may indicate that released trochus gradually acclimatised to natural conditions and became more resistant to wave action.

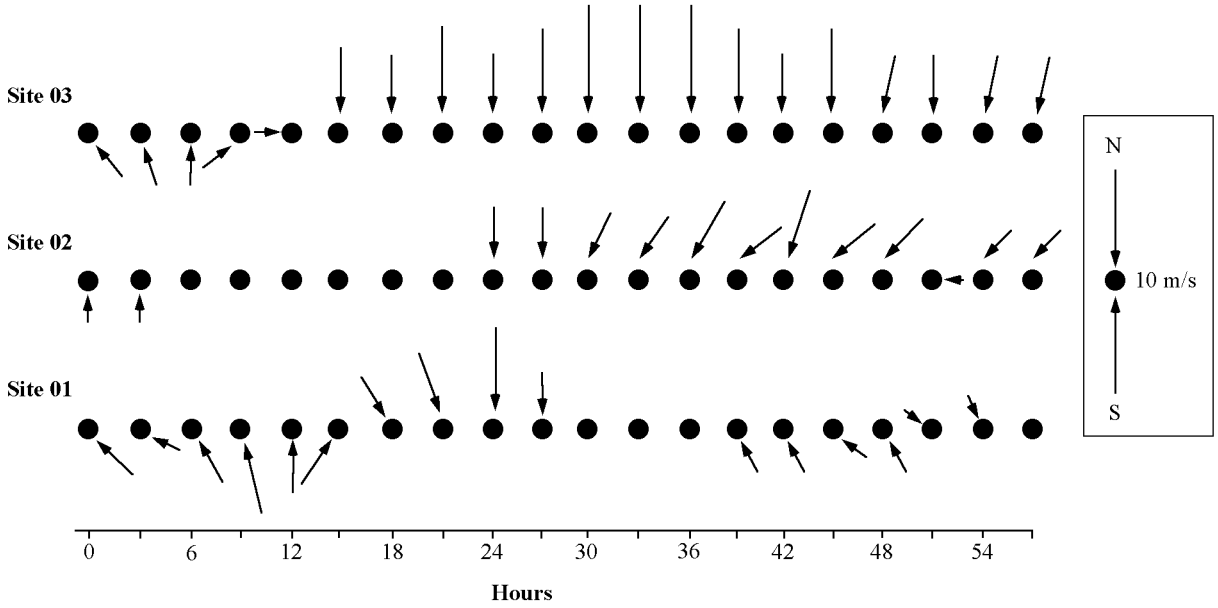


Figure 10

Direction and speed of wind after the release of trochus seed at Sites 01, 02 and 03 (according to the observation of Nago Meteorological Station)

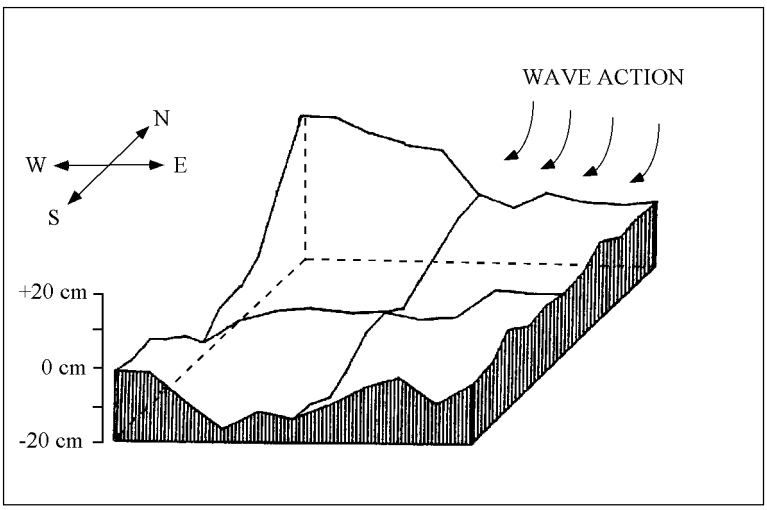


Figure 12

Topography and direction of wave action at Site 01

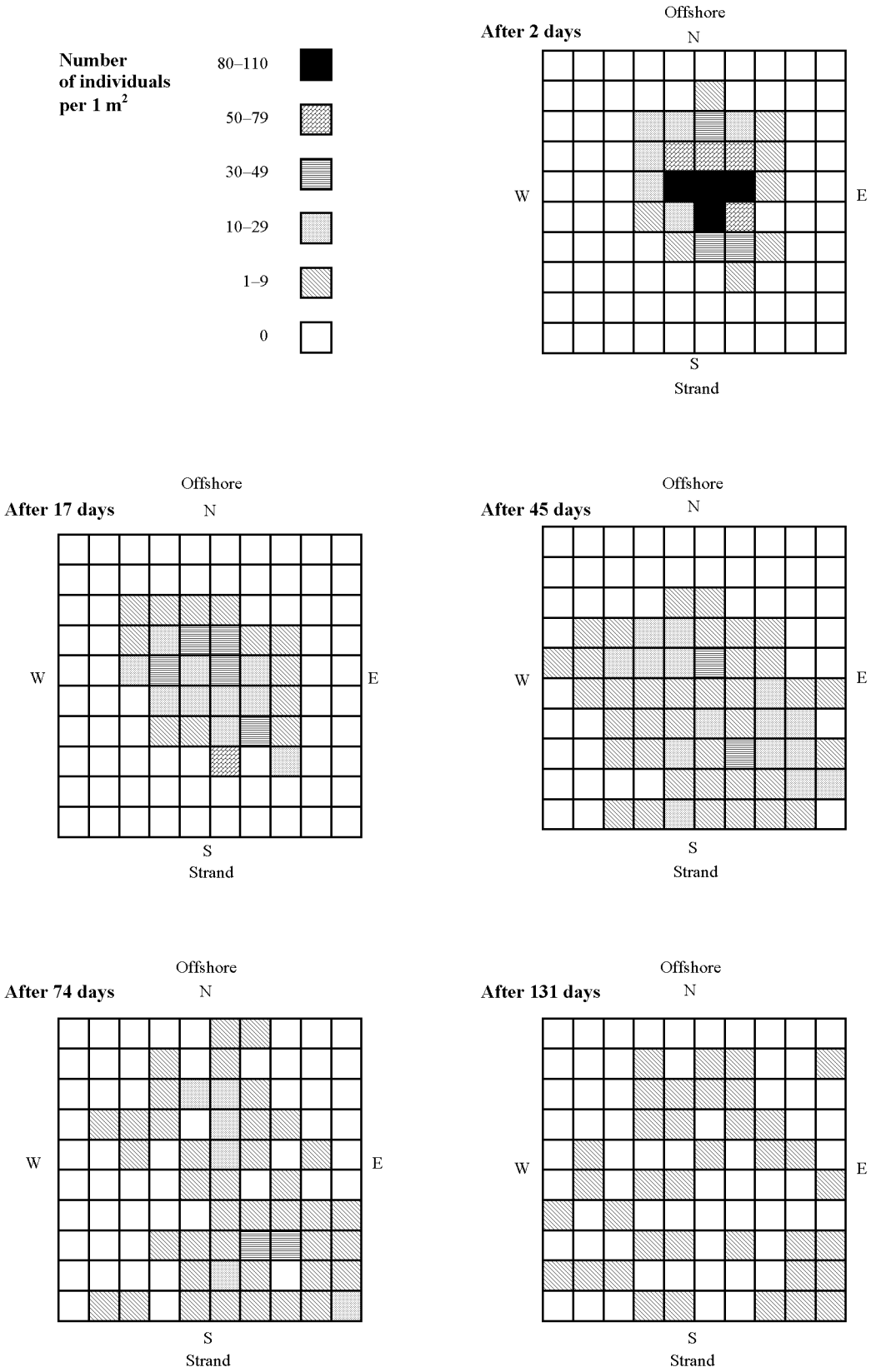


Figure 11

Dispersion of released trochus at Site 01 (one square indicates 1 m²)

Tables 3 and 4 show the results of the observations carried out both in the laboratory and in the field on the behaviour in recovering from the inverted position to the normal upright position, of young trochus.

In laboratory observations, 25 out of 40 trochus (62.5%) reared under artificial conditions could not restore themselves to an upright position even after 30 minutes. They extended their foot, but even when the foot touched something, it did not attach and maintain a grip.

In the field observations, 12 released trochus which had spent 8 days under natural sea conditions were removed from the substrata and placed upside-down. All of them, except two individuals which were lost, recovered their normal body posture within 5 minutes. The longest distance these individuals were transported by wave action from where they were first inverted to the point where a normal body posture was attained was 1.7 m.

Some of them recovered quickly by making full use of the wave action. Others initially seized a stone smaller than their body size and then fell into a hole, thus recovering an upright position.

Once the released trochus had acquired an ability to recover their body posture, the mortality rate decreased. From these observations, it was concluded that the pattern of dispersion of released trochus is strongly determined by wave action and sea-bed topography.

Table 3: Time taken by hatchery-produced juvenile trochus to recover from upside-down to normal position

Recovery time (minutes)	No. of trochus	Cumulative number
0–5	0	0
5–10	1	1
10–15	6	7
15–20	8	15
20–25	9	24
25–30	1	25
30–35	4	29
35–40	2	31
40–45	0	31
45–50	1	32
50–55	4	36
55–60	1	37

Table 4: Time taken by young trochus, 8 days after release, to recover from upside-down position to normal position

No.	Recovery time (sec.)	Distance covered before recovery (m)	Pattern of recovery
1	32	0.0	by wave
2	6	0.0	by wave
3	146	1.7	by holding stone
4	23	0.4	by wave
5	64	0.3	by holding stone
6	99	0.4	by holding stone
7	94	1.1	by holding stone
8	10	0.1	by wave
9	31	0.1	by holding stone
10	279	0.8	by wave
11	lost		
12	lost		

Wave action removes trochus from the substratum and rolls it around until it settles in some depression on the sea bed. Figure 13 shows the distribution of small depressions and stones on the sea bottom at Site 01. This distribution pattern is more or less similar to the distribution pattern of trochus 45 days after release, particularly at the southern part of the site. However, the distribution pattern of the released trochus did not show any relation to the direction of wave action and bottom topography at both 74 days and 131 days after release. This suggested that the released trochus eventually acquired an ability to move around regardless of the direction of the wave action or bottom topography.

At Site 02, trochus were released along with the substrata to which they were attached. Phyllite (flat stone), dead branched coral and the shell of giant clams were used as the substrata. These substrata were expected to function as shelter for the trochus against predatory animals and to protect the trochus against wave action until they were acclimatized to the natural sea conditions. The sea was very calm for 21 hours after the release of the trochus at Site 02 (Figs. 10 and 14). Therefore, unlike the case of Site 01, the loss rate of trochus after release was not high at Site 02 and the survival rate at Site 02 was almost twice higher than at Site 01 throughout the experiment. The trochus were distributed rather uniformly at Site 02

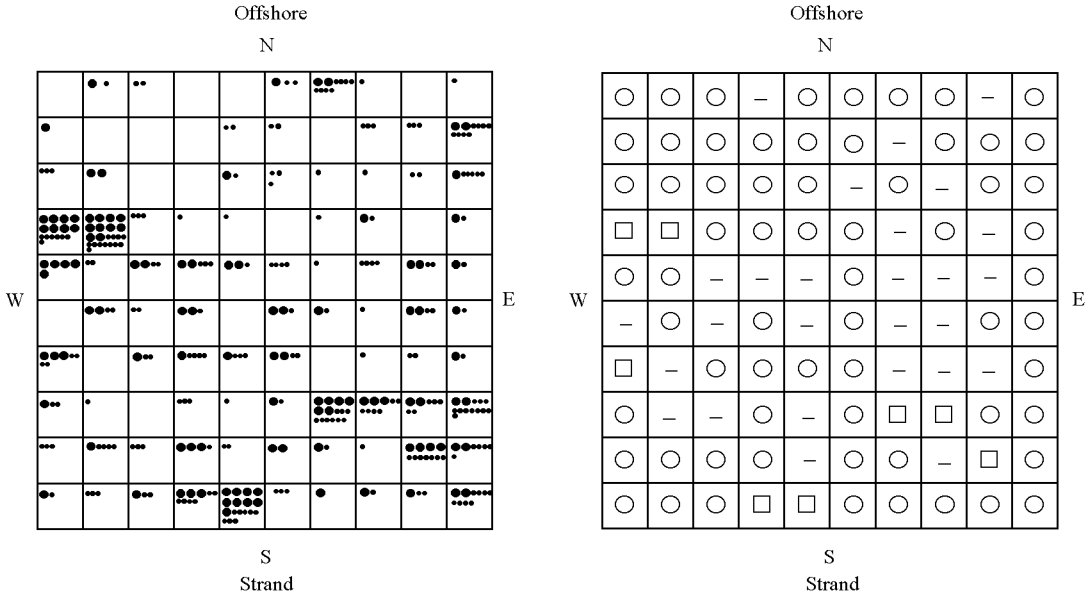


Figure 13. Distribution of stones and depressions at Site 01 (one square = 1 m²)

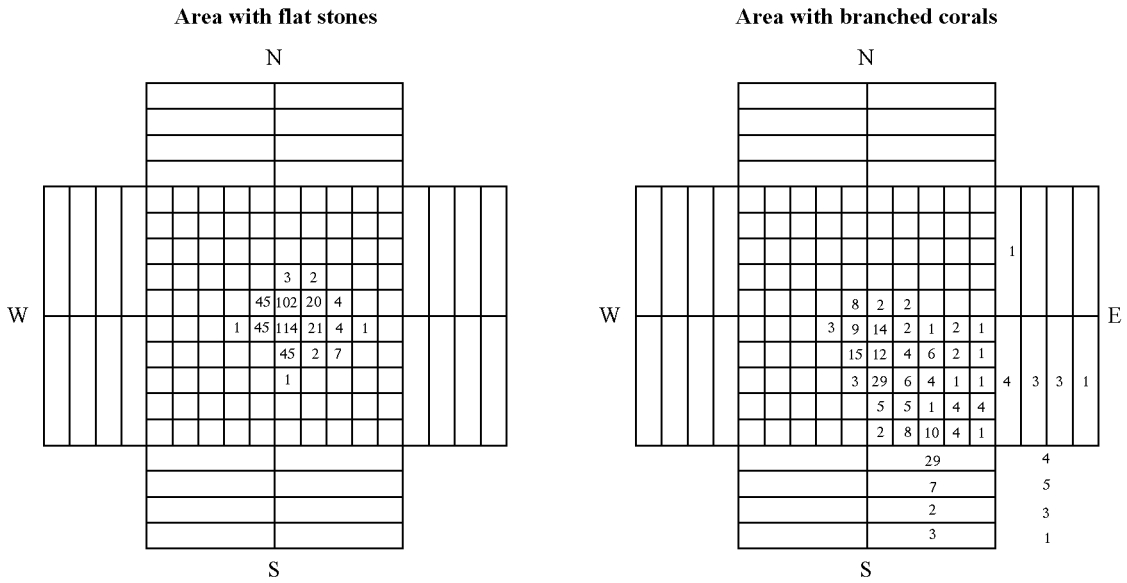


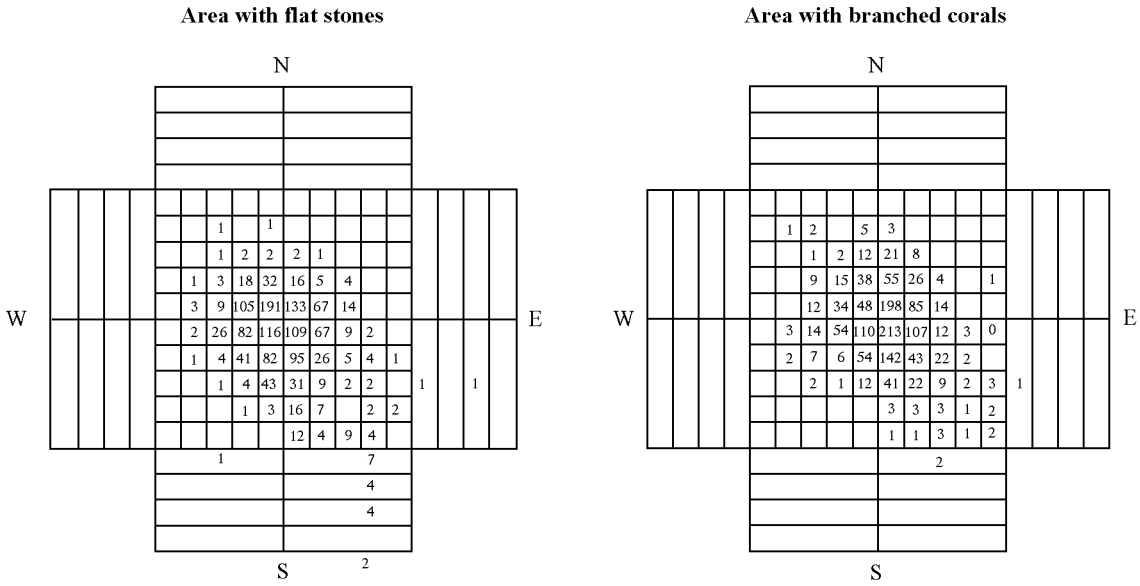
Figure 15. Distribution of trochus 19 days after the release at Site 03 (one square = 1 m²)

shortly after release (Fig. 14). The loss rate was higher for trochus attached to branched coral than for those attached to flat stones. This is because branched coral is more susceptible to wave action and is not as dense as stone.

The released trochus at Site 03 also used two kinds of substrata, branched coral and flat stone. The loss rate of the released trochus was high due to rough seas during 15 hours starting shortly after the release and a northerly wind speed of 10 m/s for 23 hours following the onset of rough seas. Branched coral with attached trochus were placed in depressions on the sea bed, while trochus attached to flat stones were placed on the surface of the reef. The loss rate of the released trochus was lower for branched coral (77.3%) than for flat stone (87.2%). However, some of the flat stones remained in the immediate proximity of Site 03, whereas none of the branched coral was found near the site (Fig. 15), suggesting that branched coral was carried far away from the site once it was removed from the shelter of a depression.

It was concluded that the time and location of trochus seed release must be chosen in relation to the weather and topographic conditions. To cope with these factors, artificial seed production and seed release should be conducted according to well-organized but flexible planning.

A few hours after release



56 days after release

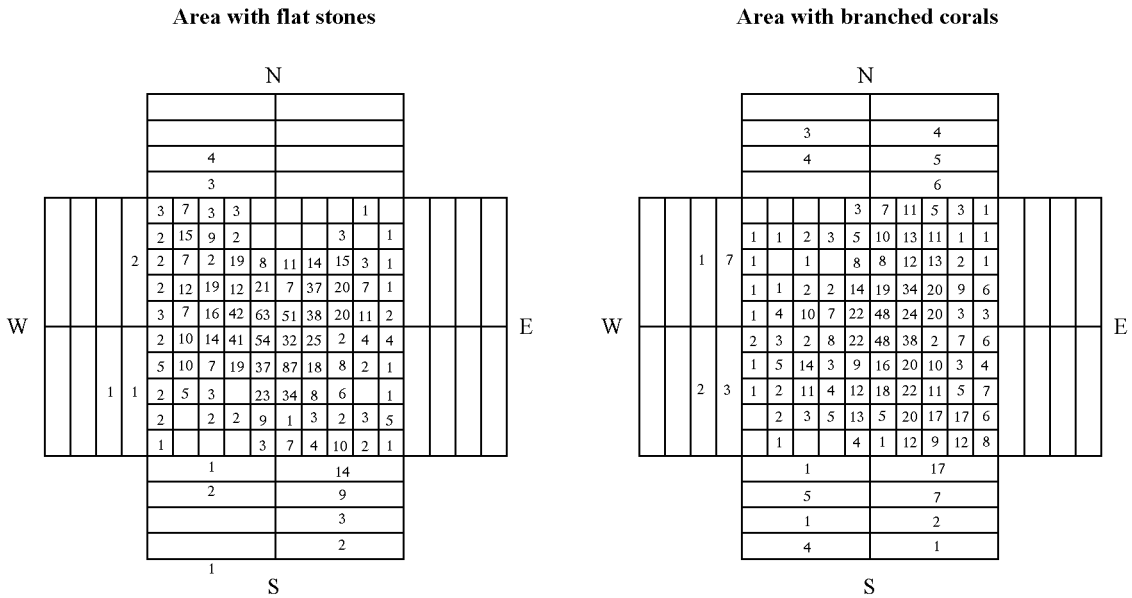


Figure 14. Dispersion of released trochus at Site 02 (one square = 1m²)

In 1990, a series of experimental seed releases were carried out to evaluate the relationship between the survival rate and condition of the bottom sediment for the released trochus. The methods of the experiment were decided as follows, based on the results obtained in 1989:

(a) Method of seed release:

Trochus seed attached to dead branched coral were released into the centre of plots which were fixed every 5 m along lines, called Dana-N, Dana-S and Gakiya, extending from the inside to the outside of the coral reef at Dana and Gakiya. Between 1,000 and 2,800 trochus seed were released in each plot.

(b) Time of seed release:

Seed was released in April and May.

(c) Nature of the experimental site substrate:

The bottom was covered with dead and live branched corals.

(d) Method to trace released trochus:

It was not possible to count all released trochus in 1990, since the number of released trochus increased from 16,800 in 1989 to 132,000 in 1990. The numbers of released trochus remaining inside the counting frame (see below) were counted to estimate the density of seeds in each plot. The total number of trochus was estimated from the estimated density of the trochus and the total distribution area of the trochus.

The sites of the experimental seed release were situated at Dana in Iheya Village and Gakiya. A counting frame was designed to count the number of released trochus. This frame was composed of 12 small quadrats of 15 cm x 15 cm each, connected in a row to form a band 2 m long. A magnetic compass was fixed to the centre of the counting frame to determine in which direction counts of the number of released trochus were to be made (Fig. 16). This frame was placed in the centre of each plot in a north-south direction and then in an east-west direction to count the number of released trochus in each small quadrat.

The first counts were made 80 days after release, as the 1989 experiments had shown that the distribution of the released trochus was almost random 74 days after release. After counting the released trochus, the substrate characteristics were recorded for each small quadrat based on 6 categories, namely:

- LC : live branched coral on rock,
- DC : thick layer of dead branched coral on rock,
- RD : thin layer of dead branched coral on rock,
- CS : dead branch coral on sedimentation of sand,
- S : sandy bottom with no coral, and
- R : rocky bottom with no coral

Table 5 shows the counts for each site categorised by substrate characteristics. At the Gakiya site, the released trochus were found to concentrate on the area covered by dead branched coral with no sand sedimentation (DC). Few released trochus were found in the areas covered with dead branched coral and sedimentary sand (CS). Many released trochus were found dead on the sand in such areas. This indicates that the trochus cannot walk on

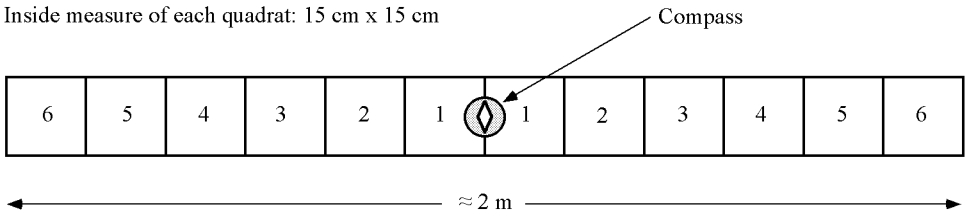


Figure 16
Counting frame used in the field survey of released trochus

Table 5: Relationship between bottom characteristics and occurence ratio of released trochus

	LC	DC	CS	R	RD	S
Gakiya	0/0	109/190	7/185	2/39	1/16	0/1
Occurence ratio (%)	-	57	4	5	6	0
Dana	35/127	22/75	9/76	3/110	1/5	0/2
Occurence ratio (%)	28	29	12	23	20	0

the sand. When trochus are removed from branched coral by wave action or some other reason and fall on a hard substratum, they can reach a branched coral and climb. However, if they fall on sand they cannot survive.

This hypothesis is supported by the fact that adult trochus and turban shells are sometimes observed dead in an inverted position on sandy areas around coral reefs. At the Dana site, the released trochus were abundant in the areas covered with live branched coral (LC) and also in the areas with dead branched coral and no sand sedimentation (DC).

Very few released trochus were found at the Dana site in the area with sedimentary sand. There are many rocky areas with no branched coral (R) at the Dana site and very few released trochus were found in such areas, indicating that branched corals are an essential factor for the habitat of trochus.

Figure 17 shows the survival rate of trochus in each plot after release. The highest survival rate of 43 per cent was recorded at plot A on the line Dana-N. Relatively high survival rates were also recorded at plots B and C on the line Dana-N. The survival rates were also high at plot A on line Dana-S and plot C on line Gakiya. Almost all released trochus died at plot D on line Dana-N and plots C and D on line Dana-S.

The majority of the areas for plot D on line Dana-N (79%) and plot D on line Dana-S (83%) contained no branched corals and this is the reason why the survival rates were low in these plots. Plots B and C on line Dana-N were dominated by areas covered with dead branched coral and sedimentary sand (CS) and were considered to be unsuitable places for the survival of released trochus. However, the survival rates recorded in these plots were relatively high as mentioned before.

It is thought that many places free of sand sedimentation were scattered in a mosaic-like pattern inside these areas due to water movement and wave action. Trochus released on such spots can survive. This suggests that the releasing sites for trochus seed should be first evaluated by a detailed examination of the substrate characteristics.

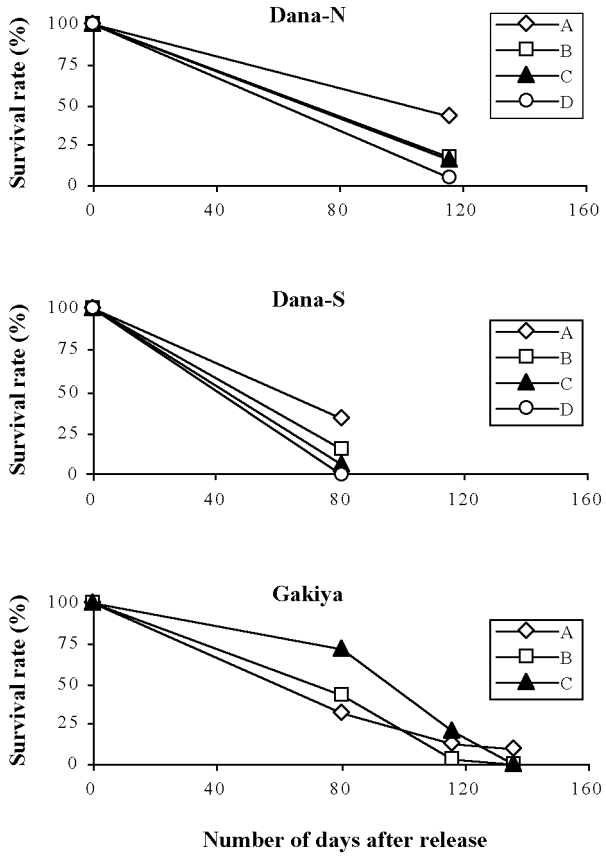


Figure 17

Survival rate of released trochus
at Dana-N line, Dana-S line and Gakiya line

Development of mass production techniques of trochus seed in Okinawa

Mass production techniques of trochus seed

Research to develop mass production techniques of trochus, *Trochus niloticus*, commenced in 1987 at the Yae-yama Branch of the Okinawa Prefectural Fisheries Experimental Station in Ishigaki Island (24° 27'N 123° 09'E). This report summarises the results obtained in the research up to the present. The seed culture techniques will be described according to the flow chart shown in Figure 18 .

Culture of attached diatoms as food for larval trochus

An artificial feed has not yet been developed for larval trochus up to 3–4 mm in shell diameter, at the stage when the larvae are first removed from the substratum. A sufficient amount of diatoms should be systematically produced, based on the trochus seed production schedule, as in the case of other gastropods' seed production. A larger number of trochus seed can be produced from a culture tank if the surface area of the substrata on which trochus attach and feed on diatoms is increased. In Okinawa, 160–400 sheets of corrugated plates, 45 x 45 cm or 105 x 33 cm in size, made of vinyl chloride, are placed in FRP water tanks of 2.75 m^3 or 4 m^3 in volume. These plates are fixed in groups of 10 or 20 on holders.

Diatoms, usually *Navicula ramosissima*, are selected as the feed algae in Okinawa (Fig. 19). Sea water for the algal culture, preferably filtered sea water, is sterilised with sodium hypochlorite and then neutralised with sodium thiosulfate. As fertilizer, 100 g of ammonium sulfate, 90 g of sodium metasilicate, 15 g of superphosphate of lime, and 15 g of Clewat-32 are used for every cubic metre of water. About a half of this amount is given at the start of the algal culture and the remainder after 2–3 weeks.

A stock of *Navicula ramosissima* is kept on an agar medium in a thermostatic room at 20 °C and is used as seed to start the culture. In mid-April, the algal culture is started in outdoor tanks. The algae is grown on corrugated plates developing a dark brown color on the surface of the plates. These plates are used to start the next culture. Algal culture tanks are covered with mosquito net of 1 mm in mesh size to keep midges out. Light intensity is adjusted by using several kinds of shading nets according to season. A shading net to reduce the light level by 85 per cent is used in spring, the rainy season and autumn, and a net resulting in a 95 per cent reduction is used in summer.

In winter, a net of 2 mm in mesh size is used to cut out 50 per cent of the light together with a mosquito net. These nets are sometimes removed to adjust light intensity depending on the weather conditions. The water is not replaced during the culture. Strong aeration seems to enhance the algal growth. However, the optimum amount of air supply has not yet been studied. One course of algal culture is completed in 5–6 weeks in spring using 85 per cent shading net. Corrugated plates covered with a growth of attached diatoms can be used to culture young trochus for up to about 2 months in summer, 2.5 months in spring and autumn and 3 months in winter. These periods, of course, change depending on the density of trochus to be cultured.

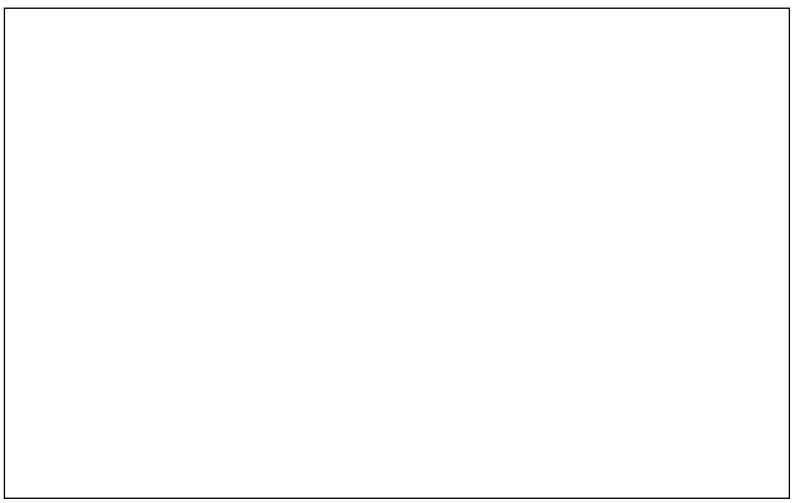


Figure 19

Attached diatoms, *Navicula ramosissima*.
Short diameter: 6.6 µ (4.5–8.3 µ); long diameter: 17.5 µ (12.5–22.3 µ)

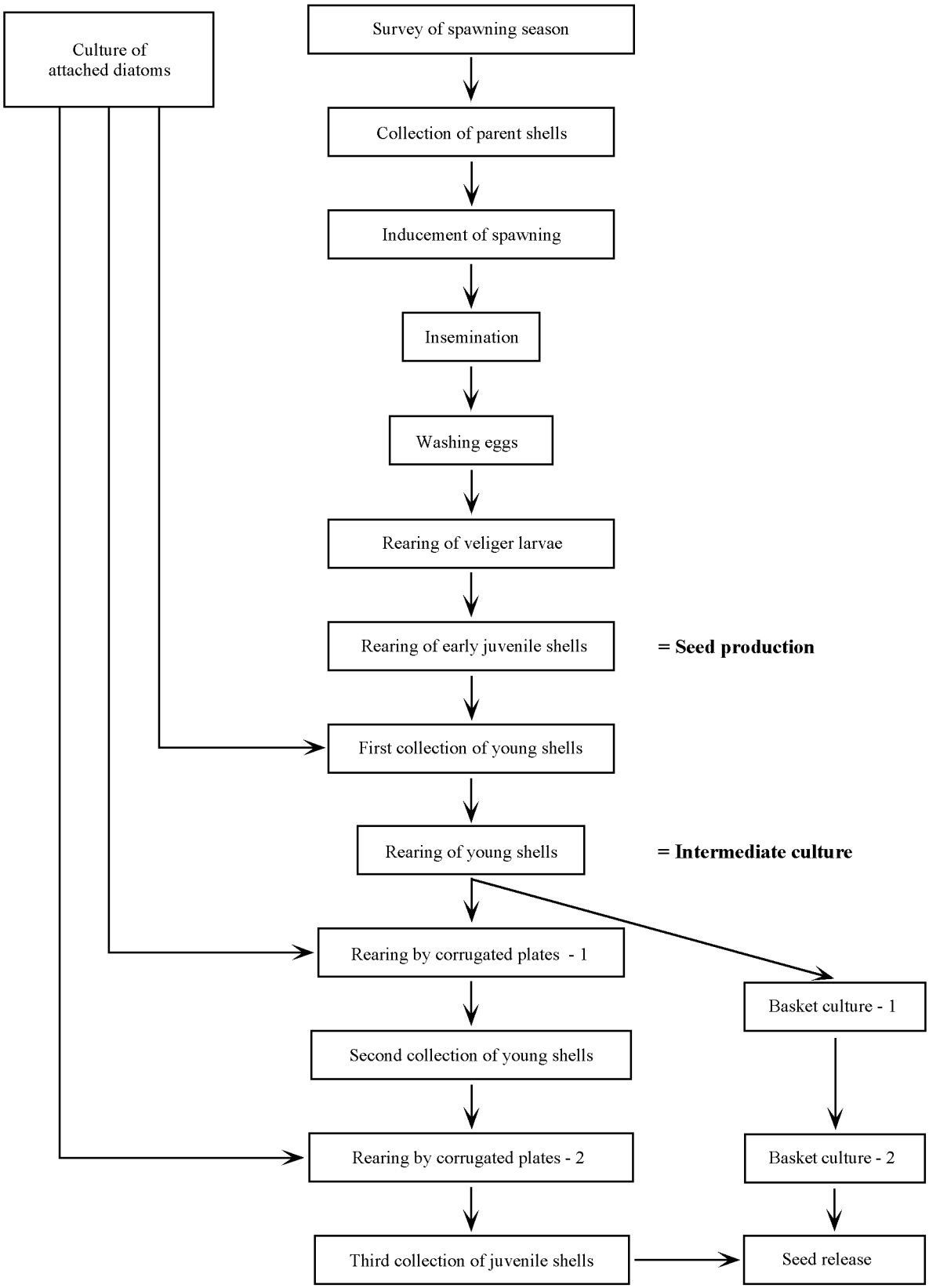


Figure 18. Process of trochus seed production in Okinawa

Spawning season

Generally, the sexual organs of both male and female trochus at Ishigaki Island increase in size from spring toward summer, remain large through the summer to early autumn, shrink in size from late autumn and are small in size over the winter. However, the percentage of sexual organ weight to total body weight differs markedly between individuals even during the summer and early autumn periods when the average percentage is highest in the year (Murakoshi et al., 1989; Figs. 20, 21 and 22). This suggests that some trochus release eggs or sperm prior to the main spawning season. Eggs can be obtained from late May to mid-October in Okinawa Island, located at 26.5°N and 128°E (Table 6). Larvae would grow faster if eggs were obtained earlier in the season, however, it is usually difficult to obtain large quantities of fully matured eggs early in the spawning season.

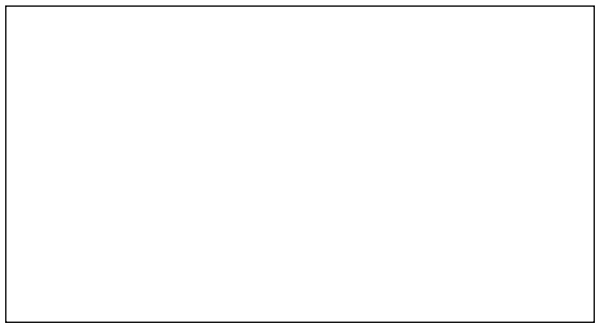


Figure 20. Shrinking stage of female trochus gonad

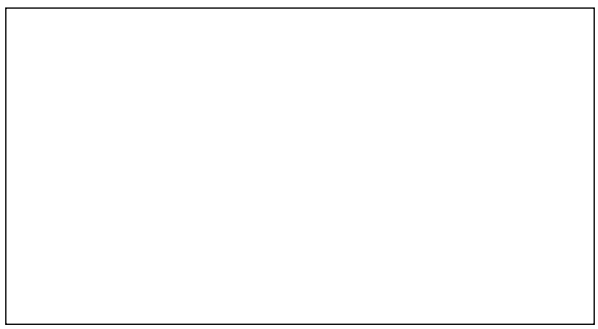


Figure 21. Development stage of female trochus gonad

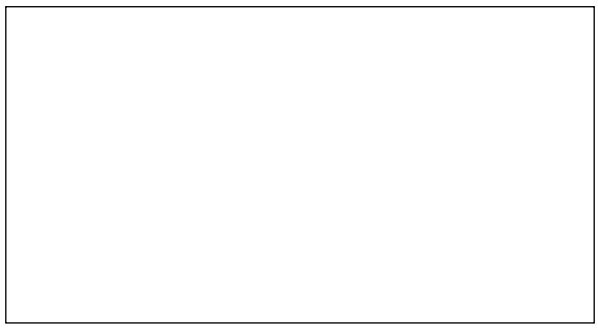


Figure 22. Full mature stage of female trochus gonad

Collection of brood stock

Mature trochus are collected for brood stock from the sea and induced to spawn in captivity as soon as possible. About 100 individuals at a time are necessary for production of 500,000 juvenile seed shells of 3–4 mm in size.

Inducement of spawning

Several artificial stimuli are known to induce spawning such as drying, temperature rise, hydrogen peroxide or a suspension of reproductive organs. In Okinawa, trochus spawn readily in sea water activated by ultra-violet (UV) rays, after the trochus have been kept in still water for a day. If the UV-ray-activated sea water does not induce spawning, the sea water temperature is raised by about 5 °C (Table 6). Fully-matured trochus might spawn without any artificial stimulation when collected and transferred to tanks. However, artificial inducement of spawning is essential for the large-scale seed production of trochus.

The practical procedures to induce trochus to spawn are mentioned as follows. The shell surface of the parent shells are cleaned, measured and are packed loosely in a strongly aerated 100 l polycarbonate water tank. They are kept there for 24–26 hours without changing the water. Shells are then transferred to FRP tanks (1.6 m x 1.0 m and 0.35 m deep), arranged on the bottom of the tank and UV-activated sea water is applied to induce spawning. Since spawning takes place mainly at night, UV-activated sea water should be applied to the parent shells during the evening. Parent shells should thus be collected during the morning of the previous day (Table 6).

Sea water, preferably filtered through a 1 micron filter, is activated by means of a UV steriliser with a 5 t/hr treatment capacity. UV-activated sea water flows into the tank containing the parent shells at a rate of 4–8 l/min (Table 7). When spawning is not induced by the UV-activated sea water, the sea water temperature is raised by 5 °C. After spawning, parent shells are removed from the tank and stored as males and females separately.

The eggs of trochus are covered with a thick layer of gelatinous material; they can easily be spoiled in warm water. For the normal development of eggs to veliger larvae, the eggs should be kept at a low density or washed often by changing the water. The water in the tank with fertilised eggs is replaced with clean water

Table 6: Results of induced spawning of trochus

No.	Date	No. of parents	Inducing method *	Spawning ratio (%)	Time inducement commenced	Time of first spawning	Time needed to obtain 1st spawning	Time inducement finished
	1988							
1	23-May	320	ST+UV+TR	Unknown	19:30	21:30	2:00	03:00
2	19-Jul	114	ST	51.8	18:30	19:00	1:00	22:00
3	21-Jul	114	ST+UV	4.4	19:30	21:00	1:30	02:00
4	15-Aug	61	ST+UV	45.9	19:30	21:40	2:10	02:00
	1989							
5	20-Jun	98	ST+UV+TR	1.0	20:00	22:30	2:30	02:15
6	21-Jun	98	ST+UV+TR	61.2	18:30	20:30	2:00	00:45
7	22-Jun	104	ST+UV+TR	20.2	20:30	21:25	0:55	02:30
8	23-Jun	65	ST+UV+TR	83.1	17:30	18:30	1:00	23:00
9	28-Jun	83	ST+UV+TR	1.2	18:00	21:50	3:50	00:00
10	29-Jun	83	ST+UV+TR	2.4	18:45	21:00	2:15	21:30
11	05-Jul	92	ST+UV+TR	0.0	16:30	After 24:00	-	21:30
12	07-Jul	92	ST+UV+TR	2.2	16:35	After 22:30	-	22:30
13	12-Jul	49	ST+UV+TR	6.1	16:00	00:20	8:20	01:00
14	23-Jul	103	ST+UV	44.7	17:30	19:45	2:15	02:45
15	17-Oct	78	ST+UV	74.4	17:15	18:15	1:00	00:00
	1990							
16	27-Jun	111	ST+UV+TR	3.6	19:00	20:20	1:20	22:00
17	30-Jun	75	ST+UV	60.0	19:00	19:13	0:13	22:00

* ST: Still water; UV: Ultra violet rays activation; TR: Temperature raising

Table 7: Results of egg collection of trochus (1990)

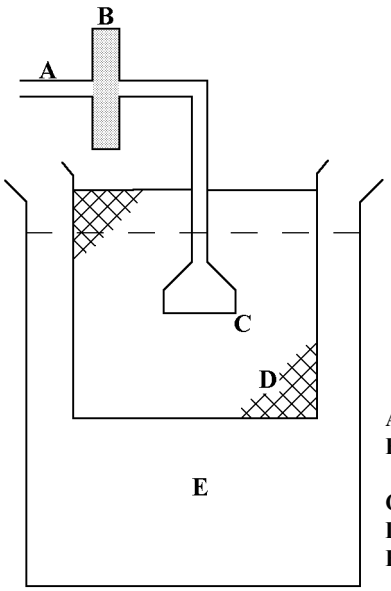
	Example 1	Example 2
Date of parent collection	26 June	29 June
Place of parent collection	Onnason	Iheya
Date of inducement to spawn	27 June	30 June
No. of parents induced	111	75
Parent shell diameter (mm) Range (mm)	10.5 (std 1.4) [7.6–12.1]	10.7 (std 1.2) [8.1–12.1]
Inducing methods	ST+UV+TR	ST+UV
Water temp. at spawning	28.7 °C	28.7 °C
No. of parents responding *	Male : 2 Female : 2	Male : 29 Female : 16
Ratio of parents responding (%) *	3.6	60
No. of eggs collected x 1000 *	170	11,933

* Results obtained between 17:30 and 22:00

4–5 times during the first 4–5 hours after the fertilisation. The eggs are then transferred to a tank of 0.5 to 1.0 m^3 made of polycarbonate.

Instead of replacing the water in the tank by hand during the night, fertilised eggs can be kept in the hatching tank with a continuous water supply in order to save labour. The hatching tank is a 100-litre polycarbonate tank fitted with a plastic basket and lined with netting of 60–70 µ mesh size. The size of the basket is 27 x 44 x 24.5 cm and the basket is placed at the water surface of the tank so the water in the basket is about 15 cm deep. Sea water, filtered by a cartridge-type filter of 1 µ filtering capacity, is supplied to the tank at the rate of about 5 l/min. The inflow of water is spread to decrease the water pressure by connecting a funnel-shaped pipe of

100 mm in diameter at the tip of the 20 mm diameter supply pipe, so that the eggs will not be pressed against the netting of the basket. The number of eggs stored in the basket of the hatching tank is calculated from the diameter of the eggs (0.5 mm) and the bottom area of the basket, so as to form a single layer of 475,000 eggs per basket (Table 8 and Fig.23).



A: 20 mm diameter PVC pipe
B: 1 micron capacity water filtering cartridge
C: 100 mm diameter PVC pipe
D: 60–70 μ mesh basket
E: 100 litre polycarbonate tank

Figure 23
Schematic diagram of a running water incubator

Rearing of veliger larvae

The initial stage of seed production is the culture of trochus larvae, from veliger or crawling stage to a small shell of 3–4 mm in diameter, or until the first collection of seed shells. Veliger larvae come up to the water surface after 20–24 hours and are counted and transferred to the FRP tank of 2.75 m^3 or 4 m^3 in volume where diatoms have been cultured on the corrugated plastic plates. The water in the tank used for algal culture is flushed and aerated to wash out the remaining nutrients before the start of larval culture. In the first 3–7 days, the water in the tank is not replaced and only slightly aerated. Following this, the water is kept running in the culture tank. Care should be taken that sea water in the outdoor tanks does not become diluted with rain. About 500,000 to 1,000,000 veliger larvae may be cultured in a 2.75 m^3 or 4 m^3 FRP tank.

Veliger larvae may be kept without food in the hatching tank until they develop to the early creeping larvae stage (Figure 24) which takes 3–5 days in spring. The production of seed shell is more reliable if early creeping larvae instead of veliger are put in the culture tank. Between 400,000 and 500,000 veliger larvae can be kept in a hatching tank.

In 1990, 51.8 per cent of the veliger larvae successfully developed into early creeping larvae (Table 9). The early creeping larvae are transferred into FRP culture tank prepared in the same way as for the veliger larvae. About 100,000 early creeping larvae were put in a 2.75 m^3 FRP tank and about 200,000 in a 4 m^3 tank. Before turning on the water flow, it is necessary to make sure that no veliger larvae are floating in the water.

Larval trochus are grown in the culture tank with corrugated plates until they reach a size of 3 mm in diameter, which is a convenient size for handling. It takes about 2–3 months depending on the densities of larvae and growth of attached diatom (Tables 10 and 11, Figure 25). The bottom of the culture tank is cleaned from time to time by removing the accumulated debris.

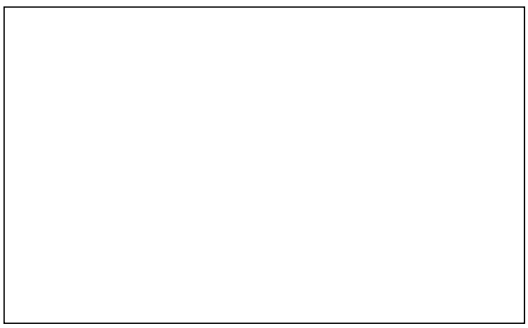


Figure 24
Trochus larvae of early creeping stage
(Some are still in veliger stage; diameter is about 0.3 mm)

Table 8: Survival rate to veliger larval stage of trochus eggs with different treatments

Egg treatment method	Running water	Still water + aeration				Exchanging water
		Streptomycin		No antibiotics		
Vessel (l)	18	100	1,000	100	500	13
No. of eggs (x 1000)	548	322	3,560	180	1,200	7,004
No. of veliger larvae (x 1000)	272	132	248	48	48	2,895
Survival rate	49.6	41.0	7.0	25.7	4.0	41.3

Table 9: 1990 results of veliger larvae rearing (x 1000)

Rearing no.	1-1	1-2	2
No. of eggs spawned	170.0	*1,986.0	11,933.0
No. of eggs fertilised	170.0	1,986.0	7,610.0
No. of veliger larvae	120.0	1,180.2	7,040.0
No. of larvae metamorphosing to creeping stage	62.7	229.3	3,649.8

* Number of eggs overflown from the tank between 22:00 and 06:30

Table 10: Results of experimental rearing of larval trochus from creeping stage using FRP tank of 2.75 m^3 in volume

		1-1	1-2	Total	2-1	2-2	2-3	2-4	2-5
Date of spawning		27/6/90	27/6/90		30/6/90	30/6/90	30/6/90	30/6/90	30/6/90
Starting date of experiment		3/7/90	3/7/90		4/7/90	4/7/90	4/7/90	4/7/90	4/7/90
No. of larvae (x 1000)		108	184	292	193	193	106.6	126.7	137.5
No. of corrugated plates		160	160	320	160	160	160	160	160
Collection date		10/10/90	10/10/90		9/10/90	9/10/90	8/10/90	8/10/90	8/10/90
Rearing period (days)		104	104		101	101	100	100	100
No. trochus collected (x 1000)		55.6	46.9	102.5	19.1	32.1	69.8	58.8	40.2
Collected from plates		31.7	17.2	48.9	10.0	14.2	25.4	33.3	15.5
Collected from other surface		23.9	29.7	53.5	9.1	17.9	44.4	25.5	24.7
Survival rate (%)		51.5	25.5	38.5 * 35.1 **	9.9	16.6	65.5	46.4	29.2
Shell diameter									
from plates:	mean (mm)	4.2 (± 1.2)	4.0 (± 1.2)		5.1 (± 1.2)	4.4 (± 1.2)	4.6 (± 1.3)	4.4 (± 1.3)	4.3 (± 1.1)
	range (mm)	(1.9–6.9)	(2.0–7.4)		(2.6–7.8)	(1.8–7.3)	(2.5–8.5)	(2.6–9.0)	(2.5–7.1)
from other surf.:	mean (mm)	3.7 (± 0.8)	3.6 (± 1.1)		4.4 (± 1.2)	3.9 (± 1.4)	3.9 (± 0.9)	3.8 (± 0.9)	3.4 (± 1.0)
	range (mm)	(2.6–7.3)	(1.9–7.9)		(2.5–7.5)	(1.7–9.1)	(2.0–6.3)	(2.4–7.6)	(2.2–7.6)

Table 10 (continued)

		2-6	2-7	2-8	2-9	2-10	2-11	Total
Date of spawning		30/6/90	30/6/90	30/6/90	30/6/90	30/6/90	30/6/90	
Starting date of experiment		4/7/90	4/7/90	4/7/90	4/7/90	4/7/90	4/7/90	
No. of larvae (x 1000)		137.5	100.5	100.5	97.7	197	396	1,786
No. of corrugated plates		160	160	160	160	160	160	1,760
Collection date		4/10/90	4/10/90	4/10/90	3/10/90	2/10/90	1/10/90	
Rearing period (days)		96	96	96	95	94	93	
No. trochus collected (x 1000)		44.5	51.5	57	26.7	57.5	72.7	529.9
Collected from plates		22.7	26.6	30.9	15.8	27	23.3	244.7
Collected from other surface		21.8	24.9	26.1	10.9	30.5	49.4	285.2
Survival rate (%)		32.4	51.2	56.7	27.6	29.2	18.4	34.8 * 29.7 **
Shell diameter								
from plates:	mean (mm)	4.5 (± 1.1)	4.4 (± 1.1)	4.1 (± 1.2)	5.1 (± 1.2)	4.7 (± 1.4)	4.1 (± 1.2)	
	range (mm)	(2.5–6.9)	(2.3–6.6)	(2.1–8.2)	(2.5–7.4)	(1.5–7.4)	(1.9–7.1)	
from other surf.:	mean (mm)	3.7 (± 0.8)	3.3 (± 0.8)	3.4 (± 0.8)	4.9 (± 1.0)	3.4 (± 1.3)	3.2 (± 0.6)	
	range (mm)	(2.1–5.8)	(1.9–6.6)	(2.0–5.8)	(2.9–8.4)	(1.4–6.6)	(2.0–4.6)	

* average survival rate in each tank
** survival rate for all tanks combined

Harvest of seed trochus attaching on corrugated plates

In the case of abalone and turban shell, seed shells are removed from the corrugated plates by using chemicals (ethanol, ethyl paminobenzoate), tools (bamboo scraper, urethane rubber) or by hand. Trochus seed can be removed from the corrugated plates by hand or by immersing the plates in fresh water. A collecting bag made of netting of 0.5 mm mesh size is fitted into the 100-litre polycarbonate tank which is filled with tap water. A group of corrugated plates fixed on a holder is taken out from the FRP rearing tank and immersed in the tap water in the collection bag. After 1–2 minutes, the holder is shaken up and down in the collection bag so that the shells drop in the bag.

Shells collected in the bag are then transferred into the sea water tank. The corrugated plates and holders are washed clean to be ready for the next diatom culture.

For large-scale production of seed trochus, a machine should be introduced to reduce the labour required in washing numerous corrugated plates.

Table 11: Results of seed production between 1987–1990

	1987	1988	1989	1990
No. produced (x 1000)	30	358	1,050	632.4
Size (mm)	5.0	5.0	2.4	4.0

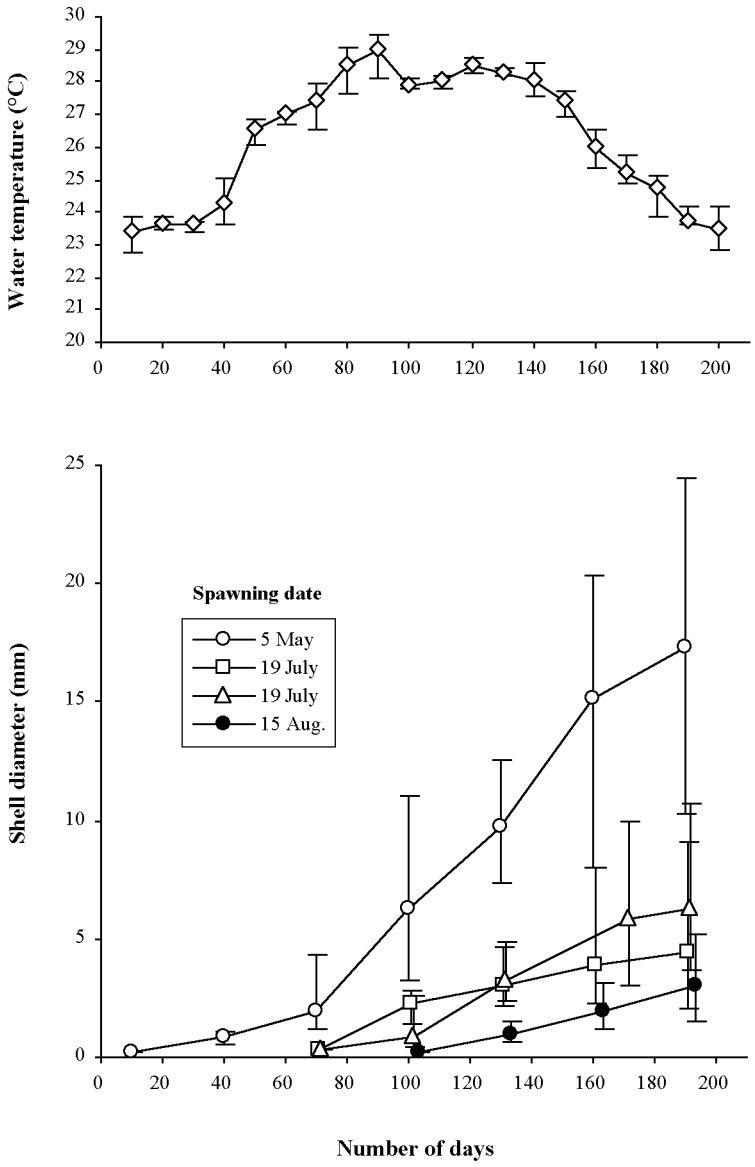


Figure 25
Growth of trochus larvae obtained with the experiments carried out in 1988

Intermediate culture

Small trochus of 3–4 mm in shell diameter are cultured until they grow to a size suitable for release. The culture during this period is called intermediate culture. The techniques used in the intermediate culture, which takes quite a long time, are still under development. Special considerations are given to technical developments, economics and work efficiency of the intermediate culture.

Food preference and growth

Experiments were conducted on several kinds of food materials to observe the food preference of young trochus as well as to study the growth of trochus fed with different foods. Diatoms have been shown to be the best food for the young trochus (Tables 12 and 13).

Intermediate culture using corrugated plates with attached diatoms

Young trochus of 3 mm in shell diameter are cultured in the FRP tanks supplied with diatoms attached to the corrugated plates. The culture density, estimated empirically, was 20,000 trochus per 4 m^3 tank and 15,000 per 2.75 m^3 tank. The trochus juveniles grow to 6–7 mm in shell diameter in about two months. They are then transferred to new tanks in order to lower the culture density, namely, 10,000 trochus in each 4 m^3 tank and 7,500 trochus in each 2.75 m^3 tank. If egg production is conducted in July, the water temperature starts to decline following this month and hinders the shell growth so that they only reach a size of 10 mm in shell diameter by the next spring.

Intermediate culture in basket

Trochus of 5–6 mm in shell diameter can be grown in a basket of 3 mm in mesh size, hung in the sea or in a pond. There are still many practical problems to be solved in basket culture, such as the culture density of trochus in the basket, the amount of food, and environmental factors affecting the growth. However, this method may be applied for intermediate culture of trochus at fishing ports or in coastal waters in the future (Tables 14 and 15).

Table 12: Food preference of trochus juveniles

Food type	*Ulva pertusa*	*Eucheuma* sp. (dry)	*Hizikia fusiforme* (dry)	Abalone culture food formula	Diatoms on corrugated plates
Preference	+++	++	+	–	++

Table 13: Growth of trochus juvenile (mean, std & range) with different feed

	Ulva pertusa	***Eucheuma* sp. (dry)**	**Diatoms on corrugated plates**	**No food**
12 October 1988		5.4 ± 0.3) (5.0–6.2)		
24 October 1988	6.3 (± 0.6) (5.0–8.1)	6.1 (± 0.6) (5.3–7.0)	10.2 (± 1.7) (7.9–13.3)	6.1 (± 0.5) (5.0–6.2)

Table 14: Results of juvenile rearing of trochus in baskets placed in seawater ponds (1988)

	Date	**Area (m^2)**	**Number**	**Survival rate**	**Size (mm)**
Basket A	21 May	3	3,000		4.2 (± 0.5) (2.9–5.1)
	21 July *	-	1,266	42.1%	6.3 (± 1.0) (4.4–8.9)
Basket B	21 May	9	6,000		4.2 (± 0.5) (2.9–5.1)
	31 July **	-	4,520	75.3%	8.6 (± 1.1) (6.0–12.1)

* Time period: 61 days
** Time period: 71 days

Table 15: Results of juvenile rearing of trochus in the baskets placed in seawater ponds (1989)

	Date	**Area (m^2)**	**Number**	**Survival rate**	**Size (mm)**
Basket A	1 June	48	5,000		5.9 (± 1.3) (3.2–9.0)
	21 Aug.*	-	3,349		13.1 (± 3.6) (7.3–22.7)
Basket B	1 June	48	5,000		5.9 (± 1.3) (3.2–9.0)
	21 Aug.*	-	2,343	67.0%	12 (± 2.5) (7.0–16.3)
Basket C	1 June	48	5,000		5.9 (± 1.3) (3.2–9.0)
	21 Aug.*	-	2,887	57.7%	14.8 (± 4.1) (8.6–23.4)

* Time period: 82 days

Problems and future development of trochus seed production

There are several problems to be solved in the course of trochus seed production. Some of the general points, not only those found in Okinawa, are discussed here.

Culture of attached diatoms

Not many species of diatoms can be cultured steadily for long periods in summer. The most appropriate species for a given region should be selected from the marine species locally available and for their value as food for trochus.

Spawning season and inducement of spawning

Seasonal changes in the features of the reproductive organs should be studied for successful egg production, particularly when there is a limited spawning season. Egg production after or before the main spawning season may be possible if artificial maturation inducement techniques are established.

The induction method for maturation of abalone might be applicable for trochus and is worth studying. Prior to the application of this method, a suitable food for the parent shell of trochus should be found. Also equipment to regulate the condition of the culture tank, such as water temperature, should be made available. It is also desirable to establish a quick-and-easy technique to identify the sex of individual trochus without breaking the shell.

Collection of brood stock

The spawning season of trochus appears to last from spring to autumn in Okinawa, based on the results of histological studies of reproductive organs. One individual probably spawns more than once during the spawning season, although the spawning periodicity of trochus is not yet exactly known. It is advisable to collect brood stock from several different places rather than to collect from one place to increase the chance of spawning, as indicated by the results obtained in 1989 (see Table 6).

Labour-saving devices used for egg production

As trochus spawning takes place during the night, technical staff has to work during night hours. In experiments carried out in 1990, eggs were collected from the overflow of the spawning tank, and these eggs showed normal development (see Tables 9 and 10). Based on this result, a labour-saving system is under construction with which eggs from the overflow system of the hatching tank are automatically collected and washed.

Techniques to produce seed trochus on a large scale

Trochus larger than 3 mm in shell diameter can tolerate handling. Therefore, it is important to improve the survival rate of trochus up to the 3 mm stage, namely, until the first removal from the corrugated plates. This is achieved by maintaining diatoms in good condition as well as maintaining suitable tank conditions for the young trochus. The survival rate of the veliger larvae until this stage fluctuated from 0.1 per cent to 14.2 per cent, when they were stocked directly into the culture tank.

The survival rate is much improved when veliger larvae are reared in a hatching tank supplied with running water until they grow to early creeping stage and then are transferred to the culture tank. The survival rate of early creeping larvae until the stage of 3 mm shell diameter was 45.5 per cent in 1989. In 1990, it was 35.4 per cent on average during a rearing period of 3–3.5 months.

A total of 102,500 and 529,900 trochus of 3 mm were produced from two trials in 1990, from 13 tanks each with a volume of 2.75 m^3. An average of 48,600 trochus were produced per tank (range: 19,100–72,700 trochus). The average size of trochus produced were 3–5 mm in shell diameter. It can be stated therefore that the fundamental techniques for trochus mass seed production have been established.

Problems met in the intermediate culture using corrugated plates

Small trochus grow best on corrugated plates feeding on attached diatoms, even after the stage of first removal of the shells from the plates at the size of 3 mm shell diameter. However, there are many problems and difficulties in the intermediate culture in tanks, since it lasts for a long period.

The culture is labour intensive requiring the additional culture of food diatoms on corrugated plates, removal of shells from the plates, grading shells by sizes, transferring shells from tank to tank and managing the rearing tanks. The management of the tanks includes tasks such as checking the condition of diatoms on the corrugated plates, cleaning the bottom of the rearing tanks, and preventing the shells from escaping through the water outlet pipe or from crawling up the tank wall out of the water.

Moreover, sea water must be filtered to get rid of any small crustaceans which feed on the diatoms or any crab which prey on trochus. This filtration raises the production cost of trochus seed considerably. Further study should be made to reduce the cost, to save labour and to raise the production efficiency of the intermediate culture. Devices to prevent the escape of shells through the water outlet and the mortality of shells by crawling up the tank wall are currently under development.

Problems met in the intermediate culture using baskets

To achieve a more efficient seed production for trochus in baskets hung in the sea, the following problems should be addressed:

(a) avoid eggs or larvae of carnivorous animals entering and growing in the basket,

(b) avoid clogging of the basket netting, and

(c) design and build stronger baskets able to withstand the rough sea conditions during typhoons.

In 1990, an experimental culture of trochus was tried using baskets hung in the sea for 211 days from 2 March to 29 September. Trochus grew from 4.8 mm to 22 mm in shell diameter on average, the largest being 30 mm. This experiment, however, indicated that damage to the baskets by typhoons and the clogging of netting were the most serious problems for this type of intermediate culture.

Artificial feed for trochus

An artificial feed should be developed to readily supply enough food to trochus for large-scale seed production. The fronds of *Ulva* spp., a green algae, seem to attract trochus. The chemical elements of the *Ulva* spp. frond should be examined to extract the attractant to be mixed in the artificial feed (see Table 12). Further study on the feeding habits and nutritional requirements of young trochus must be carried out to establish the optimum formula of artificial feed.

Additional notes

Many techniques described in this report have proved to be applicable to the seed production of the turban shells such as *Turbo marmorata* and *Turbo argyrostomus*.

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Trochus seed production in Vanuatu

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Introduction

The tropical gastropod *Trochus niloticus* is dioecious, and the gonad is white in males and green in females. It reaches sexual maturity between two or three years of age in the wild. Field studies have found that sexual maturity is reached at size 5.5–7.0 cm.

Ovary size increases exponentially with shell diameter. A 12.0 cm female has the potential to spawn 14 times more eggs annually than a 6.0 cm female. Mature females release about 100,000 to 1,000,000 eggs per spawning session, but the annual reproductive contribution may be larger than this.

Spontaneous natural spawning occurs throughout the year, indicating that there are at least some ripe individuals in the population at all times. Brood stock can be maintained in large cement or polycarbonate tanks. Brood stock will spontaneously spawn during the evening of the new moon or within a few days of new moon. They exhibit a lunar spawning cycle superimposed on a nocturnal foraging cycle (Heslinga & Hillman, 1981). Spawning usually occurs between 18:00 and 23:00 hrs. Spawning might be caused by a sudden change in water temperature (increase or decrease), desiccation, lunar cycle, release of gametes from other individuals in the population, or a combination of these factors. As a general rule, males initiate spawning and require less stimulus to induce spawning than females, although females do not always spawn in response to male spawning.

Spawning and rearing procedures

Introduction

Procedures to induce trochus spawning and to collect eggs in the Vanuatu trochus hatchery have been revised and standardised. The procedures have evolved from:

- allowing the brood stock to spawn unattended and collecting the planktonic larvae the following morning, to

- closely observing the brood stock once spawning has commenced, as spawning by females can be sudden and brief. Eggs are collected from as close to the female excurrent siphon as possible. This is done by holding a primed siphon hose directly over the female's siphon, with the hose end blocked until the moment before the first ejaculation of eggs, and finally to

- closely observing the brood stock and removing the females just before the first ejaculation of eggs to a separate container half-filled with filtered seawater.

Standardised spawning procedure

Preparation

The date scheduled to induce trochus spawning is usually set one week before the new moon. Prior to the date scheduled, all equipment (tanks, buckets, plastic tubes, etc.), are rinsed with sodium hypochlorite solution, then finally rinsed with fresh water and dried.

One week before the new moon, arrangements are made for 40 adult trochus to be collected by a ni-Vanuatu fisherman. The trochus are given to the hatchery personnel immediately upon reaching the shore. After scrubbing the exterior of the shells the brood stock is then maintained in a 500 l polycarbonate tank filled with 350 l of filtered seawater.

Based on experience with previous spawnings, the hatchery personnel are attending the brood stock a week before new moon, since the trochus tend to spawn a few days prior to the new moon rather than on the eventing of the new moon. Regardless of whether the trochus spawn on or before the new moon, arrangements are made for another 30 new adult trochus to be collected and spawning procedures are continued for another week following the new moon. The objective is to collect as many eggs as possible.

The hatchery personnel usually leave work at 16:30 hrs. Before leaving the hatchery, all faecal material from the bottom of the broodstock tank is siphoned off to ensure that eggs are spawned into clean water. Water supply to the broodstock tank is turned off so that if spawning occurs early when the tank is unattended, sperm and eggs are not lost.

Spawning procedure

Hatchery personnel return to attend the broodstock at 19:00 hrs. From this time onwards the brood stock is closely monitored for signs of spawning. First sign of spawning is a milky appearance of the water due to release of sperm by males which usually precedes spawning by females. Males are removed from the stock tank once the water becomes too opaque to see clearly, and placed in a separate container of filtered seawater where they will generally continue to release sperm. The

sperm is set aside as the sperm-bank. If the females do not spawn within 30 minutes after the males have spawned, the brood stock tank is drained out to 100 l and refilled with filtered seawater.

The draining and re-filling of the brood stock tank acts as an inducing mechanism which somehow causes the trochus to spawn. Since the bulk of the eggs spawned by a female are released in the first two or three ejaculations, the females are immediately removed to separate tanks of filtered seawater when they begin spawning. Females that are about to spawn can be easily identified, since they almost always have their siphon curled into a tube, with the tip pinched off into a point just prior to ejaculation, while the siphon of males is generally relaxed.

The eggs in each spawning container are examined using a microscope, as soon as the females in each container have ceased spawning and been removed. A little sperm from the sperm-bank is added to each spawning container only if necessary. The fertilised eggs are added to partially-filled larval tanks after the egg density in each spawning container has been estimated. The eggs are usually added to the larval-rearing tanks to give final egg densities of 5 to 10 eggs per ml. An antibiotic is only added when desirable to inhibit bacterial growth. However, the use of antibiotics is avoided as much as possible to discourage creation of antibiotic-resistant bacterial strains.

The larval tanks are insulated from extreme temperatures and are monitored for larval development rate twice daily. Sufficient aeration is provided to prevent the eggs forming a pile on the bottom of the tank. Whenever concentrations of bacteria or ciliated protozoans become unacceptably high, aeration is turned off to allow non-living material or non-swimming larvae to settle to the bottom of the tank. The bottom matter is later siphoned through a fine mesh which is held partially submerged in a bucket of water so that the larvae are not forced on to the mesh as the water flows through it. The washed larvae are placed in a separate container in which clean filtered seawater is added to an appropriate final concentration.

The larvae are transferred to juvenile-rearing tanks on Day 4, after they have settled. The juvenile-rearing tank surfaces are already conditioned two-to-three weeks prior to spawning. By the time settlement of larvae occurs, the tank surfaces already have fine films of diatoms which will be the food of the larvae once they metamorphose and commence feeding.

Standardised juvenile management procedures

There is a set management procedure which the hatchery personnel follow for rearing the juveniles from the settlement stage to a size at which the juveniles may be released on the reef.

The management procedures are separated into two categories: daily tasks and fortnightly tasks.

Daily tasks

At the start of the working day and weekends the hatchery personnel on duty:

- take the seawater temperature of each juvenile rearing tank,
- turn on aeration and seawater pumps and check that there is adequate seawater flow into the tanks and that the flow rates through the tanks are sufficient to replace the water at least twice a day,
- check that there is adequate air flow to provide vigorous aeration to ensure that there are no areas of stagnant water and that the aeration stones are distributed evenly in the rearing tanks, and
- ensure that everything is in order (e.g., tanks are not leaking, standpipes have not been dislodged).

Before and after lunch the personnel check each juvenile rearing tank for adequate air flow and seawater flow.

At the end of the working day and weekends the personnel:

- take the seawater temperature of each juvenile rearing tank,
- turn off the aeration and seawater pump, and
- ensure that everything in the hatchery is in order before they leave work.

Fortnightly tasks

Every two weeks the hatchery personnel:

- clean the juvenile-rearing tanks by siphoning all the accumulated detritus from the bottom of the tanks,
- check if it is necessary to add more conditioned algal plastic plate to the rearing tanks to substantially augment the surface area or replace those in the rearing tanks with new ones,
- check the algal density on the corrugated plates (if the juveniles are overgrazing from the surface of the plates, a second batch of plates is placed in the sea for conditioning), and
- measure a sample of 20 juveniles taken randomly from each rearing tank.

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Status of *Trochus niloticus* mariculture in the Republic of Palau

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Seed production

Spawning and field collections

The main objective of the trochus project in 1989 was to obtain a consistent production of trochus seed every month. From October 1988 to September 1989, twelve of fourteen attempts at inducing spawning were successful, producing seven million larvae (Table 1). Female spawners released an average of about 217,000 eggs each, ranging from 26,000 to 1,000,000 eggs (see Table 2 on next page). Egg release is dependent on readiness and ripeness of the female and may be inhibited by their removal from the spawning tank into individual containers. The number of eggs released was not correlated with the adult female shell diameter.

The newly-constructed spawning water tables have worked well in spawning trials. The shallow tables enable quick removal of males and females. Females and males have been tagged and released at one brood stock site. This will allow us to retrieve a known number of males and females. Problems associated with unsuccessful spawnings (overproduction of sperm in the tanks, no females present, and weather conditions) have been greatly reduced.

Hatchery construction

The trochus hatchery staff installed a temporary plumbing and electrical system inside the trochus hatchery. The hatchery contains two water tables for spawning adults and six 61-litre tubs for larval development. A permanent system will be designed based on improvement of this system. The fiberglass tank, for growth and settlement of three-month to six-month seed, has been completed.

Larval survival

Twelve spawnings have resulted in successful larval production. Fertilised eggs were concentrated into tubs of 50 l of aerated filtered seawater containing streptomycin (0.5 g). Survival rates were determined for each development phase of trochus (see Table 3 on next page). The highest mortality occurred between the trochophore and veliger stages, two days after fertilisation. No correlation was found between initial egg densities per tub and overall mortality. Further experiments will be done to determine if greater survival from egg to seed can be accomplished by adding larvae to settlement tanks before day two. Preliminary trials have shown that one day-old larvae will attach to algal panels (aged two weeks) within a few hours.

Table 1: Summary of *Trochus niloticus* production in Palau

Date	Area	Number of adults	Number of larvae	Seed
1988				
6 Oct.	East Koror	150	423,000	none
8 Dec.	Ngchesar	150	150,000	4,364
23 Dec.	Ngeraard		630,000	4,600
1989				
16 Apr.	Ngerdiluches	74	150,000	201
2 May	Ngerdiluches	211	1,300,000	252
16 May	Ngerdiluches	n.a.	150,000	none
18 May	Ngerdiluches	92	only male	
25 May	Ngeremidiu	163	too much sperm	
6 July	Ngeremidiu	88	542,200	3,500
18 July	Udel & Ngel	79	150,575	
1 Aug.	Ngchesau	77	889,954	
16 Aug.	Ngchesau	102	466,864	
31 Aug.	Ngeremidiu	87	2,196,500	
12 Sep.	Ngeremidiu	65	630,700	

Remote setting

Remote setting experiments have shown that five-to-seven-day-old larvae can survive over a 24-hour period without water (see Table 4 on next page). The presence of water and younger larvae have resulted in 100 per cent mortality. Continued experiments will be done to test for an optimum age and density of larvae used for remote setting.

Settlement and harvest

The concrete walls of settlement tanks and added plastic panels are successful settlement substrates. Removable plastic panels are ideal for quantifying the densities and depth distribution of all development stages of trochus. Four-day metamorphosed larvae are readily seen and

remain attached after a panel is removed and replaced into the tank. Preliminary results show that the larvae settle randomly on a panel. Greater densities of juveniles (two weeks to one month old) are found at greater depths on algal panels (Table 5) and along panel edges.

Trochus seed are visible on cement walls when they are one month old. During an experimental harvest of one-month-old seed, the settlement tank S-3 was divided into sections and animals were counted throughout the tank. Trochus seed were found at greater depths on the side and bottom corners of the tank (Table 6). During a harvest of three-month-old trochus, the density and shell size were greater at shallower depths along the sides of raceway R-l . Greater densities and larger-sized trochus were found near the inflow area along the bottom of the tank. The one-month-old trochus showed no significant preference for the inflow side of the tank.

Seed densities have been calculated on panels for each settlement (Table 7). Total tank densities are estimated by assuming similar densities on the concrete tank walls as on the panels, and then adding these densities together. The header tank (HT) and raceway (R1) did not have panels on which to base an estimate. However, the raceway was harvested and a total of 3,534 trochus were collected. This value is lower than the predicted survival rates for tanks with algal panels (Table 7). Present stocking densities are limited to the number of eggs collected in a

Table 2: Number of eggs released by female trochus during a spawning event

Female identification code	Spawning date	Shell diameter (mm)	Number of eggs
F1	12 Sep.	85.1	286,000
F2	12 Sep.	88.0	828,500
F3	12 Sep.	65.0	116,600
F4	30 Aug.	69.4	44,000
F5	30 Aug.	64	26,130
F6	30 Aug.	72.0	87,500
F4	30 Aug.	91.4	391,500
F3	30 Aug.	70.4	670,000
F2	30 Aug.	90.1	75,150
F1	30 Aug.	99.3	1,048,000
F10	30 Aug.	110.3	390,000
F85	17 Aug.	97.2	208,500
F31	17 Aug.	114.4	275,000
F66	17 Aug.	77.4	100,000
F54	17 Aug.	101.1	175,000
F59	2 Aug.	85.2	199,000
F65	2 Aug.	67.0	141,000
F39	2 Aug.	80.0	92,222
F2	2 Aug.	110.9	170,000
F25	18 July	100.0	157,500
F59	18 July	101.0	121,000
Average:		**87.6**	**266,791**
Std. deviation:		**15.9**	**269,410**

Table 3: Summary of Trochus niloticus survival rates between each developmental stage

	Newly laid to fertilised egg	Fertilised egg to trochophore	Trochophore to veliger	Veliger to pediveliger
Sample no.	11.0	17.0	9.0	3.0
Mean survival rate	82.5	74.2	67.6	79.7
Standard deviation	19.8	21.7	19.8	5.6
95 % conf. limits	11.9	10.5	13.2	6.5

Table 4: Summary of experiments to assess the survival rate of trochus larvae on two substrates

Date	Substrate	Time (hrs)	Larval age (days)	Initial number	Final number	Survival rate (%)
23 July	Acetate	24	5	182	169	93.0
2 Aug.	Wet nylon	24	1	2,354	0	0.0
8 Aug.	Dry nylon	24	7	2,050	400	19.5
9 Aug.	Dry nylon	24	8	257	257	100.0
15 Aug.	Dry nylon	48	1	2,963	0	0.0
30 Aug.	Dry nylon	24	2	31,816	0	0.0

spawning event and are lower than the capacity of each tank (Table 8).

Proposal for a trochus hatchery

A proposal for a trochus hatchery is being revised by the project staff for funding submission. The time frame of the project will be extended to three or four years and divided into five phases:

- construction of the hatchery,
- establishment of a reliable larval-rearing protocol,
- research of the potential market for trochus to generate revenue,
- survey and reseeding in the field, and
- development of a training programme.

Each phase will address specific problems; i.e. the seawater requirement for the hatchery must be specified and the mortality of larvae in the hatchery and the seed in settlement tanks determined.

Table 5: Average settlement densities (no. of larvae/0.01 m^2) for trochus on algal panels at eight depth increments

Tank	S2	R2	S4
Sample size	17	12	4
Depth (cm)			
8	6.9	1.2	
15	30.5	3.1	14.8
23	33.8	7.8	20.8
31	51.8	12.8	29.0
38	69.2	19.3	36.2
46	86.7	24.7	40.2
54	98.6	26.9	57.5
61	116.9	20.3	76.5
Correlation coeff.	**0.5**	**0.7**	**0.7**

Table 6: Mean settlement densities (no. of larvae/0.01 m^2) of trochus at seven depth increments of four corners of cement tank S3.

Depth (cm)	Density
30-40	5.0
40-50	6.0
50-60	3.8
60-70	6.2
70-80	9.0
80-90	8.5
90-100	10.8
Correlation coeff.	**0.86**

Table 7: Settlement tank and algal panel dimensions with actual seed densities and estimated densities of settlement in tanks

Tank code	Number of panel sides	Area of panel side (m^2)	Total panel density (no./m^2)	Tank area (m^2)	Estimated tank density (no./m^2)	Estimated total density* (no./m^2)	Number stocked	Estimated survival rate (%)
HT				3.84			266,500	
R1				5.28		3,534	275,000	1.3
R2	12	0.60	1,376	5.28	1,009	2,365	150,000	1.6
S1	20	0.82	67,804	6.46	21,899	89,703	2,119,220	4.0
S2	20	1.00	13,480	6.46	4,354	17,834	258,448	6.9
S4	20	1.00	4,625	6.46	1,494	6,119	289,448	2.1

* Value based on harvest

Table 8: Settlement tank volumes and seed numbers stocked, with estimated numbers of seed to increase stocking densities

Tank code	Tank volume (m^3)	Tank volume (l)	Number stocked	Number stocked per ml	Potential number stocked for density of: 1/ml	5/ml
HT	0.83	832	321,084	0.32	832,000	4,160,000
R1	1.95	1,954	141,025	0.14		
R2	1.95	1,954	76,923	0.08	1,954,000	9,770,000
S1	2.99	2,992	708,769	0.71		
S2	2.99	2,992	86,437	0.09		
S4	2.99	2,992	96,805	0.10	2,992,000	14,960,000

Fisheries management of trochus

Reseeding of a Ngeraard reef

One of three transects was seeded with over 12,000 seven-month-old trochus. This transect had both a control site and seeded site. The average size of the seeded trochus was 2.0 cm and the predicted size of this cohort would be 3.0–4.0 cm after one year.

An agreement was made between the Palau Marine Resources Division and the Ngeraard State Government that trochus would not be harvested from these areas, however, the staff observed harvesting of undersized trochus at the restricted areas. One follow-up survey may be conducted, however, future seeding programmes will be initiated only if a State requests it and can ensure that the study sites are patrolled. Ngermediu Reef will be used as a study site as this reef is closer to the MMDC facility and thus easier and more economical to monitor and seed there.

Comparison of the 1988 and 1989 trochus harvests in Palau

Several Palau States were monitored during the 1988 harvest season. Kayangel had good harvest regulations; no undersized animals were sold. The price per pound ranged from US$ 0.65 per pound (lb) in Kayangel to US$ 1.40/lb in Peleiliu, Aimeliik, and Koror state. The first three weeks of the season, trochus was bought for US$ 1.00/lb. During the last three weeks of the season, the price rose to a US$ 1.40/lb. Over 250 t of trochus were sold by fishermen to local businesses. The estimated revenue generated for the local fishermen was over half a million dollars.

The 1989 harvest is indicative of the increasing demand of trochus shell and meat. A three-year moratorium on the harvest of trochus went into effect as of August 1989. During this moratorium, fisheries will be conducting a baseline study to access the trochus fisheries in Palau. Reseeding of selected areas has begun in a selected area.

At the end of this period, the trochus staff recommends the following:

- stricter regulation of the price, size and number of trochus sold,
- centralised areas to sell and thus monitor sales,
- establishment of a regulation that requires all trochus business transactions be reported to Marine Resources,
- a sales tax be imposed to generate revenue for mariculture, and
- maintenance of accurate records of future harvests.

Objectives for 1990

Our goals for the year 1990 are to:

- maintain larval production at one million larvae per month, or 12 million larvae per year, and
- maintain survival rates of at least one per cent, and produce 120,000 seed.

The seed will be marketed and used for reseeding programmes in Palau and throughout the Pacific.

Kosrae Marine Resources Division trochus reseeding project

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Introduction

Although trochus resources in Kosrae have intermittently been given protection by short-term emergency regulations, it was in 1988 that the Governor of Kosrae signed Regulation no. 19-88, which officially established a permanent State Trochus Sanctuary on the reef between Salem and Finlum in Tafunsak municipality. This regulation prohibited the harvesting of trochus from within the sanctuary, unless conducted by authorised personnel from the Kosrae Marine Resources Division (KMRD) for the purpose of development, enhancement or stock preservation.

During the following year, the Kosrae State Legislature passed State Law no. 4-80 to fund a project entitled Trochus Reseeding. The intent of the project was for the KMRD to seed reefs in Lelu, Malem and Utwe municipalities with trochus from the sanctuary. Project work began in early 1990 with the hiring of Mr Maxmiller Mongkeya to work through the KMRD as the project contractor.

The specific objectives of the project, and the scope of work in Mr Mongkeya's contract, were:

- inventory of the trochus resources within the sanctuary,
- collect and segregate sanctuary trochus by size,
- mark and return a portion of the collected trochus, and
- distribute the remaining unmarked, collected trochus to reefs in Lelu Malem and Utwe.

Originally, the duration of the project was to be three months. However, due to delays in conducting project work due to bad weather, the project time period was extended. The project field work was completed by the end of September 1990.

Methods

The first step in the project was to survey the trochus resources existing within the sanctuary. This was done on the reef flat by making visual inspections while snorkelling and walking around at low tide. The upper reef slope was surveyed primarily by making SCUBA dives from a 28 ft catamaran.

In both areas, counts were made of live trochus seen within one metre on either side of a 50 m transect line. This yielded the number of trochus seen within 100 m^2 of reef, and allowed for the calculation of an average density value of the number of trochus per square metre. Horizontal transects (parallel to the reef margin) were run along depth contours of 1.5, 3.0, 6.0, and 9.0 m; and vertical transects (perpendicular to the reef margin) were run downslope between 1.5 and 30 m.

A rough size estimate was made of the trochus habitat on the sanctuary reef slope. This was done initially by measuring the physical dimensions of the area down to a depth of 9 m with a tape measurer. Then a calculated estimate was made from measurements taken off a nautical chart of the area. The two measurements were compared, and an average final estimate was calculated.

Trochus were collected by hand and brought abroad the survey boat where they were segregated into size categories according to the diameter of their bases. The size categories used were as follows: less than (<) 3 inches; 3–4 inches (legal harvest size), greater than (>) 4 inches.

The trochus in each size category were then divided into two groups. Individuals in one group were marked by cutting a notch into the bases of their shells with a metal file. These trochus were then returned to the sanctuary reef slope. The unmarked individuals in the other group were used for distribution to reefs in Lelu, Malem and Utwe. The number of trochus that made up each group was based on the following percentages:

		Marked	Unmarked
(a)	<3 inches	25%	75%
(b)	3–4 inches	25%	75%
(c)	>4 inches	75%	25%

The decision to retain most of the trochus over 4 inches was based on the fact that they are a potent reproductive stock. Retaining them within the sanctuary should aid the repopulation of sanctuary trochus, as well as trochus stocks on nearby reefs in Tafunsak municipality. Distribution of these valuable individuals to reefs outside of the sanctuary would have exposed them to possible illegal harvest during State-sponsored trochus seasons.

When trochus were returned to the reef, either within or outside the sanctuary, they were placed in clusters of

about 10 each at depths between 1.5 and 4.5 m on the upper reef slope. Each cluster was placed about 5 m away from the next one. All were placed in areas where the bottom topography appeared favourable for shelter and food.

Although one man, Mr Mongkeya, conducted most of the project work by himself, a target distribution number was set of at least 1,000 trochus per municipality. The trochus were distributed in four locations each in Lelu and Malem, and in three locations in Utwe.

Results

Inventory

Even though considerable effort was made to find trochus on the sanctuary reef flat, visual inspections revealed their total absence in that habitat. The highest abundance of sanctuary trochus was found on the upper reef slope. Within that area, six horizontal transect counts were made along depths of 1.5, 3.0, 6.0 and 9.0 m each.

Within the sanctuary, trochus were found only in the area between the surf zone and a maximum depth of 9 m. Peak trochus abundance was found around the 3.0 m contour, with density generally dropping off below that. During the project, no trochus were found either below 9.0 m or inside the surf zone on the reef flat.

Additional transect counts running from 1.5 to 9.0 m depths were made at ten locations on the upper reef slope.

While the average densities from the initial series of transects illustrate the differences in trochus distribution at various depths, the average density of 0.34 trochus/m^2 from the second series is a value more generally applicable to the trochus habitat on the upper reef slope as a whole. The trochus sanctuary habitat, from the upper reef slope (including exposed portions of the reef) to the 9.0 m depth contour line, was estimated to be approximately 120,600 m^2.

Therefore, if the average density value of 0.34 trochus/ m^2 is used, a rough estimate of total number of trochus in that habitat area is calculated to be around 41,000 individuals.

Distribution

Eleven sites were selected for the distribution of sanctuary trochus. Each site was chosen based on a combination of its suitability as a trochus habitat and on its location in relation to the other sites selected within the same municipality. Although inclement weather and rough sea conditions temporarily interrupted the distribution work on a few occasions, it was completed by the end of September 1990. By that time, a total of 3,531 trochus had been distributed to the 11 sites.

The total numbers of trochus distributed in each municipality were as follows: Lelu, 1,309; Malem, 1,170; and Utwe, 1,052. All of the trochus were placed in clusters outside the reef margin in 1.5 to 4.5 m of water.

Discussion

In 1984 the KMRD reported a calculated average density of 0.14 trochus/m^2 for our sanctuary. However, this was based on results obtained from horizontal transect counts made mostly near the reef margin in water as shallow as 1.0 m. It is likely that due to the limited area surveyed, the 1984 counts significantly underestimated the true density of trochus living within the sanctuary. It is also likely that the sanctuary trochus resource, on the upper reef slope at least, has increased since then as a result of its protected status.

In general, all of the density values calculated from data collected during this project indicate that the trochus resource in the sanctuary is relatively healthy. For example, results obtained recently by the Pohnpei Marine Resources Division have shown the average density in their sanctuary to be around 0.08 trochus/m^2 at depths between 3.0 and 4.5 m. In contrast, the density of 0.81 trochus/m^2 calculated for the 3.0 m contour in our sanctuary indicates that the resource is strong.

The total number of trochus living within the sanctuary in 1984 was calculated by multiplying the 1984 average density value (0.137 trochus/m^2) by the estimated number of square metres encompassed by the reef margin habitat. In 1984, that area was estimated from a government blue print map to be approximately 115,000 m^2. Based on this area, the estimated total number of sanctuary trochus was calculated to be around 16,000 individuals.

The figure calculated from data collected during the 1990 project resulted in an estimate of 41,000 individuals. Although the estimated habitat area of the sanctuary upper reef slope (120,600 m^2) is 5 per cent greater than the original estimated area, the 1990 value (0.34 trochus/m^2) is nearly 250 per cent greater than the one calculated in 1984.

With respect to the distribution of trochus on the sanctuary upper reef slope, it is not surprising that none were seen below 9.0 m. These animals commonly feed on algae which grow best in clear, well-oxygenated waters more common at shallower depths along either side of the reef margin. The higher trochus densities at the 3.0 m depth interval, as opposed to the 1.5 m interval, may be due to the limiting effects of greater wave turbulence near the reef margin. However, on some Pacific reefs a positive correlation between wave turbulence on the reef margin and trochus density has been reported.

It is presently impossible to explain why absolutely no trochus were found on the reef flat. This was not expected since the outer reef flat is usually a prime trochus habitat. The situation may be an indication that illegal harvesting may have been occurring within the sanctuary. Trochus are very mobile and known to display wide variations in their local distribution within relatively short time spans. Aside from the obvious possibility of poaching, there may be environmental reasons which led to the dramatic observed difference in trochus density between

the reef flat and the upper reef slope. Regular periodic monitoring of the sanctuary stock may shed light on this curious observation.

By distributing the trochus in clusters of about 10 each, and placing them about 5 m apart in areas selected as good trochus habitat, we hoped to promote trochus reproduction at the 11 transplant sites. Trochus are known to congregate in small groups to spawn, usually within a few days of the new moon. At that time, they release both male and female gametes which fertilise in the water. Since they produce planktonic larvae which can settle on the reef after only a few days of drifting, it is possible that new recruitment from the distributed trochus may have already begun.

The new recruits will require up to two years to become sexually mature and able to reproduce. Often this stage has occurred by the time they reach a size at which their base diameter is 3 inches. As trochus shells grow beyond 4 inches they become commercially less desirable because of their increased thickness and the greater chance of containing holes from predatory worms. Thus, the current Kosrae State harvest size limit of 3 to 4 inches makes good sense.

The value of high-quality trochus shell has risen dramatically over the last several years. At the present time, prices paid between US$ 3.00 and 4.00 per pound are not uncommon. Foreign buyers are usually interested in purchasing good quality, clean, dry shells in amounts convenient for shipping. For example, a standard container maximises the buyer's shipping cost. Therefore, it is to Kosrae's advantage to be able to produce harvests of good quality trochus shells in such a quantity. Seventeen tonnes of shell at US$ 3.00 per pound is worth US$ 112,404.

The only way this can happen on a regular basis is through cooperative management, on the part of the government and the public, of the State's trochus stock. Maintenance and protection of the Kosrae trochus sanctuary is essential to this effort. Distribution projects such as the one for which this report is written will undoubtedly help a great deal as long as citizens do not harvest trochus out of season. Basing the timing of State-sponsored harvests on factors which will realistically promote a productive island-wide harvest is critical. Enforcement of State regulations on harvest-size limits during the legal season will enhance the long-term protection of stocks and not undermine efforts to educate the public on the value of conservation. Ways to improve the efficiency, quality and productivity of State-sponsored trochus seasons should be developed.

The results of the present study have indicated that the trochus stocks within the sanctuary have remained healthy. It may be desirable to conduct similar projects on a regular basis. This, in conjunction with the establishment of a trochus sanctuary in each municipality, may greatly enhance the island's total trochus resource. The KMRD could provide assistance in organising a system of sanctuaries and work with the municipal governments in their maintenance and protection throughout the year, and especially during harvest seasons. The Division could help develop guidelines to assist in the planning process to protect trochus resources from the negative impacts of coastal development. Public education about the value of trochus could also be carried out in the schools and through the municipal governments and the media.

Recommendations

- Continue to maintain the Kosrae Trochus Sanctuary and explore the possibility of establishing a satellite trochus sanctuary in each municipality.
- Monitor the outcome of the current distribution project and, if it is productive, continue to conduct projects to distribute sanctuary trochus to island-wide reefs.
- Develop guidelines to assist in the planning process to protect trochus resources from negative impacts of coastal development.
- Conduct public education activities on the importance of trochus resource conservation and their potential economic value.
- Develop improved methods of protecting trochus and enforcing trochus resource regulations.
- Develop improved operating procedures for conducting State-sponsored trochus seasons.

Assessment of *Trochus niloticus* populations in Palau

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Introduction

Trochus niloticus (called **semum** in Palauan) is a well-known reef mollusc throughout Palau and a major inshore fisheries resource. The full-time fishermen and the community as a whole generate income from this resource. Over-exploitation of trochus from all reefs, including sanctuaries, resulted in the enactment of a three-year moratorium from 1990 to 1992. During this moratorium, Marine Resources Division is assessing trochus stocks and re-evaluating current laws in order to prevent depletion of this mollusc. Management of this resource is particularly important, as technological advances in fisheries gear and methods, coupled with an ever-growing demand, continue to increase the fishing pressure on stocks of trochus. If Palauans are to continue to harvest trochus, effective management is essential and requires the full cooperation of National Government and the fishermen of this nation.

The purpose of this survey was to estimate the standing stock of *Trochus niloticus* on the reefs of Palau and compare our findings with previous surveys, especially some sites on reefs around Koror. This survey includes reefs of other States that have never been surveyed. This study will be used to help develop an effective management plan for the trochus fishery.

Methods

A total of 28 transects were made in eight States in Palau. Areas were surveyed within the Koror reefs and on the Babeldaob reefs. At each site, a 100 m transect line weighed down with lead weight was placed on the substrate parallel to the reef margin. The depth ranged from one to three metres. This depth range was chosen because it is accessible to free-diving trochus fishermen, and was shown in a previous study (Heslinga, 1983) to have higher densities of trochus than depths beyond this range.

Two snorkelers carefully searched the substrate two metres on each side of the transect line, for a total area of 400 m^2. The time required for searching each transect was approximately 10 minutes. However, transects in some areas with strong current took about 15 minutes to complete.

Snorkelers used an underwater writing board to measure and record the number and size of specimens in the following categories:

- live *Trochus niloticus,*
- dead *Trochus niloticus* with empty shell,
- dead *Trochus niloticus* occupied by hermit crabs,
- live *Trochus pyramis,*
- dead *Trochus pyramis* with empty shell, and
- dead *Trochus pyramis* occupied by hermit crabs.

Results

A summary of of the survey results is given in Table 1.

The highest densities of live *T. niloticus* were found at Ngebard reef, the area around Ngeremlengui Channel and Erengoll reef. Six transect areas located in Koror had no trochus.

The largest live *T. niloticus* were found at Eikedelukes reef in Koror State, and Ngebard and Erengoll in Ngerchelong State. The smallest *T. niloticus* were found

Table 1: Summary of the survey results for trochus species on Palau reefs

Species	No. of inds./transect		Mean no./ha	Max. size (cm)	Mean size (cm)
	Range	Mean			
Trochus niloticus (live)	0–12	5.0	155	9.8	8.4
Trochus niloticus (dead)	0–8	9.9	49	9.9	8.5
Trochus pyramis (live)	0–28	5.0	120	6.4	5.4
Trochus pyramis (dead)	1–3	2.0	42	4.8	4.6

on a patch reef in Ngardmau. The highest densities of dead *Trochus niloticus* were found in transects at Ngererнlengui reef. The highest densities of live and dead *Trochus pyramis* were found at one site in Ngardmau. Only one predator, a hermit crab, was found in an empty *T. niloticus* shell at Ileak'l Chei.

Calculations for standing stock of live trochus

The total standing stock of live trochus was calculated by estimating the total trochus habitat and multiplying it by the mean trochus density. The trochus habitat was estimated by assuming that at least 100 metres of the outer periphery of the outer and inner reef is a suitable substrate for trochus. A planimeter was used to trace the total reef areas and the trochus habitat area of seven outer reefs and three inner reefs. The trochus habitat (Table 2) was estimated to represent 7.6 per cent of the total inner reef area and 10 per cent of the total outer reef area. The total inner and outer reef areas for Palau (excluding the Southwest Islands) were obtained from the 1990 MRD Annual Report. The total trochus habitat area was therefore calculated to cover 40.9 km^2.

An average density of 124 trochus per hectare was determined from this study (= 0.0124 trochus/m^2 or 12,400 trochus/km^2). The average weight of harvestable trochus was 0.7 lb or 0.32 kg (determined from weighing 93 individual trochus taken from Mekeald reef). Using these values, we determined a standing stock of trochus as follows:

Total trochus habitat area x average trochus density = total number of trochus on inner and outer reefs

40.9 km^2 x 12,400 trochus/km^2	=	507,160 trochus
507,160 trochus x 0.7 lb	=	355,012 lb
	=	177.7 tons
	=	160.0 tonnes

If a fishing mortality (number harvested) of 40 per cent of the standing stock is recommended, this is equivalent to a harvest of 64 t per year.

Our calculations suggest that the sustainable yield from Palau's trochus stocks fishery is 64 t per annum. This estimate is only as accurate as the estimated standing stock per unit area, and estimated trochus habitat, and may be higher if more of the northern and eastern reefs were surveyed. It is less than half the average tonnage exported over the last 5 years of 140 t (MRD Annual Report). The Marine Resources Division will be conducting an analysis of satellite imagery to quantify trochus habitat in Palau within the next few years. This will help us to refine our estimates of standing stocks of trochus and other important commercial species in the future.

It was only possible to make relative comparisons between our study and previous studies because the methods and sites visited differed. Our average density for the Koror reefs was lower (73 trochus/ha) than the average density of 119 trochus/ha in a previous survey of only Koror reefs (Heslinga et al., 1983). However, we were unable to survey similar reefs and exposures due to rough weather. Bad weather and rough seas prevented us from completing all the planned surveys. We plan to conduct future surveys using several comparable methods and visiting more sites.

Conclusion

Several factors may cause changes in trochus populations on a given reef with time. However, we feel that overharvesting or fishing mortality is the major cause of decline in populations in areas known historically to have high densities of trochus. Previous management strategies need to be re-established, which include:

- a one-month season for harvests in June,
- a minimum size limit of 3 inches,
- sanctuaries in areas with good trochus habitat, and
- centralised areas to land trochus before export.

These are effective measures to enable officers to ensure that laws are being followed. In addition to past measures, several new measures may be appropriate to maintain sustainable yields of trochus:

- a pre-harvest survey to determine standing stocks,
- based on the pre-harvest assessments, a recommended maximum tonnage for export,
- a pre-season meeting including all interested buyers and sellers to negotiate allocation of total maximum tonnage, and

Table 2: Summary of the results of estimating trochus habitat in Palau

Reef zone	Total reef area (km^2)	Ratio of trochus habitat (%)	Area of trochus habitat (km^2)
Outer reef	264.7	10.0	26.47
Inner reef	186.6	7.6	14.2
Total	451.3		40.9

- a market study of trochus meat to use this currently discarded portion of the harvest.

Discussion

During our trochus survey, the densities of trochus varied from reef to reef. The reefs surveyed in Babeldaob (including reefs in Airai, Aimeliik, Ngerchelong, Ngeremlengui, Ngatpang, Ngardmau and Ngaraard) had the highest densities of trochus, whereas reefs in Koror had the lowest densities of *T. niloticus*. Variation in trochus densities may be the result of several factors:

- harvesting of trochus during the 1989 harvest season,
- typhoon 'Mike',
- other natural causes, such as:
  - unsuitable habitat,
  - the presence of predators, or
  - food limitation because of competitors.

All reefs surveyed during this study were harvested during the 1989 trochus season, including sanctuary areas that were surveyed in a previous study (Heslinga et al., 1984). An estimated 343 t were harvested (MRD 1990 Annual report), which was twice the five-year average (1985–1989) of 140 t. This large harvest, especially in Koror, which has the greatest residential population, may explain the lower densities of trochus on Koror's reefs. Beckwin Mechol observed that areas where he had harvested many sacks of trochus as a young boy now contain only a few trochus. Several fishermen said that many reefs in Koror were harvested day and night during the 1989 season, and many shells were undersized. This type of harvesting seriously affects the future trochus populations in Palau.

On 11 November 1990, typhoon 'Mike' hit Palau from the south-westerly direction at sustained wind speeds exceeding 100 miles per hour. The eye of the typhoon was estimated to have passed within 10 miles of the northern atoll of Kayangel. We observed many uplifted corals, stones, rubble and heavy sedimentation in Ngardmau, Ngerchelong and Kayangel. Ptilarikl reef in Ngerchelong suffered the worst damage of all the reefs surveyed. During the survey in Kayangel and Ngerchelong, high numbers of dead juvenile trochus and adult trochus were found on the beaches. Reefs damaged during the typhoon should be visited during the calmer months to evaluate the impact of the typhoon.

During surveys made over a five-year period in the 1930s (Asano, 1962), the Koror reefs had the lowest densities of trochus of all areas surveyed and Ngeremlengui channel had the highest. These findings corroborate ours, suggesting that certain areas may be better trochus habitats than others. However, harvesting of trochus began in 1899 (Asano, 1962), thus harvesting may have already caused changes in densities in trochus between reefs at this time.

We only found one hermit crab during our survey, therefore our data provides little information concerning the possible effect of predation on variation in trochus densities. A potential competitor is *T. pyramis*, which shares the same habitat as *T. niloticus*. High densities of *T. pyramis* may affect the number of *T. niloticus*. We can only provide preliminary information on these two factors which may be useful for further surveys.

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Report on Aitutaki trochus (*T. niloticus*) research trips of 29 January – 6 February and 12–15 March 1990

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Abstract

Survey data suggests that the Aitutaki trochus population is healthy and increasing. It also appears to have stabilised to a natural size-frequency distribution pattern. This stabilisation is marked by a mean basal diameter of approximately 10.1 cm, and 58 per cent of the population being within the legal size range (8–11 cm). The population has recovered from depletion caused by past harvests to a conservative estimate of 300,000 individuals, which is considered sufficient for another harvest. It is recommended that harvest quotas be set at 60 per cent of the trochus estimated to be within the legal size range. Using this method, the next harvest's quota should be 25 t of shell, equivalent to 33 t live weight.

Extensive reef damage was observed at two sampling stations on Aitutaki. This damage was caused by two cyclones that passed through the Cook Islands between February and March 1990, and led to decreases in trochus densities in these two areas.

A management tool new to the Cook Islands, the Individual Transferable Quota (ITQ), will be used in the next harvest. Based on the total of 2,250 shares (derived from a census of all individuals on Aitutaki) and overall live quota of 33 t, this harvest's ITQ is 15 kg per share. Quotas will be determined for each household by multiplying the ITQ and the number of individuals therein.

Introduction

Trochus were successfully introduced to Aitutaki in 1957 from Fiji. The first harvest of this transplanted stock was conducted in 1981 when a total of 200 t of shell were collected.

As the whole population shares in the revenues from this resource, regular surveys must be conducted to monitor the Aitutaki trochus stock and advise the Island Council of a suitable harvesting strategy. Surveys conducted in 1989 indicated trochus numbers had not substantially recovered from the previous harvest of June 1988.

Research officers from the Ministry of Marine Resources in Rarotonga travelled to Aitutaki and conducted the first survey in 1990 between 29 January and 6 February. All but 3 of the 12 permanent transects were surveyed for trochus. Transects at Station 1, 2 and 12 could not be surveyed because of heavy cyclone swell.

A second survey was conducted during a visit by a UNIDO team to Aitutaki between 12 and 15 March. The three stations which could not be reached on the first trip were surveyed on this visit, and Stations 4, 9, and 10 were resurveyed. This was done to determine changes in trochus densities over short periods, and to detect any changes to the trochus population caused by the two cyclones that passed over Aitutaki in the interval between the two surveys.

Meetings with the Aitutaki Island Council were held to discuss research plans and any questions they might have. Also, an Individual Transferable Quota (ITQ) was determined for use in the next harvest.

Methods

The permanent transect sites (see Tuara, this volume) were surveyed by placing a 100 m line across the reef flat (perpendicular to the reef edge, running from the ocean towards the lagoon), and walking or swimming along the line. Trochus inside a 2 m width band were counted and their shell basal diameter measured, with these being recorded at 10 m intervals along the line. The total width of the reef flat band surveyed along the line ranged from 4 to 6 m. Thus, the 100 m line transects were divided into 40–60 m^2 quadrats, and the total area covered in a line transect ranged from 600 to 800 m^2.

Results and discussion

Density data and population estimates

The February 1990 survey data showed an increase in trochus densities at all sites following the June 1989 survey, except at Station 8. Apparent density increases since the June 1989 survey ranged from 1.5 trochus/100 m^2 at Station 11, to 6 trochus/100 m^2 at Station 9. The trochus density decreased by 2.3 trochus/100 m^2 at Station 8, which is almost as low as the density found there in January 1989 (see Tuara, this volume).

A reason for this decrease may be habitat change, namely an increase in substrate sand on the reef flat at Station 8. The decrease in trochus abundance at Station 8, as well as the smaller increases may, however, fall within the margin of error in density estimates from the reef flat surveys. Assuming the estimated densities are correct, however, the overall average density for all stations increased by 2.25 trochus/100 m^2 since

the June 1989 survey. This represents a 56 per cent relative increase overall to approximately 340,625 trochus, from the 218,000 trochus estimated for the June 1989 survey. This indicates that there is a healthy trochus population on Aitutaki, with sufficient numbers large enough to produce offspring for recruitment.

The trochus standing stock can also be estimated by multiplying density and area. Aitutaki's barrier reef has been divided into 12 sections, one for each station, of arbitrary length. The distance across the reef flat in which trochus can be found has been approximated through past observations at each permanent transect. This distance is used as the width for figuring each station's area.

From the total density estimates for each station, the total standing stock on the reefs at Aitutaki is estimated to be 335,589 trochus. This can also be estimated with the average density of all stations and the total area, giving 289,843 trochus (Table 1).

As suggested by Sims (1984), more accurate population estimates could be made using satellite images or aerial photographs of Aitutaki. These would permit more accurate mapping of the reef, and determination of the total trochus habitat area on Aitutaki.

The range of standing stock estimates is from 289,843 to 335,889 trochus and 340,625 trochus. The first two figures are the absolute estimates from area and density, and the last a relative one based on the overall average density found between surveys. Obviously none of the estimates can be regarded as completely accurate, but they compare favourably, with the greatest difference between them only 15 per cent. These estimates approach the highest recorded standing stock of 385,000 trochus in 1987 (Sims 1988), and are considered sufficient to declare a harvest. It is recommended that a conservative standing stock estimate of 300,000 trochus be taken from the lower end of these values, and used in determining a quota for the next harvest. This will insure against overfishing the trochus population beyond its recovery point.

Cyclone damage data

Two cyclones passed through the Cook Islands between the February and March surveys in 1990. The first, Cyclone Ofa, passed through the northern Cooks, but sent large waves to Aitutaki. The second, Cyclone Peni, passed very close to the east of Aitutaki, and also sent large waves, especially to the eastern coast. Stations 4, 9 and 10 were re-surveyed in March 1990 to assess damage to the reef and trochus stocks caused by these cyclones. Trochus densities did not change at Station 4 between the two surveys (7.5 trochus/100 m^2), but decreased at Station 9 by 2.9 trochus/100 m^2 (–22 %, from 13.0 to 10.1) and 4.7 trochus/100 m^2 (–55 %, from 9.2 to 4.5) at Station 10.

No reef flat damage was observed at Station 4 by the March 1990 survey. Due to this and lack of any decrease in trochus density, it is assumed that the cyclone did not adversely affect the trochus in this and other unsurveyed areas on the west and south reefs. Further, the fact that there was no density change in the brief time between the two surveys is favourable evidence for the accuracy and use of permanent transects for reef flat surveys.

The density decreases found at Stations 9 and 10 can be attributed to reef damage caused by the cyclones, especially Cyclone Peni. This damage was observed on the March 1990 survey. Before the cyclones, the inner reef flat at both of these stations had large amounts of branching corals growing off small coral heads, which all grew in pools up to 1 m deep. The substrate at these stations was hard reef, with little or no sand or rubble. Trochus

Table 1: Summary of density estimates for trochus at Aitutaki, February 1990

Station	Length (m)	Width (m)	Area (m^2)	Mean density per 100 m^2	Estimated total no. of trochus
1	2,260	110	248,600	1.8	4,557.6
2	2,820	120	338,400	3.0	10,152.0
3	1,560	100	156,000	6.3	9,750.0
4	4,520	120	542,000	7.5	40,650.0
5	1,740	130	226,200	5.0	11,310.0
6	4,170	150	625,500	13.3	83,191.5
7	4,170	130	542,100	9.0	48,789.0
8	3,300	100	330,000	0.5	1,650.0
9	4,500	100	450,000	13.0	58,500.0
10	3,600	100	360,000	9.3	33,300.0
11	5,200	100	520,000	6.5	33,800.0
12	3,600	80	288,000	0.0	0.0
Total	41,440		4,627,200		335,650.1
Mean*				6.3	289,842.6

* Total area x mean calculated density

were abundant at these two stations, and could easily be found in the extensive reef cover provided by the coral heads. Many trochus could also be found at the base of these coral heads on the firm, clean substrate. Observations made during the March 1990 post-cyclone survey showed that all branching corals and small coral heads were destroyed, leaving the pools of the inner reef flat leveled and covered with coral rubble. Also, on this survey, virtually no trochus were found in the inner reef flat, as most suitable trochus habitat was destroyed.

No significant amounts of empty shells or shells inhabited by hermit crabs were found, so the trochus that once populated this area were most likely washed away onto the back reef towards the lagoon. It is uncertain if these displaced trochus are still alive, or were killed in the process. Without any evidence to the contrary, it is assumed that the cyclones did not cause any significant amount of trochus mortality and that the trochus population on Aitutaki has not decreased.

The reef damage may have long-term effects on the Aitutaki trochus population by decreasing the area suitable for recruitment and subsequent survival. However, with time, the cyclone damage may be reversed, coral rubble washed away, live corals re-established and suitable habitat for trochus regained. The long-term impacts of the cyclones to trochus and the reef flat will be better understood through future surveys.

Size-frequency distribution data

The data indicate that size frequency distribution did not change significantly between the two surveys. The mean basal diameter was virtually the same (10.1 cm in June 1989 versus 10.2 cm in February 1990). This indicates that the trochus population structure has stabilised with respect to size distribution.

Further, 56 per cent of the trochus from the June 1989 survey were within the legal size range of 8–11 cm, and for the February 1990 survey this figure was basically the same at 58 per cent. This is also evidence of the stability of the Aitutaki trochus population, following the 1988 harvest.

If it is assumed that the present distribution is the optimum for the Aitutaki trochus habitat, then it can be used, along with population estimates, as a key in determining when future harvests should be allowed. The next harvest will again change this distribution, which can be compared with post-harvest size frequency data. When the present size distribution is re-established, and population numbers are sufficient, then another harvest can be conducted.

Harvest quotas

Since by law only trochus within the legal size range (8–11 cm) can be harvested, it is recommended that harvest quotas be set at 60 per cent of the numbers of trochus estimated within this range. Determining quotas in this way will more accurately reflect what is available by law, and setting it at 60 per cent will help ensure that a major portion of the trochus will always be allowed to grow out to become brood stock. Based on this, the quota for the next harvest should be determined from the conservative standing stock estimate of 300,000 individuals, as follows:

Standing stock estimate = 300,000 trochus

Proportion of trochus in legal size range = 58 %

= 174,000 trochus in legal size range

Proportion of legal size trochus
that can be harvested = 60 %

= 104,400 trochus for harvest

Shell quota ≈ 25–26 t
(104,400 trochus x average weight
of legal trochus shell (0.25 kg))

Live trochus quota = 34.5–35 t
(104,400 legal size trochus x average weight
of live trochus (0.33 kg))

The goal of trochus management is to ensure the long-term viability of the resource as a commercial product. It is hoped that basing quotas as above on conservative standing stock estimates, and 60 per cent of those in the legal size range, will maintain a maximum sustainable yield from the Aitutaki trochus population.

It is also hoped to have a yearly trochus harvest which will allow trochus buyers to depend on a regular supply of trochus shell from the Cook Islands, and possibly ensure higher prices for the product.

It is recommended that either satellite images or aerial photographs of Aitutaki be examined to improve the accuracy of trochus population estimates. These would allow exact mapping of the reef, and determination of the total area of trochus habitat on Aitutaki for making such estimates.

A harvest-management tool new to the Cook Islands, the Individual Transferable Quota (ITQ), will be used in the next harvest. Based on the total number of shares (derived from a census of all individuals on Aitutaki) and overall quota of 33 t of live trochus, this harvest's ITQ is 15 kg per share. Quotas will be determined for each household, by multiplying the number of its individuals and the ITQ (e.g. 10 inds. x 15 kg = 150 kg household quota). The Island Council will organise and administer the harvest and buying of live trochus.

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Experiences in trochus resource assessment and field survey

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Introduction

Trochus resource assessment and field surveys in Vanuatu are a relatively recent initiative. The programme to study trochus stocks within the archipelago began in January 1990. The planned duration of the programme is three years.

The socio-economic conditions prevailing in Vanuatu have provided an incentive for stepping up trochus fishing. The world demand for trochus shell products has increased substantially. This is illustrated by the establishment of new shell processing factories in Vanuatu. During 1990, two new shell processing factories were established in addition to the already existing facility. Competition between these three shell processors has led to a spectacular increase in trochus price in Vanuatu, and hence an increase in trochus fishing.

This situation could undoubtedly lead to exhaustion of trochus stocks within the archipelago, and emphasises the need for an assessment of trochus populations.

Planning

Any project requires a lot of careful planning if it is to be successful. A major priority is to have the project objectives clearly established to avoid any misunderstandings. Methodologies to be employed have to be specifically defined to meet each project objective.

Familiarising oneself with facts and features of the regions or areas where the project is to be implemented is very important. It is always useful to have some back-up information about the selected project implementing site(s).

Trochus stock assessment survey

Although this project has not yet been completed, the theoretical and practical experiences gained so far have been very helpful.

The Trochus Stock Assessment Project, funded by USAID, defined the following objectives:

(a) History and monitoring of trochus collection by the three shell factories and their associates.

(b) Study of the biological parameters of *Trochus niloticus*:

- study of *Trochus niloticus* growth rate, and
- study of *Trochus niloticus* age at sexual maturity.

(c) Analysis of trochus stocks in Vanuatu:

- analysis by population size and movement,
- estimation of *Trochus niloticus* catchability, and
- quadrats and sampling of size groups.

The choice of study locations is made with respect to the specified project objectives.

The following preliminary data are adopted as guide-line information:

> *It is noted that trochus growth rates vary considerably from one region to another in the South Pacific and this variation influences both the management (usually based on size limits) and marketing (shell quality may vary in accordance with the size of the specimen and possibly the catch zone).*
>
> *In addition, size at sexual maturity also seems to vary by region: 60–70 mm in the Andaman Islands; 50–60 mm in Australia; 54–65 mm in New Caledonia.*
>
> *Ease of access to the reef influences the fishing effort and the frequency of fishing; a reef exposed to high seas and remote from population centres is not fished in the same way as a reef located close to a village.*

Using these initial data and information as guidelines and wishing to account for climatological, biological, sociological and economic considerations for the whole of the archipelago, a number of reefs are selected for the same study programmes to be undertaken.

The choice of reefs is based on a number of criteria:

- possibility of recording the quantity of *Trochus niloticus* removed from a heavily-fished reef,
- geographical distribution of reefs studied throughout the archipelago, and
- simplicity of socio-economic systems.

Description of the selection criteria

Recording quantities of trochus removed from the reefs

Monitoring the quantity of trochus removed from the reefs under study is essential to comply with the aims of the study. One of the major problems is obtaining accurate information on trochus quantity removed. By closely working with a shell processing factory (Melanesian Shell Products) it is possible to select islands where MSP agents are established. Thus it is possible to identify the quantity of trochus removed from the selected studied reef.

Geographical distribution

The geographical distribution of the islands within the archipelago means that the study locations are divided between North and South. This will make it possible to highlight any differences in the assessment of the biological parameters, such as growth rate and size at sexual maturity.

Choice of a simple socio-economic system

The reef chosen as a study location must not belong to an excessive number of villages. To satisfy the objective of the study, the reef should only be fished by one village. This will make it easy to monitor the production rate of a single village, to identify the number of fishermen and describe the socio-economic aspects of the fishery.

Selected methodologies to meet the Project objectives

The most important aspect of a project is the preparation, selection and allocation of appropriate methodologies to meet the various project objectives. For the Trochus Stock Assessment Project, the following selected methodologies are assigned to satisfy each objective:

Objective 1: History and monitoring of collection by business.

Method: *Analysis of data on production and exportation of* Trochus niloticus*, supplied by the processing factories.*

Objective 2: Demonstration of the biological parameters of *Trochus niloticus.*

2a: Study of growth rate.

Method: *Tagging and recapturing of* Trochus niloticus *on different reefs within the archipelago*.

2b: Study of age of achieving sexual maturity.

Method: *Microscopical analysis of the* Trochus niloticus *gonad system.*

2c: Study of biotope suitable for *Trochus niloticus* habitats.

Method: *Underwater surveying of existing* Trochus niloticus *habitats.*

Objective 3: Analysis of *Trochus niloticus* stock in Vanuatu.

3a: Structure analysis by population size and movement.

3b: Evolution of *Trochus niloticus* catchability.

Method: *Analyse the evolution of* Trochus niloticus *catchability throughout a lunar month.*

3c: Quadrats and sampling of size groups.

Method: *Analysis of the stock movements on various representative reefs.*

Project implementation

For this section, I shall deal briefly and generally with only two major project objectives:

(a) growth rate study, and

(b) study of trends in the structure of the *Trochus niloticus* population.

Growth rate study

A study of trochus age and growth was carried out in Efate in 1982 (Bour & Grandperrin, 1985). However this study was limited to only one location within the archipelago and thus does not provide enough understanding of growth parameters applicable to other trochus populations in Vanuatu.

This newly-revised growth-rate study is extended to different locations within the archipelago, with the aim of gaining further understanding of the trochus growth-rate parameters. There are a number of reasons why the study should be extended:

- the difference in the water temperature existing between the North and South of the archipelago may generate differences in the growth rate of *Trochus niloticus* within the two regions,
- a growth-rate study based on reefs with more or less favourable biotope may make it possible to re-define the existing knowledge and determine the optimum biotope for *Trochus niloticus*, and
- growth rate may be considered as one of the vital factors required in monitoring the population structure of *Trochus niloticus*. Thus it is necessary to obtain at least an accurate estimate of the growth parameters.

Catch and drop zones

The locations for the growth-rate study are chosen with reference to the behaviour of the trochus fishermen (i.e. favourable fishing areas, ease of access to fishing grounds, etc.). If possible, it is very useful to select a reef zone where a custom taboo or ban has been instigated. This will prevent any possible vandalism by the fishermen towards the research work (e.g. collecting tagged trochus and selling them to buyers).

Each study zone is marked on a sea chart on a scale of 1.0 cm to 25.0 km. A combination of three recording methods are used for this purpose:

(a) recording a seamark,

(b) placing numbered 16 mm steel rods on the study zone, and

(c) marking a specific point on the coast (rock, tree, building, etc.).

Marking method

From each study area, all the collected trochus are measured across the base to obtain basal diameters. The trochus are marked with an epoxy resin which is applied onto a dry, clean patch on the trochus shell. A number is inscribed on the resin 15 to 20 minutes later. The marked trochus are returned to the study area when the resin on each shell has dried completely.

The growth-rate study must be conducted on trochus of varying sizes. Special attention must be taken to measure and mark as many small trochus as possible as growth rate is inversely proportional to age and size, (i.e. it decreases with age and size). Growth increments in larger, older trochus will be small, and there is a greater likelihood of error when estimating growth parameters based only on large animals.

Recapture rate

According to Grandperrin and Bour (1985), recapture rate decreases as the interval between capture and recapture increases. In order to minimise error when assessing growth-rate parameters, it is necessary to maximise the number of trochus recaptured and to vary the time interval between capture and recapture. Thus new trochus are marked during each visit to the study site.

Processing of results

The Von Bertalanffy growth function can be easily fitted to growth rate data and used to establish size/age ratio, which is useful for the purposes of fisheries legislation.

Obtaining a growth curve

The accuracy of the growth-rate parameter estimates can be improved by diversifying the intervals between measurements. The end of the research programme will be determined by the degree of accuracy obtained in calculating the growth parameters. The correlation coefficient obtained from fitting the Von Bertalanffy growth curve to the growth increment data should be high, i.e. close to unity, and the standard errors of the growth parameters should be low.

Once the trochus have been recaptured during several occasions, a better estimate of growth rate of trochus in various parts of the archipelago can be made.

Study of trends in the structure of the **Trochus niloticus** *population*

This study may make possible the quantification of effects corresponding to exploitation of the *Trochus niloticus* population. To assess whether exploitation is greater or lower than the optimum level, the following data are paired:

- the production data by reef obtained from the shell factories, and
- the trochus sizes found on the reef.

The methodology is based on the monitoring of the size structure of the *Trochus niloticus* population in specific areas of the reef, and comparison of this with the quantity of trochus caught on the same reef by fishermen.

Survey methods

In 1981, Nash (1981) tested the three following reef surveying methods for the purpose of studying trochus populations: transects, quadrats, and swimming with a flow meter. According to him, none of the methods proved to be entirely satisfactory. Nevertheless, transect and quadrat survey methods were tested to determine which method would best answer the specified project objectives.

Transects

A test study was conducted in February 1990 in the bay of Touktouk in Efate. This provided an opportunity to quantify the problems encountered when attempting to conduct a survey using transects. The variation in the number of trochus collected in each transect is indicative of the clustering behaviour of trochus. An accurate estimate of the average number of trochus found per transect is difficult to determine. To obtain a 95 per cent chance of achieving an accurate estimate of the population density with a 20 per cent error margin, more than 500 transects would be required to survey the bay of Touktouk. Because of the topographical complexity of the reef and the clustered distribution of trochus, the use of transects is not suitable for studying the trochus population in the bay of Touktouk.

Quadrats

According to Nash (1988), this method is more suitable to survey the distribution of trochus populations on a reef

flat. A comparative study was conducted at the same site where transect counts were made in February 1990, and this provided some very interesting results. The quadrats were set with areas of 900 m^2 and with a search time of 30 minutes. The divers in the transect study were used for this second test trial. The observed number of trochus was considerably higher than that from the transect method.

Comparison of methods

This small experimental study highlights the fact that the number of trochus collected using transect methodology is not representative of the population on the reef flat. A search team is more efficient using quadrat surveying methods. With quadrat methods the number of trochus visible in a specified area can be evaluated. As this specified area can be fixed, the search team can search the area in the same way that fishermen collect trochus, by inspection of all possible holes, crevices, etc., for trochus.

Placing of quadrats on selected reefs for study

For each reef studied, the location of quadrats is decided according to the fishing habits of the local fishermen. Thus the quadrats are usually placed on areas which are known to be fishing grounds, and thus heavily fished.

The location of each quadrat is recorded as follows:

- placing of numbered steel rods at the corners of each quadrat, and
- a description of the main characteristics making it possible to locate each quadrat (e.g. the distance from a specific point on the land).

Recording of data

In accordance with the same principles used for studying growth rate, a whole range of data concerning biotope, depth and condition of the sea are recorded.

Frequency of surveys

Once a year the survey team returns to the reef to carry out fresh surveys of the number of trochus at the same locations, and to record their size and population density. The same survey method is used. To avoid any problems associated with the phases of the new moon or the sexual cycle (Heslinga, 1981), future surveys in the same areas will be conducted during the same lunar phases from year to year.

Effectiveness of divers in collecting trochus

The variation in the average size of the trochus collected by each search team was analysed for all the zones surveyed during 1990. The result shows that the average size of the trochus collected does not vary from one team to another for the same initial trochus population. The consistency of this result means that it is possible to compare the development in time of the average size of trochus. The search time of 30 minutes per quadrat of 900 m^2 minimises possible errors in the number of trochus collected due to the efficiency of each diver.

General remarks

The worst attitude that a project leader or coordinator could have is an inflexible attitude. It can be concluded after one year of coordinating the Trochus Stock Assessment Project that being inflexible does not usually help in carrying out a project smoothly. It is always important to allow room for flexibility and open-mindedness.

A few rules have resulted from some bad experiences during the first year of carrying out the project:

(a) never go against the laws of nature,

(b) call off the mission whenever danger arises (e.g. possibility of losing lives by shark attacks),

(c) always be cooperative, gentle, and understanding with the reef owners and the village dwellers and accept whatever accommodation is allocated,

(d) be attentive and cooperative with your colleagues,

(e) always have an alternative Plan B, just in case Plan A does not work out and be prepared to carry out Plan B, and

(f) be prepared to repeat the research study if the first one is disturbed by natural phenomena or vandalised by fishermen (e.g. collecting of tagged trochus).

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Recommendations for the 1991 trochus harvest in Yap

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Introduction

After the 1990 trochus harvest, it became evident that the trochus surveying, harvesting, monitoring and purchasing systems in Yap State needed reviewing and amending. The State Governor formed a committee to review and provide recommendations on MRMD's suggestions for modifying the harvest for 1991 and future years. The following are the draft recommendations of the committee.

The recommendations within this draft still require some input from the committee to ensure that the suggested system is workable. This year's harvest should be considered a trial of the system. As there are bound to be unforeseen problems, changes can be made for future seasons as deemed necessary or appropriate.

MRMD surveys

Methods

Prior to any harvest, it will be necessary for MRMD to conduct surveys of both Yap proper and the outer islands. For this year, the methods used for past surveys will again be used. The cost of surveying is included in MRMD's operational budget.

In May, Joe Fanafal (who will be running all MRMD trochus work) will be attending a South Pacific Commission workshop on 'Trochus Resource Assessment, Development and Management' in Vanuatu. One purpose of the workshop will be to standardise trochus surveys throughout the Pacific so that data will be comparable. We will adopt the suggested method for future surveys once he is trained.

Analysis and reporting

MRMD now has suitable computer hardware and software to analyse the survey and harvest results. The staff are currently being trained in their operation.

Timing

MRMD will carry out surveys of Yap proper as soon as our boats are serviceable and the weather conditions permit, hopefully within the next month.

Surveys of the outer islands will also be conducted as soon as possible. The breakdown of the *Micro Spirit*, combined with our other work commitments, makes it impossible to estimate when that survey will be completed.

Biological considerations

Without adequate stocks of trochus, there can be no viable trochus fishery. To maintain a sustainable fishery some controls are required on harvesting. The following are recommended for 1991:

- *Minimum size limit:* The minimum size limit will be set at three inches across the widest part of the base of the shell. This is slightly above the size at which trochus begin to reproduce.

- *Maximum size limit:* The maximum size limit will be set at four inches across the widest part of the base of the shell. The large shells are needed to provide the brood stock to replenish the trochus population. Larger shells are also of lower quality.

- *Only live trochus to be brought in:* Live trochus only will be brought to the weighing stations so that any oversized or undersized shells can be returned to the reef alive.

- *SCUBA not to be permitted:* The use of SCUBA is an unfair advantage to those few people who have access to it.

- *Harvesters provide catch-effort data:* MRMD requires as much information as possible from the harvesters as to where they collected shell (general areas only), the number of collectors and the number of hours they spent collecting.

Registration of harvesters and buyers

Registration of buyers

All potential buyers must register with the Division of Commerce and Industries (Department of Resources and Development) prior to the harvest season. They should notify DCI (DRD) of their minimum buying price. The buyers should be required to obtain all relevant FSM and/or Yap State permits. Upon registration they will be provided with details of the purchasing and monitoring systems, and their responsibilities and obligations.

The questions of a) whether or not a registration fee should be required for buyers, and if so, b) how should it be collected, and c) should a 'tonnage fee' be levied, still need resolving. The reason for collecting fees is to help defray the costs of harvest monitoring.

Having a local counterpart is optional, but encouraged. All registered buyers will be allowed to compete freely in

purchasing from the harvesters to ensure that the highest price possible will be obtained for the benefit of harvesters and the local economy.

Registration of harvesters

All harvesters must register with MRMD prior to collecting trochus. Only FSM citizens can register. At the time of registration all restrictions and procedures will be explained to them. A $US 5.00 fee will be charged and a numbered collecting permit issued. The permit will have the restrictions written on the back.

The harvesting permits will be non-transferable. Each boat, raft, etc. collecting must have at least one permit and permit holder on board. The permits must be available for inspection at all times while collecting, or in possession of trochus shell.

The permits must be presented by the harvester at the weighing station for their shell to be inspected and weighed. The permit plus the inspection receipt must be presented by the harvester for inspection at the time of selling their shell. Payments can only be made to registered harvesters in possession of their permits.

Monitoring

Monitoring of boats

The monitoring of boats will start one day before the harvesting is due to commence. This is to prevent people from collecting trochus into 'stock piles' before the season opens. Boat patrols will be carried out at irregular intervals throughout the harvest season. The crew should check for permits, illegal sized shells, SCUBA equipment, etc.

Three boats will be used: one from MRMD, the police boat, and EPA's boat. Each boat will have a crew of three, consisting of one person from MRMD, Public Safety, and YFA/EPA.

Monitoring at weighing stations

Three weighing stations will be set up: one at MRMD's dock, one at Gatumoon, and one at Amin (Maap). Each weighing station will require five inspectors. Each of the above boats and associated crew will be assigned to one of the stations, and supplemented with two more people who will drive by vehicle to the stations. The boats will be required at the inspection stations to take any confiscated oversized and undersized trochus back out to the reef. Having the boat crews work at the inspection stations will reduce the total number of personnel required each day.

The inspectors's duties, for each harvester with a valid permit, would be as follows:

- inspect and measure all trochus shell,
- confiscate all oversized, undersized, smelly (dead), and empty shells,
- weigh the good trochus,
- weigh and count all the illegal shells,
- collect the catch-effort data, and
- fill out and sign the inspection receipt.

At the end of each weighing session, the boat patrol should return the illegal sized trochus to the reef.

Inspection stations will be open only twice a day, starting from the first morning after the harvesting commences and ending on the last morning of the harvest. The stations will only be open for two hours at a time: from 07:00 to 09:00 hrs and 17:00 to 19:00 hrs. No inspection will be conducted outside those hours (harvesters who arrive before the closing time will be inspected, but not those who arrive after closing). By having set times the personnel requirements will be kept to a minimum.

Buying system

For the 1991 trochus season only live shell will be bought. For future harvest seasons the system can be modified as deemed necessary or appropriate.

No set time was decided on for when buying should commence, but it should be between three to five days after the close of the harvest season, i.e. long enough for the shells to be cleaned.

At least one person from MRMD and one from Public Safety should be present when the buyers are purchasing to check the permits and inspection receipts of the harvesters. Only up to 80 per cent of the live weight recorded on the receipt at the first inspection can be sold to the buyers. The buyers cannot purchase any trochus shell without it being checked by inspectors. All of the buyers records should be made available to the inspectors and MRMD.

Buyers will notify DCI of their buying price prior to the start of purchasing, and any changes in their prices, so that the harvesters can be notified. They should also provide notification of their buying location.

Buying will only be permitted for six hours (e.g. 09:00 to 15:00). No shell will be purchased outside that period.

Announcements

No decision was reached as to whether a two- or three-part announcement should be used:

The following outlines a three-part announcement. A two-part system would combine parts one and two together. The main advantage of a three-part announcement is that it will allow adequate time for the new system to be understood prior to setting the harvest dates.

The purpose of the announcements is to notify all potential harvesters and buyers of the coming trochus harvest season. In addition, they should contain all the relevant

information to ensure that people are aware of the new system, its requirements and restrictions.

First public announcement

This announcement should notify the potential harvesters and buyers that there will be a harvest season. It should contain the restrictions, instructions to harvesters, penalties, etc. The wording needs to be checked by the AG's Office to ensure that it is legally adequate.

The restrictions for the 1991 harvest should be as follows:

- All harvesters must register with MRMD prior to collecting trochus. At the time of registration all restrictions and procedures will be explained to them. A US$ 5.00 fee will be charged and a numbered collecting permit issued. Only FSM citizens can register and harvest.

- All buyers must register with the Division of Commerce and Industries, Department of Resources and Development prior to the season. They should notify DRD of their minimum buying price. Upon registration they should pay a fee of US$ 100.00, and provide proof of having obtained any relevant FSM or Yap State Foreign Investment Permits.

- Only trochus shells that are 3 to 4 inches across at the widest part of the base can be collected, be in people's possession, or be sold.

- All trochus must be brought into the weighing stations alive to be inspected and a receipt of the shells' weight issued.

- Only shells with a receipt can be sold to the buyers. No cleaned shell in excess of 80 per cent of the recorded live weight can be sold.

- No SCUBA equipment can be used in the harvesting of trochus shell.

- The harvesters will provide MRMD inspectors at the weighing stations information on the number of collectors, how many hours they spent collecting and the general areas from which they collected.

- During the harvest season the meat can only be sold locally ('on-island').

Second public announcement

The second announcement should be made just prior to the proposed start date. It should contain the information on when the season will open and close, the location of the inspection stations, and the times that the stations will be open. The opening time for the collecting season should be set at 18:00 and the closing time at 06:00. The season should be for, at most, seven days (the actual duration will be determined after the MRMD surveys).

Third and final announcement

The third and final announcement should contain information on the buying process, who the buyers are, their locations, the prices they offer, and the time the buyers will be permitted to buy.

Sale of trochus meat

Due to difficulties with ensuring that oversized shells are not harvested just for meat, this year the sale of meat should be limited to local/on-island sale only. The pros and cons of monitoring and enforcing the sale of trochus meat off-island need to be considered in detail before permitting it in future years.

Outer-island harvests

A number of problems need to be considered by the outer-island representatives on the committee and by the Council of Tamol, before the proposed system will be workable for the outer islands. Until MRMD completes the outer-island section of the trochus survey, we are unable to say which islands and atolls will be able to harvest this year. From last year's survey it appears harvesting might be possible at only Ulithi and perhaps Woleai.

MRMD is due to receive money for reseeding some of the outer islands later this year. Reseeding stock will have to come from Ulithi and perhaps Woleai.

Some questions that need to be considered for adapting this system for the outer islands are:

- How will harvesters be registered?

- How will the harvest be monitored, and by who?

- How will the live trochus be inspected, and by who?

- How will the shell be purchased?

- How will it be transported to Yap, and who will pay?

- How should the outer island harvest be timed in relation to the Yap proper harvest and *Micro Spirit* scheduling?

- What will be the personnel and budget requirements?

These questions were not addressed at the first committee meeting.

Personnel and budget

Personnel

At MRMD, all trochus activities are the responsibility of Joe Fanafal. He will be responsible for organising and coordinating MRMD's trochus survey and harvest assignments.

It is assumed that for the harvest on Yap-proper, only MRMD, Public Safety and YFA personnel will be used. EPA has offered the use of their boat and one person to drive it. MRMD may have to hire temporary workers to achieve their commitments.

Three boats will be required, one each from MRMD, Police and EPA. At least three vehicles will also be needed to transport inspectors and equipment to the weighing stations. One vehicle will be provided by each of MRMD, Police and YFA.

Each of the above agencies should prepare an outline of their personnel situation for the next committee meeting.

Budget

The following consumable goods budget is based on a seven-day harvest of Yap-proper. A personnel budget will not be included until the above agencies review their manpower situation. The cost of the surveys of both Yap-proper and the outer islands is covered by MRMD's operational budget.

Consumable goods

- printing of inspection receipts (1000 carbon copy)
- paper for harvesters' permits, reports, etc. (1 rm @ US$ 5.00)
- 'zip-lock' plastic bags for permits (4 boxes @ US$ 22.00 ea.)
- weighing scale (112 1bs) (3 @ US$ 14.00 ea.)
- copra bags for weighing (30 @ US$ 8.50 ea)
- communications/postage to buyers
- fuel (gasoline: 6 drums @ US$ 51.04 + oil: 5 cs @ US$ 32.57)

Regulations and legislation

The AG's Office has provided two memorandums and two draft bills for review. The memorandums discuss:

- User fees and the rule-making authority of Marine Resources.
- Other approaches to the collection of user fees:
  - Yap Fishing Authority
  - Enterprise fund
  - By decree of Governor
- License and permit requirements for trochus buyers and harvesters:
  - FSM Business License
  - FSM Foreign Investment Permit
  - Yap State Business Licenses
- Non-citizen participation in trochus harvesting.
- Format and wording for trochus harvester's permit.

These need to be discussed at the next committee meeting.

A synopsis of the biology of green snail (*Turbo marmoratus*)

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Introduction

The green snail is a gastropod belonging to the family Turbinidae. The main species of turban shells harvested in the South Pacific are the green snail (*Turbo marmoratus*), the rough turban (*Turbo setosus*) and the silver-mouthed turban (*Turbo argyrostomus*). *T. setosus* and *T. argyrostomus* are mainly targeted for food in the South Pacific region and their shells are discarded.

The majority of this paper is concerned with *T. marmoratus*, the largest species of the family, which grows to more than 20 cm in shell diameter and 2.0 kg in weight. It is herbivorous and its nacreous shell is highly prized for inlay material of lacquer-ware, furniture and jewellery. It has been commercially exploited throughout its Indo-Pacific range for at least a century.

In the southern Ryukyus in Japan, divers harvesting sedentary resources have targeted green snail since the 1880s (Yamaguchi, 1988a). As a result of the experience in southern Japan, and more recently elsewhere, it appears that green snail populations cannot sustain intensive fishing over long periods. This is apparent from the rapid depletion of green snail in actively-fished areas and the slow rate at which populations re-establish after the termination of fishing.

The green snail is not an abundant resource in the South Pacific. However, despite its relative scarcity, compared to many other South Pacific marine resources, increasing demand for pearl shell, and the relative value of green snail compared with other pearl shell species for inlay work, has resulted in premium prices being paid for green snail. As a result, it has made significant contributions to the total value of exports of marine products from several member countries of the South Pacific Commission in the period since WW II. Until a few years ago, the majority of exports were in the form of complete shells. More recently, in an attempt to add value to exports, it has become increasingly common for the shell to be transformed locally into button blanks and exported.

Until recently, relatively little was understood about the biology and ecology of green snail (Yamaguchi, 1988b). With success in rearing other molluscs such as trochus (*Trochus niloticus*) and giant clams (*Tridacna* spp.) in hatchery systems at a number of locations in the Pacific, researchers in Okinawa began aquaria-based investigations on the biology and ecology of green snail in the mid-1980s. As a result, scientists today have a reasonable knowledge of the life history of this mollusc (Yamaguchi, 1988b) although information concerning growth, recruitment and mortality remains poorly documented.

This chapter reviews available information concerning the biology, distribution and ecology of green snail. It includes an overview of the development of fisheries for green snail in the South Pacific and elsewhere and provides information on the volume and value of current exports of this shell from the region. Appropriate research strategies that could be developed to monitor fisheries for green snail in the South Pacific, and possible management options that could ensure long-term sustainable exploitation of the resource, are discussed.

Taxonomy

The class Gastropoda is the largest class of the phylum Mollusca. Over 35,000 extant species have been described, and to this total should be added some 15,000 fossil forms (Barnes, 1968). The class has an unbroken fossil record since the early Cambrian period and is considered to be at the peak of its evolutionary development (Barnes, 1968).

The green snail, *Turbo marmoratus,* belongs to the family Turbinidae in the order Archaeogastropoda, subclass Prosobranchia of the class Gastropoda. Other important members of the family in the tropical South Pacific are *Turbo setosus* and *Turbo argyrostomus*.

Distribution

The green snail is generally distributed throughout the Indo-Pacific region in the western Indian Ocean (Seychelles, Chagos, Andaman and Nicobar Islands), throughout South-east Asia (Malaysia, Indonesia, Thailand and the Philippines) to the South Pacific, as far east as Fiji. It has not been reported from Micronesia, and is rare in Australia south of the Torres Strait. As a result of a successful introduction from Vanuatu in the 1950s, it is now established in French Polynesia. In the western Pacific its distribution extends to approximately 29°N in the Ryukyus Islands in southern Japan.

Habitat

Green snail share similar habitats with other large gastropods such as the trochiids, *Trochus niloticus* and

Tectus pyramis, and turbinids such as *T. argyrostomus*. Although the degree of overlap between habitats occupied by these gastropods has not been clearly defined, all prefer healthy coral reef environments subject to a constant, good flow of clean oceanic water.

Adults are found on reef crests in water from one to five metres deep, although they are also found in deeper water. Deeper habitats are characterised by well-developed reefs with abundant live coral growth. The topography of the reef crest–seaward reef slope is characterised by elevations, depressions and crevices, having a rich flora of microscopic algae on consolidated limestone substrates or terraces. Green snail range deeper than trochus, extending down reef slopes to at least 20 m. Throughout their habitat they usually retire during the day beneath coral thickets or into crevices or depressions.

Juvenile green snails smaller than three centimetres shell diameter have not been found in the field. At Tokunoshima in the Ryukyu Islands, large juveniles and sub-adults have been collected from reef crest areas within crevices made by burrowing sea urchins *Echinometra mathaei* (Yamaguchi, 1988b).

Locomotion

The green snail is nocturnal. It emerges after sunset from crevices and depressions to graze. The foot of *T. marmoratus* is peculiar in having a central axis along the dorsal central line from the top to the tail of the muscular foot. When moving, either side of the half-foot glides forward and then the other half follows. This alternating movement of the foot is unique in the family Turbinidae.

Life history and population biology

Reproduction

Although many gastropods are hermaphrodite, the green snail is dioecious, i.e. the sexes are separate. The single gonad, either ovary or testis, is located in the spirals of the visceral mass next to the digestive gland. Gametes of both sexes are freely released in the water column.

K. Kikutani (see article in this publication) sexed live green snail by the sexual dimorphism of the genital papillae that surround the right kidney opening. Female animals have large, bean-shaped papillae, while the papillae in males are small and conical. Similar sexual dimorphism in genital papillae is found in *Turbo intercostalis* (Joll, 1980) and *T. argyrostomus* (Tanaka, 1988). The papillae in green snail are visible when the adult snails fully extend their bodies outside their shell.

Devambez (1961) estimated adult green snail become sexually mature above 15 cm shell diameter in Vanuatu. The smallest female snail with well-developed gonads reported from the Reeky Islands was approximately 13 cm shell diameter (Yamaguchi, 1988b). Although requiring verification, it is possible that sexual maturity in green snail may be detected by the presence of a continuous rib formed on the upper whorl on the shell of adult snails.

In the Ryukyus, where significant seasonal fluctuations in water temperature exist, green snails appear to breed only in the summer months. Mature specimens are found during much of the warmer period of the year, with peak breeding activity in both early and late summer. It is possible that in tropical areas of their distribution, mature animals breed repeatedly throughout the year.

A female green snail of 2.0 kg (total weight) may contain up to 7 million eggs in a fully-developed ovary. Green snail has not been observed spawning in the wild. In the laboratory, spawning has been induced by a method established for the related species, *Turbo cornutus* (Yamaguchi, 1988b). It was first successfully attempted on green snail in 1986.

Brood stock animals are kept in a holding tank in crowded conditions with strong aeration for one day, by which time the water becomes fouled with excretions and mucus. Within one hour after changing the fouled seawater with fresh running seawater, some of the snails commence spawning, the males first. The spawners must be retained in a dark environment during spawning induction. Due to the copious amounts of sperm produced by males, they should be removed from the holding tank as soon as they begin producing sperm to avoid the possibility of polyspermy of eggs released from the females in the same tank. This method is effective in spawning induction of most larger archaeogastropods, including trochus. Since males are more responsive to induced spawning, the sex ratio of snails should be kept in favour of females in the hatchery production of larvae. Seawater treated by UV-light appears to enhance spawning induction.

Eggs and sperm are ejaculated repeatedly, with contractions of the snail's body into the shell. This activity can last for half an hour. Spawned eggs are slightly heavier than seawater, so that they settle on the bottom of a container if the water is not agitated. However, the eggs can be kept suspended with slight agitation, so they are likely to be easily dispersed when spawning occurs in the wild.

Early life history

Knowledge of the early life history of the green snail has resulted from observing the development of fertilised eggs in laboratory conditions following the induction of spawning. Fertilised eggs of green snail hatch into trochophores about 22 hours after spawning in water temperatures between 21 and 23°C. This is reduced to 12 hours in water temperatures of 25°C. During the first day after hatching, first the trochophores and later the veligers swarm near the surface. Pediveligers are formed in the third day and the majority of larvae settle during the fourth day.

Early juvenile green snail show a series of step-wise transformations in shell morphology as they grow. Just after settling, the first whorl following the transparent proto-

conch extends with a slight extension of the aperture, so that the juvenile appears as a disc with a series of small knobs along the outer corners of the opaque white shell. The juvenile body retains the light green colour of the embryonic stages. Next, the shell aperture expands in the second whorl, and two rows of dark brown blotches interspaced with knobs form. By the time the third whorl develops the shell sits relatively flat on the substrate, in contrast to the earlier discoid stage which holds the shell upright. Thereafter, the juvenile shell grows spherically. The shell surface gradually becomes uniformly dark green with a series of brown blotches. The juvenile assumes adult-like morphology at about 7 mm shell diameter, which is reached about 6 months after fertilisation.

Age and growth

Juvenile green snails grew on average to about 2.0 cm (shell diameter) in laboratory experiments (Yamaguchi, 1988a) but probably did not realise their full growth potential during this exercise, as the supply of suitable algae was limited. It is likely that juvenile green snail grows to between two and three centimetres in shell diameter one year after spawning. Judging from the results of field-rearing experiments, the estimated age of the green snail at sexual maturity is three to four years (Kikutani, pers. comm.).

Feeding behaviour

Adult green snail graze on epibenthic microalgae from surfaces of limestone substrates. They also ingest macroalgae. The animal can hold blades of soft algae between the two halves of the frontal part of its foot so that it may pick up and eat algal fronds deposited on the bottom of aquaria.

In the laboratory, green snail prefers green and red algae to brown algae. Among the green algae, *Enteromorpha*, *Monosroma* and soft varieties of *Ulva* are readily consumed. However, those with a hard texture and consistency, such as *Ulva conglobata*, *U. reticulata, Cladophoropsis* spp. and *Dictyosphaeria* spp. are not consumed. Perhaps the most favoured algal genus is *Celdium,* which grows on substrates as short turfs. As long as this genus is available, green snails in aquaria do not select other algae. Red algae favoured include *Gracilaria, Hypnea* and *Eucheuma*, all of which are carageenan or agar-producing genera in the same category as *Gelidium*. *Dasya* and some other conspicuous species are not accepted as food.

Several species of dried algae, available commercially for human consumption, have also been offered to green snail in the laboratory. All brown algae (kelps, *Hizikia* and *Undana*) tested were not consumed, and dried *Enteromorpha* did not appear to stimulate the appetite of the snail. Dried *Glacilaa* and *Eucheuma* were consumed, but only in small amounts by starved animals. It is also possible to feed green snail with blocks or films of agar or carageenan jelly originating from commercial agar processed from *Gelidium* or carageenan from *Eucheuma*.

Juveniles can be maintained in laboratory aquaria by feeding with epibenthic microalgae covering coral rubble and other substrates such as plastic plates that have previously been submerged in the sea for several weeks. Feeding substrates in aquaria should be renewed weekly. At about six months of age, juveniles can be fed in laboratory aquaria on fleshy algae such as *Gelidium* and *Monostroma*. During the winter months, when water temperature falls below 18°C, juveniles cease feeding in laboratory aquaria.

Parasites

Although parasitism and commensalism have not been studied in detail for *T. marmoratus*, some obvious ectoparasites have been recorded as common in field observations of *T. argyrostomus* populations. Yamaguchi and Kikutani (1989) recorded that adult *T. argyrostomus* from Federated States of Micronesia were infested with a number of conical hipponiciid shells, *Sabia* sp.

These shells, measuring up to 15 mm at the base, attach around the aperture of the host's shell where they bore small depressions. Thus if *T. marmoratus* populations are also susceptible to infestations of *Sabia* sp., mortality of juveniles will be significant and the commercial value of adult shell will be adversely affected.

Predators

Very small juveniles less than 1.0 mm in diameter have been observed to be preyed upon by small acoels, which cohabit coral rubble substrates on which veligers settle (Yamaguchi, 1988b). Other small turbellarians, probably a species of *Rhabdocoel*, have also been observed to feed on large numbers of newly-settled green snails. Although not tested systematically, there are a large number of potential predators, such as small crabs, predatory gastropods, and others, which could take a large toll on newly-settled juvenile green snail.

Juveniles less than a few centimetres in diameter (i.e. less than one-year old) are particularly susceptible to predation. In aquaria, polyclad turbellarians, introduced accidentally with feeding substrates, have been observed to attack and kill juvenile snails by blocking the shell apertures with their flat bodies (Yamaguchi, 1988b). Xanthiid and portunid crabs also attack juveniles by cutting outer shell apertures with their pincers. Some juveniles can survive such attacks by withholding their soft bodies deep inside the shell behind the opercula.

Large hermit crabs frequently occupy green snail shells but whether or not hermit crabs are significant predators requires clarification. Other potential predators of juvenile green snail may be octopuses, spiny lobsters, hawksbill turtles, some fishes such as wrasses and puffer fish and elasmobranchs such as carpet sharks and rays. Porcupine fishes are probably important predators because their stomachs often contain shell fragments and operculae of gastropods, including turban snails (Yamaguchi, 1988b).

Fisheries and resource enhancement

Fisheries

Green snail has been exploited in the Indian and Pacific Oceans and throughout South-east Asia for centuries for the mother-of-pearl trade. However, figures for production are generally inaccurate and highly variable. The Food and Agriculture Organization of the United Nations (FAO) cites the total world production in 1985 at 500 t [based on Australian and Malaysian figures only]. This increased to 800 t in 1986 and 1,000 t in 1987 and 1988 (FAO, 1990).

Historical catch information is difficult to obtain from areas outside the Pacific. In the Indian Ocean, green snail is harvested in the Andaman and Nicobar Islands where 105 t were harvested in 1976 (Appukuttan, 1977; 1979). In the 1940s it was fished commercially in the Seychelles and Chagos Archipelago, fetching up to £ 400/t, but as in other regions, the market declined rapidly with the introduction of plastic substitutes (Travis, 1959).

In Asia, green snail has been fished commercially in the Philippines since the beginning of this century when fisheries existed in Davao Gulf, off the east coast of Mindanao, at Tawi-Tawi and Sitanki (Seale, 1916). In the 1920s, exports went to the United States of America and Japan (Talavera & Faustine, 1931). In 1979, at least 32 t were collected from the region of Capiz and Zamboanga (Anon., 1980). Indonesia exported an average of 100 t annually mainly to Japan, Singapore and South Korea in the 1960s but exports are now banned. Wells (1989), using data from government custom's statistics, listed major exporting nations of green snail outside the SPC area as follows: Malaysia (400 t in 1980), Andamans (105 t in 1976), Indonesia (77 t in 1981) and the Philippines (32 t in 1978).

In the Pacific, Papua New Guinea, Solomon Islands and Vanuatu have been exporting green snail since WW II. The total amount of export from these three countries was 100–200 t per annum in the mid-1970s, but that fell to less than 60 t in the 1980s.

Glucksman and Lindholm (1982) examined developments in the commercial shell industry in Papua New Guinea since WWII, and Dalzell and Wright (1986) summarised available information for green snail exports from Papua New Guinea for the period between 1950 and 1984. Wells (1982) reviewed the commercial shell trade in Papua New Guinea, including some discussion on green snail.

During the period 1950–1984, green snail exports averaged 59.7 t per year and contributed 12 per cent to the total volume of exports of mother-of-pearl from PNG, the balance being made up of trochus (84%) and pearl oyster shell (*Pinctada* spp.) (Dalzell & Wright, 1986). Current fisheries legislation in Papua New Guinea prohibits the harvesting of green snail less than 15 cm shell diameter. However, as elsewhere in the Pacific, subsistence fishermen diving for sedentary resources do harvest smaller live snails for their meat. The size of such fisheries is unknown.

Annual exports of green snail from Solomon Islands averaged 7.1 t for the period 1981–1989, with a range between 3.1 t and 22.3 t. Skewes (1990) estimated that at recent levels of exploitation, stocks were probably being overfished. Solomon Islands currently has no legislation regulating the harvest of green snail.

The annual production of green snail from Vanuatu was documented during analysis of data relating to the production of trochus in 1983 (Grandperrin & Brouard, 1983). As with trochus, harvest records for green snail from Vanuatu are limited to the period since 1966. For the period between 1966 and 1982, exports of green snail averaged 21 t annually with a range of 7 t to 65 t. The Government of Vanuatu has legislated against the harvest of green snail with a shell diameter less than 15 cm (Wright, 1989).

Export of unprocessed green snail shell was banned in Vanuatu in 1987 in order to promote value-added exports. In early 1990 there were four factories processing green snail in Vanuatu and two in Solomon Islands. The establishment of a factory for processing shell was under consideration in Papua New Guinea.

Although a small portion of the total green snail harvest in the South Pacific is directed to the domestic souvenir trade, the majority of green snail is exported to the commercial button and ornamental trade. Thus, export statistics provide a reasonable estimate of the amount of harvested green snail, although with the increasingly common occurrence of exporting cut shell, it is difficult to estimate the weight of shell being processed.

Stocks of green snail in the South Pacific, as elsewhere, are limited. As a result of an increasing shortage of suitable shell for the principal market in South Korea, where the shell is used for inlay work in wooden furniture, prices have increased steeply during the last decade. South Korea imported about 150 t of green snail in 1987 (Philipson, 1989). The rise in value of green snail exports from Solomon Islands from less than $SI 5.0/kg in 1985 to $SI 40.0/kg in 1989, is indicative of the rapid increase of value of green snail shell in recent years. This is also true for the Ryukyu Islands where the landed price of the shell rose from about ¥ 1,000/kg to more than ¥ 4,000/kg during the period 1986 to 1989.

Translocations

A number of translocations of green snail have been attempted in the South Pacific, one successfully to French Polynesia from Vanuatu (S. Yen, pers. comm.) and one unsuccessfully from Vanuatu to New Caledonia (R. Gillett, pers. comm.). Other countries in the region, for example Federated States of Micronesia (Yamaguchi & Kikutani, 1989) are currently considering the introduction of green snail.

If further translocations are attempted in the South Pacific region in the future, extreme care should be exercised to ensure that organisms other than the target species are not inadvertently introduced at the same time. As with the translocation of trochus, pearl oyster, giant clams and other marine organisms, fisheries administrators and resource managers need to establish suitable protocols for the movement of organisms within the region.

There are a number of potential benefits from the careful introductions or translocations of marine organisms of commercial value in the South Pacific. These include the reintroduction of species to areas in which their populations have become extinct because of over exploitation and the establishment of commercial resources in areas currently fisheries-resource poor. However, extreme care and extensive research concerning mixing of gene pools and the development of rigorous quarantine methodology should precede any movement of organisms in the South Pacific.

Research

Green snail has not been the subject of any significant research effort in the South Pacific. Virtually all that is currently known about its biology and ecology has resulted from the work of researchers based in Okinawa (Fujimori, 1964; Tanaka, 1988; Yamaguchi 1988 a & b; Yamaguchi & Kikutani, 1989). The results of some of this work relate to the South Pacific.

In the South Pacific, research is required to establish the relationship between adult snail population numbers and recruitment. The relatively short larval life of the snail probably limits the extent to which populations remote from fished areas can supply recruits to active fisheries. If this proves accurate, it is necessary to research the possibility of establishing reserves within areas supporting active fisheries so that snails within the reserve can successfully reproduce.

Therefore, research on green snail in the South Pacific should examine the effects of different levels of fishing intensity on snail populations. In conjunction with this, estimates of the ability of snail populations to re-establish themselves could be addressed. After staff become proficient in locating the snail in its natural habitat and providing good relations are established with fishermen and processors and that poaching is negligible, a field programme addressing this would be easy to execute.

Research on the biology and ecology of green snail is probably best left to established marine research institutions, as the expertise and funds required to support such work is generally not available in SPC member countries. However, efforts to monitor the developments of research elsewhere should be encouraged. This may lead to hatchery-rearing of larvae and the enhancement of natural populations. However, experience with other gastropods, such as trochus, suggests that applied research still has some way to go before the benefit of this approach can be evaluated.

Although not research per se, a priority among South Pacific countries is the development of a proper information system to monitor resource exploitation, to establish guidelines for green snail harvests and to provide a basis for necessary legislature. Effective research strategies that will provide information for monitoring and efficiently managing fisheries for green snail in the region are required. This also applies to other sedentary fisheries resources such as trochus and beche-de-mer, and as a result, developments in fisheries management for those resources may be applied to green snail.

Few SPC member countries, Fiji possibly being an exception, are addressing current deficiencies in recording the volume and value of exports of marine produce (Wright, 1990). This requires the establishment of a coordinated programme between customs departments, taxation offices and fisheries administrations. A concerted effort to accurately record all exports of marine produce will not only provide information useful for the development and management of fisheries in each country but it may result in an increase in revenue for the country as exporters are encouraged to report more accurately.

Resource management and conservation

With a rapid increase in the value of green snail shell, an increase in fishing pressure on stocks of green snail has resulted. In many areas, this has probably led to a substantial reduction in snail populations throughout its distribution. Although in some regions such as the Ryukyu Islands, the general availability of self-contained underwater breathing apparatus (SCUBA) and hookah gear may have contributed to this demise, the majority of the harvest is still taken without this assistance throughout the Pacific. As green snail is found beyond free diving depths in the region, the potential remains for deep-water individuals to continue to supply recruits to shallow-water areas. However, should harvesting with SCUBA become widespread in the region, this conservative mechanism would be removed and the green snail resource could thus become more threatened.

Even when the snails were harvested by divers without diving apparatus, the stock in the Ryukyu Islands tended to be over-exploited (Fujimori, 1964). In that region there were previously many diver-fishermen who harvested a number of sedentary resources, including green snail, by free diving. Many of these fishermen have retired, mostly without successors, because local green snail stocks have been so reduced they can no longer support such fishing.

In order to protect green snail resources and to increase the possibilities of long-term sustainable exploitation, SPC member countries need to urgently assess current fishing, processing and export legislation. This could involve the introduction of minimum and maximum size limits and the establishment of reserves to protect brood stock.

A minimum size limit would reduce the possibility of overfishing. The introduction of a maximum size limit is

attractive because large shell tend to be damaged due to worm infestations and thus are of a negligible commercial value. In addition, larger individuals are more fecund.

If the relatively short larval life of the green snail restricts the distribution of larvae over a wide area, recruitment to any over-exploited area from stocks located a large distance away might not be expected to occur. Detailed consideration of the spacing of reserve areas adjacent to green snail fisheries, that are preferably accurately monitored, could include an experimental arrangement of reserves spaced varying distances apart.

In Okinawa, fishermen are prohibited from harvesting live shell less than 6.0 cm in shell aperture diameter. This size corresponds with about 13.0 cm in shell width, and is close to the size of first maturity. Therefore, this regulation, as a means of ensuring adult snail mature to reproduce and supply new recruits to the fishery, is inadequate.

However, because the growth rate of young adults is not known, it is difficult to estimate a more reasonable size limit based on the reproductive efficiency of the animal. The size limit for harvesting green snail in Vanuatu (15.0 cm shell width), is also of questionable value.

Hatchery production of juvenile green snail is now established at the Okinawa Sea-Farming Center. Techniques involving juvenile release for reef-ranching of green snail are being developed using hatchery-produced juveniles. Provided hatchery-reared juveniles can successfully establish themselves on reefs once released and provided the coral reef ecosystem can support the release of a large number of juvenile green snail without disrupting the general ecological status of the reef, there is some hope that commercial green snail fisheries can be maintained or even enhanced. In addition, these developments also offer potential for the introduction of commercially-valuable resources to areas with few cash-generating opportunities.

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Present management regimes for *Turbo marmoratus* in Vanuatu

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Introduction

Although there are no data to indicate appropriate levels of harvesting of green snail, *Turbo marmoratus*, in Vanuatu, this resource has been very poorly managed. Like *Trochus niloticus*, the harvesting of this marine gastropod in Vanuatu is influenced by the high demand of its shell, and thus the high prices offered.

Sexual maturity study

There is little biological and ecological data available on *Turbo marmoratus* in Vanuatu. In 1961, the first study was carried out by Devambez (1961) on the sexual maturity of *Turbo marmoratus* in Vanuatu. A first series of specimens were examined on 5 March 1961, at Anietyum Island, the southern-most island of the archipelago.

Devambez noted that the differentiation of green snail sex was easy, after removing the flesh from shells measuring 17.0 cm across the base. Like *Trochus niloticus* the male gonads were pale cream or ivory-coloured, while the female gonads were dark green.

Devambez noted that the five specimens had well-developed swollen gonads. Devambez collected another 10 green snail specimens of varying sizes and examined them.

No justifications can be drawn from such a rudimentary study. However, Devambez concluded that it seemed probable that green snails reach sexual maturity at a size between 11.0 cm and 15.0 cm. However, he stated that one 6.0 cm female had some clearly visible eggs, but this was, in his opinion, an aberrant case.

Population densities

Devambez noted that during his first survey in 1959, it took 6 divers 45 minutes to gather 11 green snails at Anelgohat reef in Anietyum. During his second survey in 1961 at the same site, it took 2 divers 10 minutes to collect 13 green snails. Three men diving on the the fringing reef in Erromango (Port Narrawin reef) produced 6 green snails in 75 minutes. With these results, Devambez suggested that the ban on green snail harvesting be lifted.

Management

Since the three-year moratorium on green snail harvesting (1958–1961), there have not been any further bans on green snail harvesting. The only implemented management measure that covers the harvesting of green snail is a minimum size limit of 15.0 cm:

> *'No person shall harm, take, have in his possession, sell or purchase any green snail which is less than 15 cm in length when measured in its longest dimension.'*

Export of raw shells is also prohibited:

> *'No person shall export green snail except with the written permission of the Minister and in accordance with such conditions as he may specify.'*

The following penalty is in force for persons who contravene the above regulations governing green snail harvests:

> *'Any person who contravenes any of the provision of this Part shall be guilty of an offence and liable to a maximum fine of VT 100,000.'*

A new drafted penalty still to be approved reads as follows:

> *'Any person who contravenes any provision of this Part commits an offence and is liable on conviction to a fine not exceeding VT 25,000,000.'*

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Method to determine the sex of *Turbo marmoratus*

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Introduction

A study of the different form and size of sexual dimorphic papillae of the right kidney opening of *Turbo intercostalis* had been reported by Joll (1980). A similar study of *Turbo argyrostomus* has been reported by Tanaka (1988). The author surveyed nine *Turbo marmoratus* viscerae (5 males and 4 females). The foot had been removed from each animal at the fish market in Tokunosima before the examination. The papillae of both sexes were located beside the base of the rectum. The papillae of the females were bigger than the papillae of the males. The papillae of the males were about 3–5 mm long, with a bright yellow colour, and tubular in shape. The papillae of the females were about 15–20 mm long, bright yellow, and bean shaped. Although few animals were sampled, sexual dimorphism was observed for the right kidney opening.

Tanaka (1988) then studied the behaviour of the green snail when it was taken from sea water to air. The green snail tried to extend its body as much as possible for the purpose of sticking to the substrate, even if it was held in the air. At this time, it was possible to observe its papilla beside the base of the rectum. The author carefully examined the papilla beside the base of the rectum, determined the sex and wrote a mark of male or female on its operculum with an indelible pencil. The sex of each marked animal was confirmed through inducing spawning. Five spawnings were induced, and the gametes released by each marked animal agreed with the sex determination made before the induction.

Method to determine the sex of green snails (Fig. 1)

Take the green snail and position its aperture downward. Wait for a few minutes until the animal opens its operculum. Bring the animal slowly upward with its aperture opening facing the observer. Wait until operculum is fully open.

Look into the right side at the base of the rectum. The bright yellow papilla can be seen there. Male and female can easily be distinguished by the difference in size and shape of the papilla.

The papilla of the female's right kidney opening is large and can easily be identified. However, it sometimes takes time to confirm the papilla of the right kidney opening in the male as it is much smaller than in the female. Wait until the animal's foot muscle is fully extended.

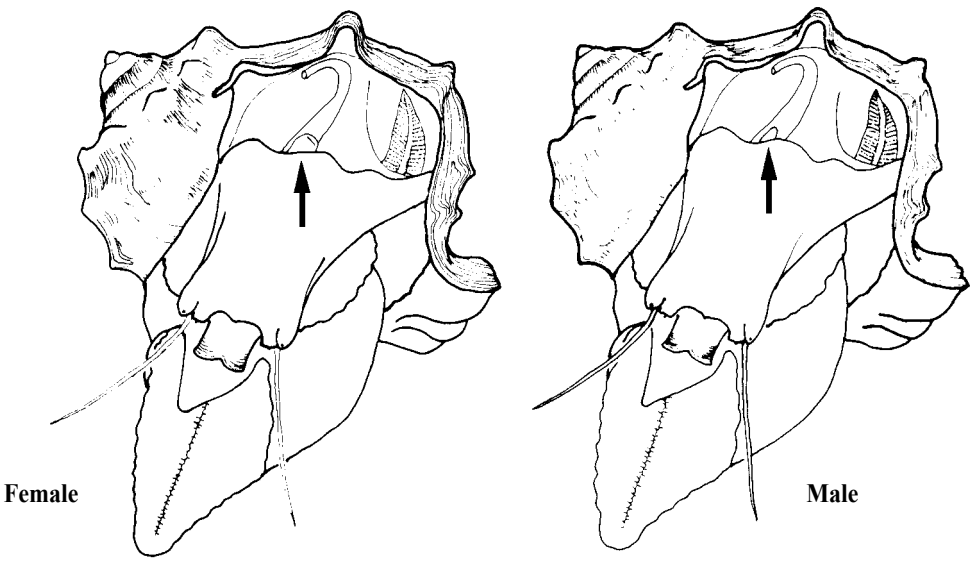

Figure 1

Female and male *Turbo marmoratus* showing the position of the right kidney when the foot is extended, allowing gender to be identified

This same method might be applied to other large-sized Turbinidae.

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Note

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