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incorporating molluscs and other shellfish

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INFORMATION BULLETIN

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Editorial

In keeping with the theme of broadening the *Trochus Information Bulletin* to other gastropod species, this issue contains articles and news on *Trochus niloticus* and several other gastropods. The themes of the articles are diverse. There are two papers by Jean-François Hamel and Annie Mercier on the spawning and development or general biology of two non-trochid species (the egg cowry, *Ovula ovum*, and the spider conch, *Lambis lambis*) in the Marshall Islands. Three papers by Gilbert David explore the management of *Trochus niloticus* fisheries, covering the economics of the fishery, development of indicators of stock depletion, and types of management.

A note on the editorship of the *Trochus Information Bulletin*: Chan Lee, the previous editor, passed the baton to me after overseeing the production of five issues. Shortly after taking on this role, the scope of my job with the WorldFish Center broadened, and — as the lateness of the release of this issue indicates — my ability to give the *Bulletin* the attention it needs, from canvassing articles through to editing them, was diminished. As a result, this will be the first (and last) issue of the *Bulletin* that I edit.

Thus, the *Trochus Information Bulletin* is now seeking a new editor. The position requires someone who is willing to cast the net widely for useful and interesting articles among biologists, socio-economists and fishery managers at all levels (governments, universities, NGOs or within coastal communities themselves). The geographical focus has traditionally been the Pacific, but in the past couple of issues, readers may have noticed an increasing number of articles from southern and south-east Asia and the Middle East. This is a desirable trend that should be continued.

If you are interested in this role, please contact Aymeric Desurmont, SPC Fisheries Information Specialist, by email (aymericd@spc.int), telephone (+687 262000) or letter (SPC, BP D5, 98848 Noumea Cedex, New Caledonia).

Warwick Nash

Inside this issue

Socio-economic and bio-economic indicators for rational exploitation of trochus: general considerations

Gilbert David[1]

Introduction

Trochus and sea cucumber have the longest history of commercial exploitation of any of the Pacific Island's coastal fishery resources.

Beachcombers brought them into the market economy in the nineteenth century with the establishment of the first trading posts, even before the sandalwood traders began to call. This was the first example of globalisation in the Pacific Islands and the first example of the islands being integrated into international trading circuits (Doumenge 1966; David 2003). It produced the first business-based lingua franca, Pidgin English, which was called Bislama in Vanuatu in reference to bêche-de-mer. This also became the language of the trochus trade. Rocheteau (1968) reports that Bislama was still being used in the 1920s in the northern tip of New Caledonia, which was the main trochus trading centre on the island.

Despite this long tradition, there have been few changes in the commercial exploitation of trochus. Harvesting requires little capital investment, the only requirement being a diving mask. It is also the least costly form of commercial harvesting, only limited by the time and energy that fishers devote to it. With this background, it is hardly surprising that this activity occurs in even the region's most remote islands.

While trochus resources may be locally abundant, they are still vulnerable to any form of intensive exploitation (Nash 1993) and should be subject to strict management regimes. Such management requires the introduction of measures to reduce fishing effort (fishing season, total allowable catch) or make it more selective (size limits). The implementation of these measures should be the responsibility of individual national fishery services. However, management requires data. Without data, it is impossible to assess the effectiveness of management measures and whether changes are needed for greater efficiency. To manage the trochus resource, the relevant data on the resource and its exploitation needs to be managed. This task is made much easier if the information collected is processed into a synoptic form that can be used to provide indicators.

Rational exploitation of fisheries and guidance for fishing systems

In previous research on Vanuatu (David 1991), I showed the value of considering reef fishing as a system. It seems that this finding could be extended to all small Pacific Island countries and territories, which show many similarities in terms of coastal fishing (Wright and Hill 1993; Dalzell and Adams 1995). In every country, the village and its adjacent reef area form the smallest geographical unit by which the fishing system can be understood. In the pre-colonial era, this unit encompassed the functions of production, consumption and fishery resource management. At present, the latter two functions are managed nationally, or at the international level when overseas markets are involved, but the village remains the place of production. However, the dual nature of these functions, in terms of level and fishery resources, can result in serious malfunctions in the development and management of resources. Thus, the village is frequently a theatre of contradictory economic forces: villagers are anxious to retain full enjoyment of the natural resources in their area, while the public authorities, claiming sovereignty, purport to organise the exploitation of these resources for the benefit of the national community under rules that they have set.

The village and country therefore form two interlocking levels within which the fishing system can be conceptualised. In Vanuatu, as throughout the South Pacific (David 1999), the system consists of three subsystems: the market system, commercial/subsistence system, and subsistence system proper. The latter two together make up the overall subsistence system. As outlined below, the basic differences between market and subsistence systems relate to their structure:

As the successor to the traditional fishing system, the subsistence system is part of the informal sector. Fishers enjoy total control over their production resources. They also control the distribution of their catch even when it is sold because they deal directly with the purchaser, who lives in the same village or nearby.

The commercial system, on the other hand, is part of the formal sector. Fishers are less able to make

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independent decisions about their catch and its distribution. The cost of the fishing gear is high. It usually exceeds fishers' self-funding capacity and may have been acquired as part of an artisanal fishery development programme subsidised by the government. This programme may sometimes continue to provide technical support to fishers through extension officers in the islands. The use of such gear requires the regular purchase of inputs, such as fuel, ice and possibly bait, from specific supply lines. Distribution of the catch is also part of an organised chain, the structure of which expands with the distance between the landing site and the consumer's home.

Although it is part of the market sector, since it stems from the desire to sell, trochus harvesting is an atypical form of commercial activity. As already mentioned, it is a low-cost activity that is carried out irregularly and is not usually a specialisation. The non-standard nature of trochus production is due to the fact that, in contrast with most fishery products, the item being marketed is not a fresh product but a shell that can be stored for several months or even years without deteriorating. This long storage period encourages trochus buyers to prefer harvests to take place at well-spaced intervals enabling large quantities of shells to be purchased at once, rather than frequent harvests producing only small quantities. As a result of these large-scale but infrequent sales, fishers consider this form of trochus harvesting not as a source of regular income but as an intermittent financial windfall that enables them to cover occasional outgoings such as school fees for their children. This is a major constraint for the rational exploitation of trochus resources in the Pacific Islands region.

The expression "rational exploitation of fisheries" is a new one. It would appear preferable to "balanced resource management" or "sustainable resource management", which are no longer in common use, or the "precautionary approach", which associates resource conservation and ecosystem protection and is becoming a fashionable concept in the sphere of fisheries resource management (FAO 1995; Richards and McGuire 1998). These expressions ignore the role of people as a core management component (Larkin 1988) and have a standard-setting connotation that could be controversial because only the opinions of ecologists and fishery biologists are taken into account. However, as pointed out by Quensière and Charles-Dominique (1997), the biological, economic and social optima of a fishery activity often vary. I will therefore not attempt to define rational exploitation of fisheries in terms of objectives because these are difficult to define in a context marked by the complexity of the processes and diversity of the players involved (Gascuel 1995), but rather using a method based on the assumption that *fishing is a complex system whose dynamics imply that it experiences crises*. Rational exploitation of fisheries therefore involves guiding the fishery system in such a way as to minimise the impact of crises. It could also be described as a system of 'good governance'.

Any form of management of a renewable resource requires good knowledge of both the resource itself and the people exploiting it, as well as the dynamics informing the 'resource-exploiter' relationship. To be usable, such knowledge must be summarised in a form that is concise and easy to use. These qualities are provided by indicators, which can be organised in the form of a control panel or graphic representation of a set of indicators.[2]

Use of indicators to minimise the risk of a crisis

Each of the three subsystems (subsistence, subsistence/commercial, market) that make up the fishery system can be associated with bio-economic and socio-economic indicators. Morand (2000, p. 10) provides two complementary definitions of an indicator: *"a statistic that facilitates the interpretation and assessment of the situation of an element of the world or a society"* and *"an item of information that has been constructed using an explicit and consensus-derived or interpretative data model. This means that everyone will infer the same information from the same data set, which can therefore be termed an indicator"*. Fishing systems therefore have many potential indicators but not all offer the same value. In this connection, Morand stresses that, generally speaking, an indicator should have the qualities of any piece of information. In other words, it should be (a) integrated into the user's reality; (b) enjoy the user's confidence (i.e. be considered accurate and reliable); (c) recent; (d) clear and easy to interpret; and (e) unambiguous. *"But it must also possess specific qualities: conciseness and simplicity of expression; reproducibility and objectiveness (not dependent on the person who collects or processes the data); and feasibility (not based on data that is unavailable or impossible to collect). If it possesses all these qualities, an indicator will be able to play a full role in communication and assist in decision-making"*.

Personally, I consider that there are two main criteria that make it possible to differentiate between indicators: effectiveness and cost.

To be effective, an indicator must be relevant and accurate. The states or processes that it characterises should reflect the objectives of the indicator and estimations should be sufficiently accurate.

The cost of an indicator depends on the duration of implementation of all the resources mobilised to

2. This method offers interesting prospects, especially for bio-economic and socio-economic aspects. It has already been successfully used for retrospective analyses designed to compare fishery development projects based on fish aggregation devices in Comoros, Reunion Island and Vanuatu (Rey et al. 2000).

record it and the mean daily cost of these; the number of person-days required is a good way of estimating this.[3]

The function of an indicator is another essential selection criterion (Fig. 1). The indicators chosen must make it possible for the manager to guide the fishery system at "cruising speed" in a crisis situation, which implies that these crises may be planned for, or that their possible occurrence has been foreseen and their potential impact on the operation of the system has been estimated. A set of indicators must therefore go beyond a simple description of a system and include a range of functions. It can then be evaluated on the basis of the criteria of effectiveness and cost.

Generally speaking, three types of crises may disturb the fishery system:

- those whose occurrence is haphazard, whether they occur within the system or "contaminate" it from outside;
- those generated by internal malfunctions of the system;
- those arising from the system's environment and that comply with its own inherent forms of logic.

By definition, the first type of crisis cannot be predicted. However, two types of responses can be planned on a preventive basis. One goal is to maximise the system's adaptability so that it can satisfy Ashby's Law of Requisite Variety[4] to the best of its ability and also avoid any chronic internal malfunction that could hinder the circulation of flows in the system. Fisheries managers operating such a system must first recognise as quickly as possible that a crisis is arising, and secondly must pass on their decisions to all undamaged parts of the system. Preparing for a fishery system crisis without knowing where or when it is going to occur requires firstly that the system operates perfectly when in cruising mode. To be sure of this, the manager must have indicators for assessing the system's overall performance. The primary indicator required is information on the quantity of fishery items captured by operators. Generally speaking, there is a lack of effective indicators for estimating fishery production other than surveys at the point of landing — a research field to explore. This is an arduous task, but recently developed methods for participatory assessment of fishery stocks (Medley et al. 2005) show that significant progress can be achieved if boldness

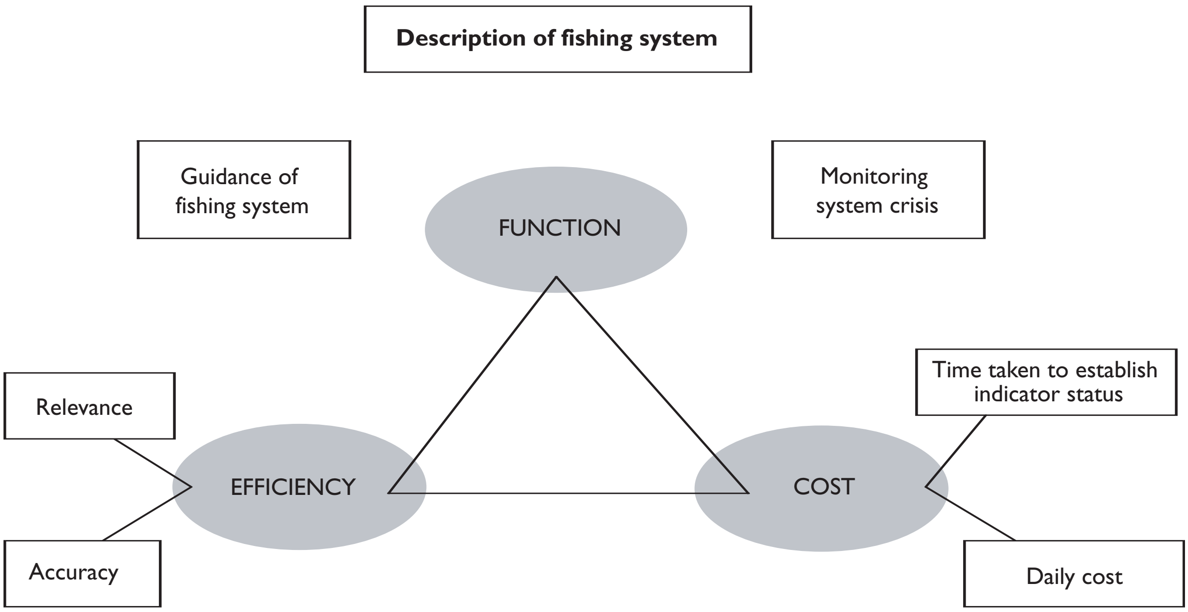

Figure 1. **Descriptive parameters of indicators relating to the fishery system**

3. For example, if the formulation of an indicator requires the mobilisation of two people full-time for 10 days, it will have a cost of 20 person-days. In the absence of a precise estimate, we must be satisfied with a gradient of 1 to 5 (the costliest).
4. According to this law, knowledge of the previous states of the environment is essential for the regulation of a system, which can only be effective on the specific condition that the system control module has at least the same freedom of action as the disturbing environment. In other words, if the control module is to impose its will on the system, the range of controls it has to hand must be at least equal to the variations in the environment (Ashby 1956).

and imagination are used and fishers are associated with the assessment process (Fig. 2).

Because of its internal nature, the second type of system crisis is easier to plan for, providing that managers have indicators available that make it possible to:

- identify risks of malfunctioning;
- estimate the vulnerability of the system to these risks.

Generally speaking, system malfunctions take the form of a very clear slowing down of the speed of the circulating flows. In such cases they can be considered similar to one or more constraints on the latter, and result from a difference between the real flow environment and the optimum circulation conditions that this environment should provide. Identifying risks of malfunctioning means that this difference must be assessed and a warning signal triggered when it is considered to have fallen below a certain threshold.

The vulnerability of the system as a whole to such malfunctions can be estimated from the nature and number of constraints weighing on the circulation of each type of flow and also from the amount of synergy existing between constraints that are liable to have cumulative negative effects. For example, the exposure of fishing grounds to strong currents, and the dominant swell and large waves when the wind is blowing, can be considered as a powerful constraint on fishery activity when associated with another factor: limited boat size and poor performance at sea.

The third type of crisis stresses the importance in guiding the system of information flows between the fishery system and its environment. This implies that system managers should not consider trochus fishing as a closed system but as a component of the village system. The logic and rationale of the latter, even though they are external to the marine environment, are liable to have a significant influence on fishery activity. For example, the marriage season in the Pacific Islands, school holidays, or the agricultural calendar may result in significant variations in fishing effort. Information flows in the system and communication between the system and the outside world should therefore be considered as part of the overall performance of the system and should be monitored using specific indicators.

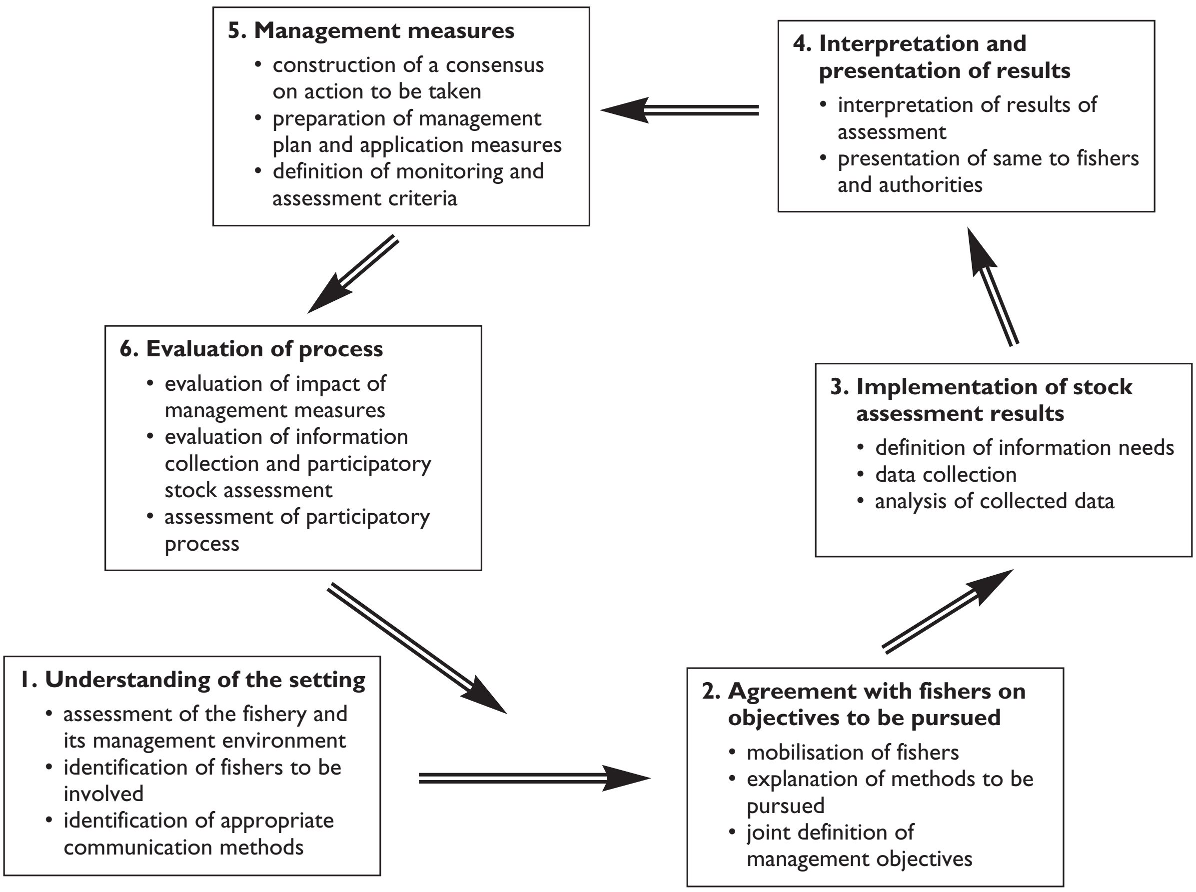

Figure 2. Stages in the participatory assessment method for fish stocks (after Medley et al., 2005)

An adequate response to a crisis requires that the action taken be proportionate to the estimated impact of the crisis rather than to the flow represented by the crisis itself. Therefore, cyclone preparedness will require a different level of effort depending on whether the dwellings under threat are made of cement or wood. After identifying the risks of malfunctions in a fishery system, and estimating its vulnerability to the crises that are most likely to occur or influence it, the final task of fishery system management in the event of a crisis is therefore to estimate the thresholds at which risks can be minimised or absorbed. This will enable the system manager to modify his or her response to the crisis depending on the expected impacts.

Conclusion

Managing a fishery system requires five kinds of indicators, covering:

- system description;
- assessment of the system's overall performance;
- identification of risks of malfunction;
- estimation of the vulnerability of the system to malfunctioning;
- monitoring of crises through establishing risk minimisation or absorption thresholds.

Management approaches to this indicator-based system for trochus harvesting will be described in an article outlining indicators that can be adopted downstream (with the fisher) and upstream (at the market level) to manage the resource more rationally. A second article will address participatory village management and the indicators needed for such participatory management.

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Indicators for village-scale trochus management as part of government/community co-management arrangements

Gilbert David[1]

Introduction

Since the establishment of national fisheries services, Pacific Island reef fishery resources have been the subject of scientific monitoring programmes and management measures designed on a national basis with the support of international organisations (Pacific Community, Forum Fisheries Agency, FAO). As discussed in the previous article in relation to the trochus resource, the difference in scale between the geographic decision-making level and the level at which management rules are applied is a major factor in the vulnerability of a fishing system to the risk of overexploitation. This difference means that it is difficult to implement management measures established on the national level at the village level at which the fishing is in fact organised. Villagers want to retain full enjoyment of their local natural resources, while — on the grounds of sovereignty — the national government seeks to exploit these resources for the benefit of the national community under rules that it has established. However, these rules may be ineffective because they are unenforceable when no government representatives are present at the local level.

This realisation has prompted the authorities to devolve some of their responsibilities for fishery management to the provincial or territorial district level, which is closer to the fishers. But the results have not been convincing. Firstly, the decentralisation of decision-making has been incomplete. The province is regarded more as an intermediate level through which decisions taken at the national level are passed on to local communities, rather than as a level for making management decisions. Even when decentralisation has been more effective, as in New Caledonia where each of the three provinces has a fisheries service that is totally independent of the maritime affairs administration in terms of fishery policy, the provincial scale remains too large for villagers to feel ownership and for fishery policies to be effective. This is largely because production is scattered over too many locations and is on too small a scale.

The problem for central government therefore remains unresolved: how to act so that villages with valuable resources such as trochus can exploit these as part of a rational fishing system while avoiding overexploitation. To continue the decentralisation process would mean creating a new level between the province and the villages or indeed devolving resource management to the local level based on the relevance of ancestral management practices, which involve temporary closures of resource access. These practices could be revitalised and combined into a management mode applicable on a national scale based on the principle that good resource management at the local level will provide good overall management (Dahl 1988; Ruddle and Johannes 1990; Sims 1990; Johannes 1994; South et al. 1994; Dalzell and Adams 1994). This article discusses co-management arrangements between central government and local communities for managing reef resources, in particular, trochus. The emphasis is on the conditions that must be met for efficient co-management, particularly with regard to social cohesion, and the indicators required for assessment.

1. Co-management issues and the contemporary relevance of ancestral management practices

The idea of revitalising ancestral practices for managing fishery resources and converting them into a mode of co-management applicable at both local and national levels is a novel one that implies:

a) it is no longer the resource that is managed but the habitat in which the resource lives, which is considered to have heritage value. Good management at the local level will help secure the sustainability of the national heritage, which is made up of numerous such areas.
b) management rules no longer stem from mathematical models but rather from collective decision-making at the village level on periodic opening and closing of the fishery resource. When the closure of a village fishing territory is decided in conjunction or agreement with the national authorities, it is legitimate to refer to it

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as co-management or collaborative management (Barrow et al. 2000; Nurse and Kabamba, 2000). This concept has emerged from research on the management of forests in Asia (Gilmour 1990; Fisher 1995), which in every case presupposes that local communities are closely involved in the management of the resources they exploit; 'anglophone' authors refer to this as community-based management.

The introduction of a co-management arrangement for fishery resources at the local level, using ancestral management practices and giving them fresh relevance, is based on the assumption that, from the perspective of sustainable development, these ancient practices are superior to modern management systems because in the past they have shown their ability to conserve the natural environment and the exploitable resources it contains. The validity of the assumption that traditional methods of managing renewable resources have enduring relevance is subject to two essential preconditions: the permanence of the environmental, social, and economic conditions surrounding the management of the resource, and the permanence of the management objective. These conditions, however, are often not met and it is legitimate to query the efficiency of these management practices in an island setting increasingly influenced by globalisation (David 2003).

Local communities have, of course, changed considerably over the past two centuries. The closed systems that operated autonomously have had to open up. Money has reached even the remotest places and there have been fundamental changes in people's concept of the universe. The external flows to which coastal village communities are exposed have also changed. It would thus be a delusion to think that traditional management methods will operate well in the future solely on the grounds that they worked well in the past. Previously, traditional management methods were applied to subsistence resources, while it is now hoped that village communities will be able to undertake participatory management of commercial resources such as trochus, which attracts high prices on the international market. In addition, village-scale management of this resource before the 1990s was never very successful. Like sea cucumber (bêche-de-mer), trochus have been commercially exploited in the Pacific Islands since the first half of the nineteenth century and, like whales, have contributed to the integration of this region into the global economy to such an extent that the Sabir (lingua franca) languages spoken in Vanuatu, Solomon Islands and Papua New Guinea (i.e. Bislama or Pidgin) emerged to facilitate the trade. This exploitation was conducted as part of a mining-based economy, with beachcombers scouring one area before moving on to the next. This heritage seems to be a likely explanation for spatial variations in the export output of these two commodities with one country leading the market for two to three years before giving way to another after seriously depleting its stocks (Bettencourt 1995). This alternating trend can be seen as a reflection of high demand on the international market (Bour 1990) being relayed to the Pacific Islands by buyers visiting even the most remote islands and offering local communities amounts of money that were sometimes considerable in terms of purchasing power. Communities sometimes accepted these offers, taking the risk of seriously overexploiting their pearl shell stocks. This behaviour might seem illogical given that trochus accounts for a major proportion of the annual income of these villagers and that it is therefore in their interest to manage the fishery resource sustainably to guarantee future income. On the other hand, if it is considered that the village's priority is not to maximise income from a commodity but to enhance the viability of their territory, such behaviour is quite logical.

Territorial viability covers a dual dimension: firstly the ability to meet families' needs, and secondly the provision of community services by the village. For some traditional leaders in islands far from the capital, approaches from trochus buyers can be hard to turn down in the face of financial disengagement by governments that may be increasingly less able to maintain health, education and transport infrastructure. What importance is given to the threat of overexploitation of fishery stocks when the well-being of the community can be improved with money from trochus sales? In contrast to subsistence fishing, commercial harvesting does not generate territorial identity. A fishery territory is an economic resource. This economic territoriality serves the overall viability of the village territory and as such it may be rational to overexploit the fishery stocks that are most in demand on the international market if the resulting income makes it possible to enhance the overall viability of the village territory and its resident communities.[2]

2. Indicators for assessing a community's ability to manage its resources

Various issues surrounding collaborative management, and the current relevance of traditional management practices, mean that the establish-

2. According to Doumenge (1983), viability results from the combination of a static state, 'the creation of the conditions needed and sufficient to exist and endure' and a dynamic state comparable to the conditions 'needed for development, in terms of the most complete possible use of natural resources and for the social and economic advancement of the community'.

ment of a co-management system for trochus resources based on these management practices will probably not be possible everywhere. In a setting marked by the exposure of villages to the global system and the disengagement of government from rural areas, some communities have the ability to resist cash offers that they sometimes receive for the unsustainable exploitation of their reef resources. Others have lost it.

If a fisheries service attempts to establish fishing reserves under a co-management regime where the majority of villages are in the latter category, it is very likely that the programme will fail. The difficulties facing governments wanting to promote this kind of management at the local level relate to spatial variation in situations. Two neighbouring villages may show quite different levels of ability to manage their resources. Therefore, all villages should be assessed before a programme of this kind is undertaken. Technical assistance can then be channelled to communities that are found to be less able to manage their fishery resources. Alternatively, the programme could focus only on villages that offered a high probability of success.

These assessments can take the form of surveys that make it possible to define synoptic indicators of ability to manage reef resources at the local level (Fig. 1). Four synoptic indicators can be developed for this purpose, expressing:

- the value on the world market of marketable fishery commodities; the higher this value, the more the local communities will be approached. For trochus, this value is likely to be at the highest level, presenting a formidable constraint to the establishment of joint management operations;
- the involvement of the national government at the local level, especially in health, education and transport. The lower this level of involvement, the higher the risk that local communities will give way to cash offers for the purchase of fishery commodities as the money thus earned will, to some extent, enable them to offset the lack of government services;
- the social cohesion of the village;
- the authority of traditional leaders.

The latter two indicators both measure the intrinsic ability of the community to withstand external commercial pressures.

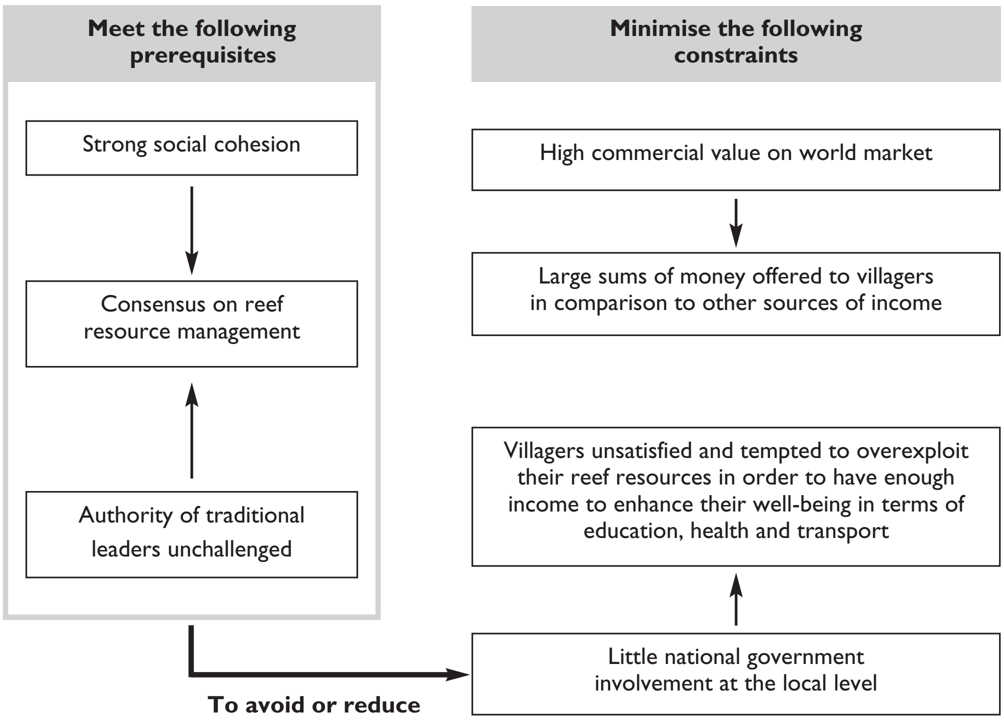

Figure 1. Conditions required for the sustainable management of reef resources at the village scale

These indicators can be represented in the form of tables (refer to previous articles) or graphically on four axes presenting two levels of value: low and high. In Figure 2, two maxima are represented: good ability to manage reef resources and poor ability.

Conclusion

Because of the complexity of the reef ecosystem and the associated 'human system', it is difficult to manage fishery resources using conventional rules based on the dynamics of exploited populations and the use of forecasting models. A broader scope is required. The fishery system cannot be considered only in terms of the predator-prey relationship. All the components of the system need to be taken into account, which implies that socio-economic aspects should be dealt with in a more complete and integrated manner rather than simply as non-biological determinants of fishing effort. It should also be recognised that the reasoning of the fishers may vary from that of *Homo oeconomicus*. Coral reefs should be considered as an eco-socio system within which fishing is a major component. Given this background, management of the trochus resource by both the government and local communities within the framework of a co-management system that follows traditional rules for the control of fishing grounds is a worthwhile alternative. However, not all villages have the same ability to succeed using this kind of approach. Fishery services wanting to establish shared management need to have indicators available that enable them to assess the ability of local communities to successfully undertake co-management. The criteria that should be assessed include social cohesion, the authority of local custom chiefs and the involvement of the government in local development.

Generally speaking, sets or control panels of multi-thematic, multi-disciplinary indicators are a worthwhile tool for managing trochus resources. A broad area of research is opening up in this regard. It could ultimately transform the management of fishery resources in the coral environment and elsewhere by offering new concepts and methods.

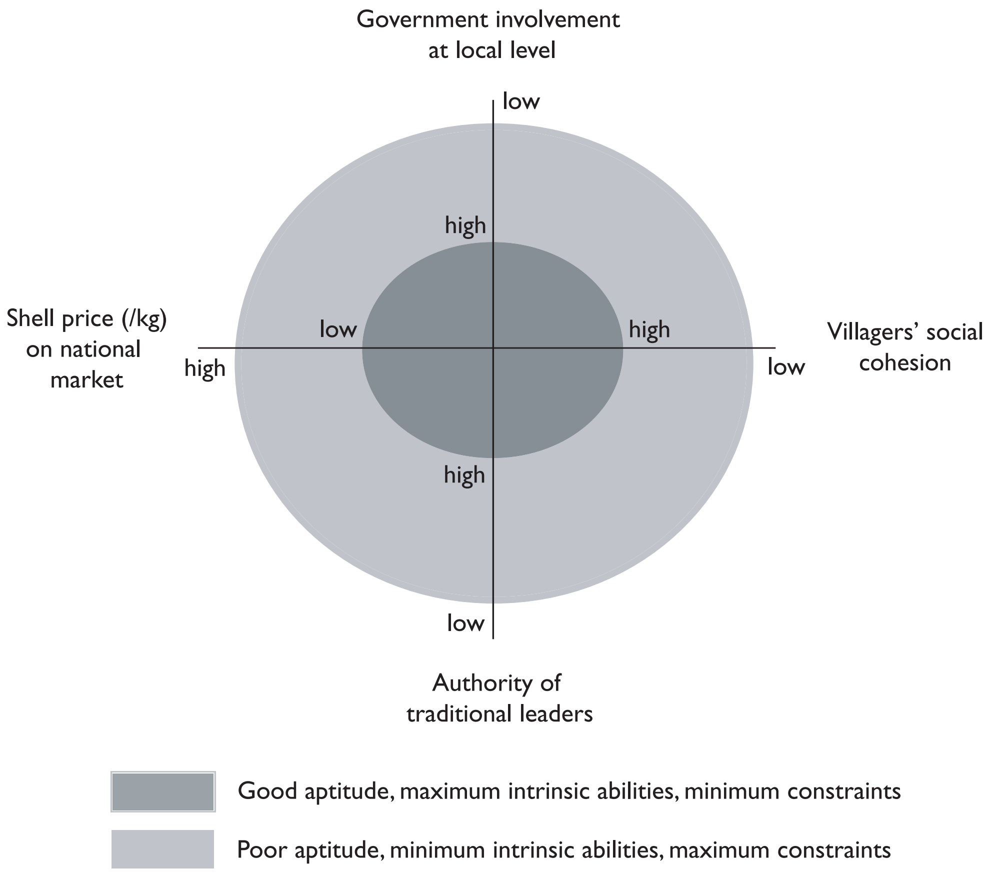

Figure 2. **Indicators of ability to manage reef resources at the local level**

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At what level should trochus management take place: at the fisher or market level?

Gilbert David[1]

Introduction

In work on coastal resources in the Pacific, Nash (1993), who was responsible for the chapter on trochus, listed seven ways of managing this nacre-producing shellfish, which is particularly vulnerable to any form of intensive exploitation. They involved setting up (a) catch size limits (minimum and maximum), (b) fishing area access limits, (c) catch quotas (total allowable catch), (d) fishing seasons, (e) fishing reserves, (f) reseeding of natural settings with farmed juveniles, and (g) catch and fishing effort log-books and statistics. Although these statistics are not management measures as such, they provide a way of assessing the stock's status before implementing management measures and of monitoring the effectiveness of such measures.

In addition to setting up village-level fishing reserves that are jointly managed by public authorities and village leaders (this issue will be discussed in a later article), the choice of management method or methods for trochus stock is made by public authorities, i.e. national or provincial fisheries departments, which must also oversee their implementation or enforcement at the local level, i.e. with fishers. This monitoring/assessment of management methods is under the control of the national fisheries system that covers the entire "trochus" sector — from the resource to its exporters and managers (Fig. 1). Management of the system requires collecting, at a moderate cost, relevant and accurate information to develop indicators that will enable crises to be avoided or will minimise their negative impacts (see previous article). The main question for fisheries departments managing such a system is: At what level should information on the sector be collected — upstream at the fisher level or downstream at the level of the national trochus market in relation to the exporters and processors of this shellfish? These two possibilities are explored below.

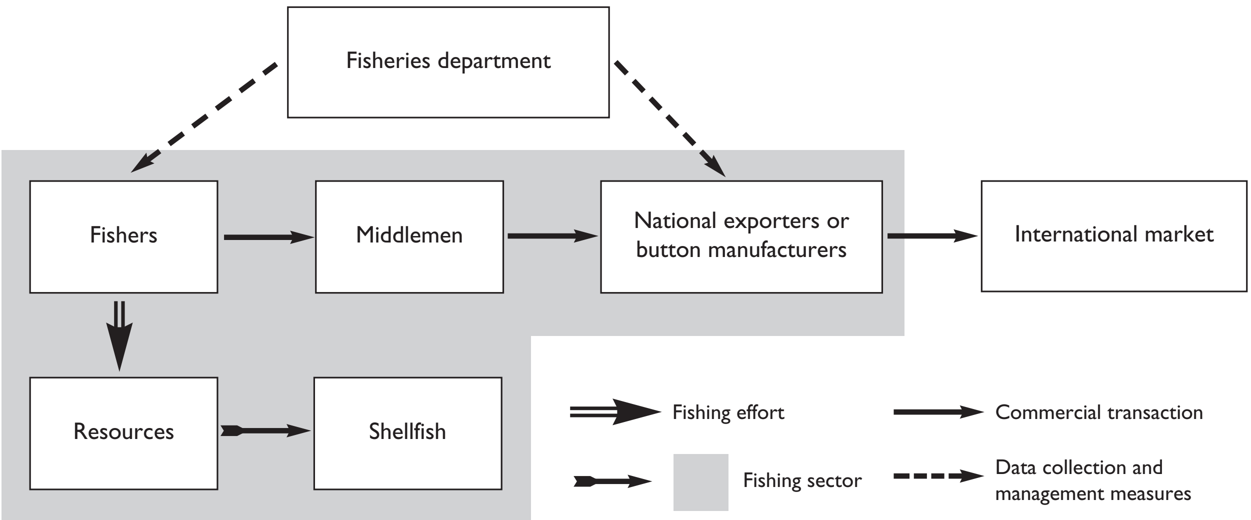

Figure 1. **Trochus fishery system and its management by public authorities**

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1. Data collection and management work with fishers

Conventional methods of fisheries management involve working with fishers to manage the resource. When there are signs that the stock is being overexploited, managers try to reduce fishing effort. Aside from reseeding in natural settings, all the management methods listed in the introduction come under this approach.

In general, overexploitation of fisheries stocks is characterised by an imbalance in the population structure; e.g. trochus that have not yet reached the stage of sexual maturity are overrepresented and adults, particularly older ones, are underrepresented. The whole problem of overexploitation arises from the fact that fishing effort is not determined by the status of the exploited resource but according to other production expectations since fishers treat their production as income. For that reason, the fisheries exploitation dynamics of trochus, and by extension the dynamics of overexploitation, are based on the "resource/production expectations" ratio.[2]

Trochus fishers operating in an area subject to overexploitation can choose one of three strategies:

- They can go to a new area where previously little fishing has been done but which is also further away. They can then hope to maintain the same level of production, although at a higher cost due to the increased travel time. Thus, they will have to fish for a longer period to maintain the same level of income, unless increases in productivity and associated income compensate for the higher costs.
- They can maintain their efforts in the zone subject to overexploitation and accept a drop in income due to the smaller catch.
- They can continue to exploit the current fishing area but give top priority to maintaining existing production volumes and income. The only way to do that is to increase their fishing effort to compensate for the drop in productivity resulting from the increasing scarcity of the resource.

The latter two strategies will inevitably lead to a greater imbalance in the population structure of the stock.

In this context, two types of indicators are likely to be helpful in managing the information system. The first deals with characterising the risk of overexploitation, while the second emphasises the system's vulnerability to this risk. A third indicator is aimed at assessing efforts made to reduce this risk or to reduce overexploitation that already exists.

1.1 Characterising the risk of overexploitation

Indicator of existing overexploitation

The number of juveniles caught compared to the total number of catches surveyed is the most relevant indicator in this regard. This type of indicator is generally derived from data collected at landing sites. The wide geographic spread of such sites is a characteristic of the Pacific Islands with trochus being landed on beaches near fishing villages. This situation, which can be described as the "scattering" of landing sites, imposes serious constraints on data collection (Cillaurren and David 2000). Maximum efficiency would require field deployment of a "flying squad" of surveyors for several months a year — a very costly exercise (Table 1).

Table 1. **Indicator of risk of actual overexploitation**

Indicator no. 1:	*Number of juveniles caught compared to total number of catches surveyed at landing*
Relevance	Very good
Precision	Very good as verification is visual and carried out by fisheries department agents
Cost of acquisition	Very high as a team of several surveyors must be mobilised full time

Socio-economic indicators of potential overexploitation

These indicators provide information on fishing pressure, which is estimated in terms of exploitable surface area units. There are two different indicators:

a) Number of trochus fishers in villages near the exploited reef compared to the total exploitable surface area of the reef;
b) Annual number of fishing trips compared to the total exploitable surface area of the reef.

Information on the number of trochus fishers can be obtained at no cost through national maritime affairs or fisheries departments when the fishers are registered (which is rare). When this information is not available, field surveys are required,

2. This involves using a socio-economic approach to fisheries exploitation to supplement the biological approach that is of course more common (Laurec and Le Guen 1981).

but the cost/relevancy ratio is prohibitive (Table 2). The number of fishers is, in fact, a poor indicator of fishing effort due to large differences between fishers in the frequency of fishing trips.

Establishing the boundaries of the exploitable space is also a problem due to uncertainties about both bathymetric readings and marine facies. In general, the bathymetry of the shallow areas (5–25 m) that correspond to the trochus habitat is poorly known. Sounding points are rare and interpolations made from them are imprecise. Airborne laser altimetry should significantly improve this situation in future years, but this technology is still being developed and is costly, as was shown by the conclusive experiment carried out on Reunion Island with the CASI system (Despinoy et al. 2003). Without precise bathymetric readings, it is difficult to differentiate between various marine bottom features at depths of more than 15 m, whether the signals originate from airborne or satellite technology. In fact, aerial photos and satellite images are the two resources normally used to map reef formations (Bour et al. 1986; Bour 1988; de Vel and Bour 1990; Bour et al. 1992). The launching of very high resolution (i.e. about one metre) satellites such as Ikonos or QuickBird now makes it possible to consider reef cartography at scales of 1:25,000 or even 1:10,000. However, the cost of using such images to map large surface areas of reefs can quickly become prohibitive.

The annual number of fishing trips compared to the reef's total exploitable surface area is a much more relevant indicator since the number of fishing trips is a better indicator of fishing effort than the number of fishers, but this indicator is costly. In fact, several series of surveys are necessary to take into account intra-annual variability in the number of fishing trips. However, an experiment

Table 2. **Potential overexploitation risk indicators**

Indicator no. 2: *Artisanal fisher population of the villages near the exploited reef compared to the total reef surface area that can be exploited by commercial fisheries*			
	Numerator	Denominator data	Overall indicator
Relevance	Low: (a) it is assumed that fishing effort is the same for all fishers (b) it is assumed that fishing effort is evenly spread over the entire exploitable surface area	Low: (a) the exploited surface area is depicted by the exploitable surface area (b) it is assumed that abundance is evenly spread throughout this zone	Low
Precision	Good to average: Depends on the number of informal artisanal fishers (by definition not registered) compared to the total number of artisanal fishers	Low for bathymetric data, which are poorly known for the 5–25 m depth zones (few sounding points so poor quality interpolation) Good to low for marine facies identified by satellite detection; the precision decreases with depth	Average
Cost of acquisition	None, when the indicator is derived from government data High if new data have to be acquired	None if existing data are used Average to high (depending on the surface area to be mapped) if new data have to be acquired (cost of purchasing and processing very high resolution satellite images)	None (rarely) to high (usually)
Indicator no. 3: *Yearly number of fishing trips compared to the total surface area that can be exploited by commercial fisheries*			
	Numerator	Denominator data	Overall indicator
	Good	Low: (a) the exploited surface area is depicted by the exploitable surface area (b) it is assumed that abundance and fishing effort are evenly spread throughout this zone	Low
	Good	Same comments as for indicator no. 2	Low
	High, requires several series of surveys throughout the year	Same comments as for indicator no. 2	High

in monitoring deep-bottom fishing in Vanuatu showed that this cost can be lowered significantly if the fishers actively cooperate in collecting information (Cillaurren and David *op. cit.*).

1.2 Indicator of fishery system's vulnerability to the risk of overexploitation

The fishery system's vulnerability to overexploitation does, of course, depend on the status of the resource and the fishing effort. It also depends on the ability of public authorities to act at the community level to set up fisheries management systems to reduce this vulnerability or the effects of overfishing when it is already a fact. This ability is easy to assess and provides a good indicator of the fisheries system's vulnerability.

In general, trochus exploitation and sales of fishery production are organised within fisheries systems on four different spatial levels, i.e. village, provincal, national and international. Public policy decisions are made and resource management is organised at the national level except in cases where this organisation is decentralised to the provincial level. In contrast, management measures are implemented at the village level, which is also the level of production and fresh consumption, as final consumption of the shellfish after processing takes place at the international level.

This duality in scale between the spatial frameworks for organisation of management and those for production and the implementation of management makes it difficulty to put management measures designed at the national level into effect at the village level. In general, the greater the difference between the two levels, the harder it will be to establish relationships between those levels in order to manage the fishery and oversee the fishery system and thus, the greater the vulnerability of that system to overfishing. Vulnerability is therefore highest when management measures are designed at the national level but implemented at the village level (Table 3). For that reason, the difference in scale provides a good indicator of vulnerability (Table 4).

1.3 Indicator of reduction of risk of overexploitation

Reduction of the risk of overexploitation can be measured directly by evaluating the effects on the stock or on fishers of measures taken previously, or indirectly by measuring the effort required to reduce overexploitation. The difference in catch per unit effort between "t_0", the period corresponding to maximum overexploitation, and "t_1", the period following implementation of management measures, is the most relevant indicator in terms of direct measurement (Table 5).

Table 3. Difference in scale between organisation and implementation levels of resource management

	Implementation level:	Country	Province	Village
Management organisation level:	Country	No conflict		
	Province	Level 1 conflict	No conflict	
	Village	Level 2 conflict	Level 1 conflict	No conflict

Table 4. Indicator of vulnerability to overexploitation

Indicator no. 4: *Difference in scale between organisation and implementation levels of resource management*	
Relevance	Good
Precision	Good
Cost of acquisition	None

Table 5. Indicator of vulnerability to the risk of overexploitation

Indicator no. 5: *Difference between CPUE corresponding to implementation of management measures and CPUE corresponding to maximum overexploitation*	
Relevance	Good
Precision	Good
Cost of acquisition	Very high

However, there are two problems in deriving this indicator: (a) overexploitation of trochus stocks must have already been noted, and (b) catch and effort data must be monitored — a costly and labour-intensive operation.

2. Data collection and management of the trochus market at the national level

2.1 Indicator to characterise the risk of overexploitation

As shown in Table 1, characterising the risk of overexploitation using data collected from fishers is very costly. However, it is possible to significantly reduce the costs of acquiring the information used to derive this indicator by looking at the fishery from a socio-economic and regulatory angle. Fishery control can then be carried out at the national sector end (Fig. 1), whether this involves the shell exporter or the plant that processes the shells. This method is also much simpler since rather than trying to describe a demographic structure, the emphasis is on simply looking for specimens below the legal size (Table 6), which indicates current overexploitation and is a warning of even more severe future overexploitation. Inspections carried out with customs agents make it possible to rapidly determine if fisheries products that are smaller than the legal size are included in exports. This type of system is easy to set up when there is political will to control overexploitation of fishery resources. It is also quite inexpensive as one or two duly-sworn agents can do the work part-time. When there are no trochus button factories and all of the production is exported, inspection of exporters' trochus stocks can be left to customs agents.

2.2 Indicator of fishery system's vulnerability to the risk of overexploitation

In general, the trochus export or processing facilities that will be inspected are located in the capital and are thus in the same geographic area as the national fisheries department that oversees trochus stock management. Application of the indicator described in Table 4 shows that this alignment between the geographic level of trochus resource management and enforcement of management rules minimises the vulnerability of the fisheries system to overexploitation as long as the inspections are properly carried out. In fact, seizing products that are under the minimum authorised size puts all the sanctions on exporters or on the manufacturers who process buttons and does not penalise village producers, whose responsibility is much less. They simply respond to demand from buyers, who are the real driving force behind this fishery since fishers are just their agents. The trochus market does, in fact, have the characteristic of being controlled by demand. Punishing the end buyer situated at the far end of the sector has two advantages: (1) control is much simpler than trying to take action at the level of fishers because there are a limited number of operators and they are located near the departments in charge of carrying out inspections, and (2) this measure has real value as a teaching tool for offenders. Seizing a buyer's trochus stock because it contains a large number of shells under the regulatory size will cause significant financial losses to the buyer – repeating these losses too often could jeopardise the buyer's business. For that reason, it is highly probable that next time the buyer will refuse any shells that are too small. A refusal, whatever the number of middlemen between fishers and the penalised end buyer, should lead fishers to concentrate solely on trochus of adequate size at the risk of not being able to sell their catches to the middlemen who come to buy them.

2.3 Indicators of reduction in risk of overexploitation

Two indicators can be identified in this area:

- The mean annual number of inspections carried out in facilities that export or process trochus;
- Total annual fines for trade in illegal fishery products or the value of the seizures of such products (Table 7).

Table 6. Overexploitation risk indicator

Indicator no. 6: *Percentage of juveniles in stocks of national shell exporters or processors*	
Relevance	Good if all exporters and processors are inspected
Precision	Good, as verification is visual and carried out by fisheries departments or customs agents
Cost of acquisition	Low, as only one or two agents have to work a few weeks each year depending on the number of establishments to be visited None if these inspections are carried out by customs agents

The first indicator shows the efforts made and the second makes it possible to estimate their effectiveness. In fact, all positive inspections must be followed by dissuasive sanctions so that the offender does not repeat the offence. In general, offenders are likely to resent the sanctions imposed and public authorities must arbitrate between their anger and the risk of overexploitation. When the latter is seen by the general public and judges as a grave threat to the sustainability of coastal economic and social systems, the choice is clear: the exporters or manufacturers must be convicted. If not, this weakness can be seen to reflect a lack of concern on the part of the authorities about overexploitation of reef resources. It also suggests that the general public and the judicial system lack information about the threat because the public authorities have made insufficient efforts in this regard.

In the end, making laws and implementing management measures do not achieve anything if there are no means (regulatory and especially non-regulatory) of enforcing them. This is particularly the case for fisheries. This highlights a paradox that will have to be dealt with in future; i.e. the law, whose standard-setting aspect is by definition exclusive, increasingly involves a participatory aspect as a prerequisite to low-cost enforcement (both financially and socially)[3].

Conclusion

The question is "At what level of the sector should trochus be managed — with fishers or at the market end?" This brief overview of possible indicators (i.e. (a) to characterise the risk of overexploitation, (b) to estimate the fishery system's vulnerability to this risk, and (c) to assess the effectiveness of the management measures implemented to reduce this risk or to reduce overexploitation) shows that it is clearly less costly and much more effective to intervene at the end of the sector once minimum catch sizes have been set. The lower costs and maximum effectiveness of this approach can be explained largely by the absence of a difference in scale between the fisheries departments that set up and enforce the regulations and the trochus exporters or processors who are supposed to follow the regulations. Eliminating differences in geographic scale between the decision-making level and the level at which management rules are implemented must be one of the guiding principles of fishery system management. However, this principle does not mean that work by fisheries departments is limited to just the end of the sector. They can also work upstream with fishers as long as they delegate a large part of their prerogatives to them and allow them to manage their own resources as part of a co-management approach. This aspect will be discussed further in another article.

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Table 7. **Indicators of reduction in risk of overexploitation for commercial fisheries systems**

Indicator no. 7: *Mean annual number of inspections carried out in facilities that export or process trochus*	
Relevance	Good if the inspections are followed by severe sanctions for offenders
Precision	Very good, as verification is visual and carried out by fisheries department agents
Cost of acquisition	None, as data are available from fisheries or customs departments
Indicator no. 8: *Annual total of fines for trade in illegal fisheries products or value of seizures of such products*	
Relevance	Good – a very few positive controls followed by severe sanctions guarantee a reduction in overexploitation
Precision	Very good
Cost of acquisition	None, as data are available from fisheries or customs departments

3. In regard to protected marine areas, the appearance of participatory management reflects as much an economic reality (controlling poachers through eco-police on boats is very costly, which is why it is better to reduce poaching in neighbouring communities by involving them in management) as it does a change in conservation philosophy.

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Note on the spawning and development of the common spider conch *Lambis lambis*

Jean-François Hamel[1] *& Annie Mercier*[1]

The common spider conch *Lambis lambis* (Fig. 1a) of the family Strombidae is abundant in the shallow waters of the Indo-Pacific. The species is sought by shell collectors in several locations including the Philippines, Solomon Islands, Indonesia and India, and is harvested for food in Japan. Common spider conches are found mainly on sand among rocks or on coral reefs from the intertidal zone to ca 20 m depth. For the present study, 12 specimens were collected in the lagoon of Majuro atoll, Marshall Islands, in ca 2–3 m of water on protected sand beds. They measured ~ 20 cm long. The conches were maintained at the Marshall Islands Science Station in groups of four individuals per 50 L concrete tank under flow-through conditions at ca 200 L h^{-1}. All parameters fluctuated naturally, including salinity (29 to 33‰), temperature (24 to 29°C) and photoperiod.

Pairing and copulation were recorded on three occasions (Fig. 1b) in the middle of the day. Male and female were positioned face to face throughout copulation, which lasted at least 2–3 h (probably more, as copulation was already in progress when noticed). Spawning occurred at night in the 2 weeks following copulation and was not correlated with any obvious environmental factor. Several masses of cylindrical egg filaments (Fig. 1c) were observed early in the morning of 10 October 2001. The maze of egg filaments (ca 1800 µm in diameter) looked like very fine, pale brown threads of various lengths tangled and glued together as if they were one continuous coil.

The lecithotrophic embryos were already in the cleavage stage, typically positioned in a single or double row within the egg filament (Fig. 2a). Embryos measured ca 560 µm in

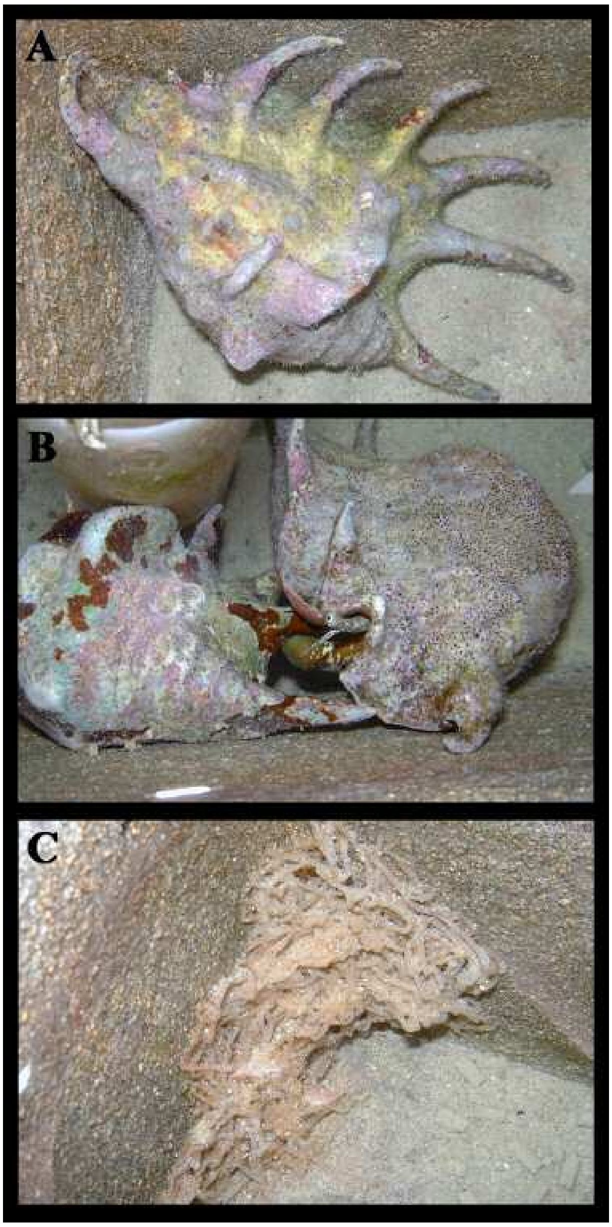

Figure 1.
(A) The common spider conch *Lambis lambis* collected in Majuro, Marshall Islands;
(B) male and female *L. lambis* during copulation;
(C) newly deposited egg filaments.

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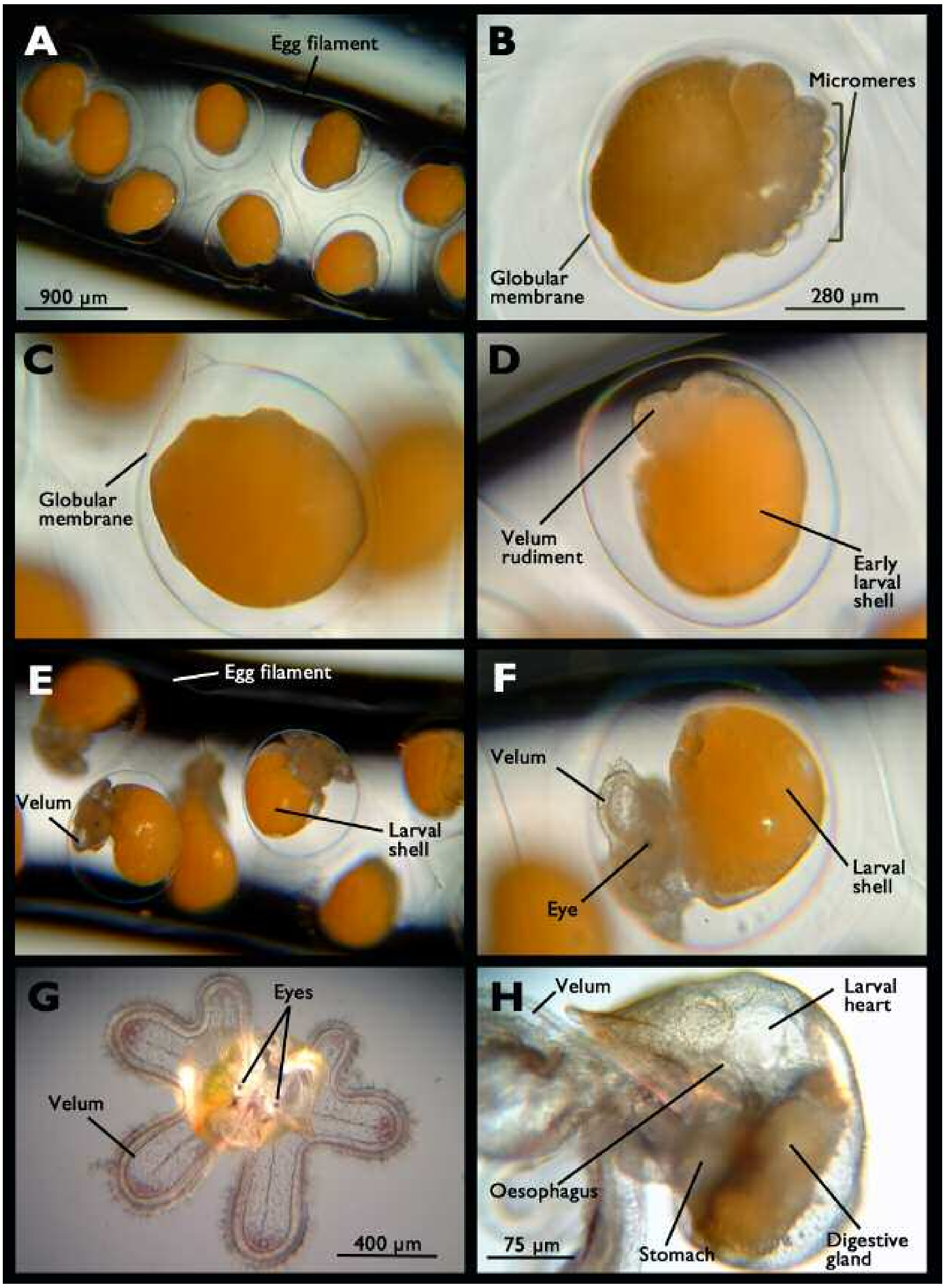

Figure 2. Development of *Lambis lambis*.

(A) Egg filament containing embryos at the cleavage stage;
(B) embryo at the cleavage stage showing the globular membrane and micromeres;
(C) embryo at the late gastrula stage;
(D) trocophore larva showing the rudiments of the early larval shell and velum;
(E) egg filament containing early veliger larvae still enclosed in the globular membrane, showing the larval shell and velum;
(F) close-up of the early veliger before hatching, showing the eyes, velum and shell;
(G) newly hatched veliger larva swimming in the water column, showing the velum with the crown of cilia and eyes;
(H) close-up of fully developed free-swimming veliger showing the oesophagus, stomach, digestive gland, shell, velum and larval heart.

The scale bar in A also applies to C, D and F and the scale bar in B also applies to E.

diameter and were ciliated and rotating clockwise (Fig. 2b) within a transparent globular membrane. The macromeres and micromeres were distinctly visible (Fig. 2a, b). About 10 h later, the embryos started developing early larval shell and velum rudiments (Fig. 2d). Roughly 24 h later, 50% of all embryos had reached the early veliger stage, measuring 670 µm (Fig. 2e, f). Still in the egg filament, they had developed a well-defined larval shell, velum, crown of cilia and two eyes.

From egg-laying until the early veliger stage, the females remained close to the spawn, covering it entirely or in part with their shell. This protective behaviour ceased at the beginning of the third day of development. The females moved away a few hours before the veligers hatched from the filament at a size of 900 µm on day 3 (Fig. 2g). After five days of development, the veligers measured 1100 µm and were swimming close to the water surface. They possessed a well-defined stomach, digestive gland, oesophagus and larval heart (Fig. 2h). Cardiac pulse was around 1 pulsation sec^{-1} during active swimming but varied with the level of activity of the velum and the response to stress that also elicited retraction of cilia into the shell. The veligers were very photo-reactive and sensitive to physical contact. They were fed *Spirulina* powder. Although they seemed to feed, as shown by the green coloration of the stomach, the veligers died after a total of seven days under laboratory conditions for reasons unknown.

Acknowledgments

We would like to thank the staff of the Marshall Islands Science Station (MISS), College of the Marshall Islands, for their help during the collection of *L. lambis* and the laboratory observations.

Observations on the biology of the common egg shell *Ovula ovum* in Majuro, Marshall Islands

Jean-François Hamel[1] & Annie Mercier[1]

The common egg shell, *Ovula ovum*, is found in shallow reefs (down to 20 m) throughout the Indo-Pacific. It belongs to the family Ovulidae and is closely related to the true cowries of the family Cypraeidae (Abbott and Dance 2000). *O. ovum* are very common in the Marshall Islands especially around Majuro atoll where the local people collect them extensively. The shiny white shells are sold alone or as decorative elements in handicraft items.

The current literature on *O. ovum* remains scarce. Most of the existing knowledge has been gathered from anecdotal mentions, often generalised for all ovulids. A number of authors have mentioned that *O. ovum* is commonly found in association with large fleshy soft coral (Wilson and Gillett 1979). Furthermore, Johnson (1991) and Griffith (1995) indicated that egg shells feed on soft coral, while other sources state that they prey specifically on *Sarcophyton* and *Sinularia* and on some toxic species. Rudman (2003) recently reported that the genus *Ovula* feeds on polyps of soft and stony coral, like other ovulids. The reproduction of *O. ovum* is known to follow the typical pattern of ovulids, with egg capsules being deposited on soft coral, although specific accounts are lacking.

This report presents novel information on the daily activity, feeding, reproduction and development of *O. ovum*. These data will contribute to a better understanding of ovulids, which are under increasing threat from human activities in many island countries of the Indo-Pacific.

Collection and maintenance

Egg shells, *Ovula ovum*, were collected by local people at a depth of 3 to 5 m on the outer fringing reef of Majuro atoll in the Marshall Islands in July 2001. The habitat was characterized by dead and live hermatypic corals, coral pebbles and abundant crevices with only rare occurrences of soft corals and sponges. The egg shells were abundant (ca 1.7 individuals m^{-2}) and distributed in patches of ca 14 individuals within the area explored (400 x 10 m). A total of 237 adults were collected in ca 3 h of snorkelling, and most of them were returned to their natural habitat immediately after data collection. The lengths of individual shells varied between 5.9 and 8.3 cm. No juveniles were found.

Following collection, a few individuals were transferred to 10-ton tanks filled with a substrate of coral sand and pebbles (ca 15 cm thick), and a few concrete blocks. The specimens were kept at a density of 0.8 individuals m^{-2}, and seawater flow-through was adjusted at ca 3000 L h^{-1} to maintain water quality. The tanks were exposed to the natural light regime. The salinity fluctuated between 29 and 33‰ and the temperature between 24 and 29.5°C.

Daily activity

Laboratory observations revealed that *O. ovum* remained immobile, usually hidden in crevices, from 05:30 to 18:15 h. In 87% of cases, they always used the same crevice or area as diurnal shelter and started moving in search of food or a mate when the sun went down. After 5 months in captivity, all individuals (marked on the shell) retained the same homing behaviour. The egg shells seemed to move (ca 2.2. cm min^{-1}) and feed simultaneously (observation of the radula through a glass aquarium), thus ingesting food continuously. Analysis of intestinal contents (see below) indeed revealed the continuous presence of food in the first section of the digestive tract between sunset and sunrise. Furthermore, the addition of artificial light delayed and even prevented the nocturnal feeding behaviour.

Observations showed that the mantle of *O. ovum* is continuously stretched out, day and night, only

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occasionally revealing a tiny section of the white shell underneath. The only exception noted was for specimens in poor physical condition which eventually stopped feeding and sometimes died. The mantle of healthy individuals also remained fully extended during copulation.

Diet

Some of the freshly collected *O. ovum* were preserved by injection of 70% ethanol. Investigation of the digestive tract revealed the presence of large quantities of benthic algae, although most of the content was made up of unrecognizable structures. No trace of sponge elements, spicules or other, were found. Under laboratory conditions, the egg shells fed on deposited organic matter and grazed on the benthic algae growing on the various surfaces available in the tanks. Several species of sponges, hermatypic corals and soft corals (described as the main diet of *O. ovum* in the field) were introduced alternatively in the tanks for several weeks. They did not seem to significantly attract starved individuals or well-fed ones, and no sign of predation was noted.

Copulation

Formation of pairs became evident as the breeding period approached, often several days before copulation (usually between 2 and 6 days under laboratory conditions). In 27 cases, the female was observed to carry the generally smaller male on its back without any signs of copulation for 3 to 4 days. In those instances, the same male was found on the back of the same female every day, yet they moved separately during the night even if they remained close to each other.

Copulation was typically observed 2 to 3 days before the full moon, every month from July to November. No multi-copulation involving different individuals was ever recorded. Most copulations occurred in the morning between 04:00 and 10:00 h, although a few were recorded at various times of the day. Breeding behaviour accounted for the rare instances where *O. ovum* were observed to be active during daytime. In preparing for copulation, individuals positioned themselves head to tail, the male being located alongside the female or sometimes directly mounted on its shell. Copulation typically lasted between 34 and 72 min, both male and female generally remaining immobile throughout the process. After copulation, the female usually moved away first, thus stretching the male's reproductive organ. The male started moving, generally in the opposite direction, and finally detached ca 20 sec later. Nonetheless, male and female remained close together (less than 5 cm apart) for ca 5–10 h before dispersing definitively. Females were found to store spermatozoa for 1 to 7 days before spawning.

Capsule-laying (spawning)

O. ovum laid egg capsules every month from July to November on hard substrata (e.g. on the sides of the tanks or inside crevices in the concrete blocks). Spawning either coincided with the full moon or occurred a few days afterward. The laying of egg capsules by a single female could take as long as 74 h, although the average was between 32 and 48 h. Sometimes the process was uninterrupted, even during the daytime. It took between 5 and 15 min to release a single capsule, but the interval between each laying varied greatly. Some females released their capsules in a rapid sequence

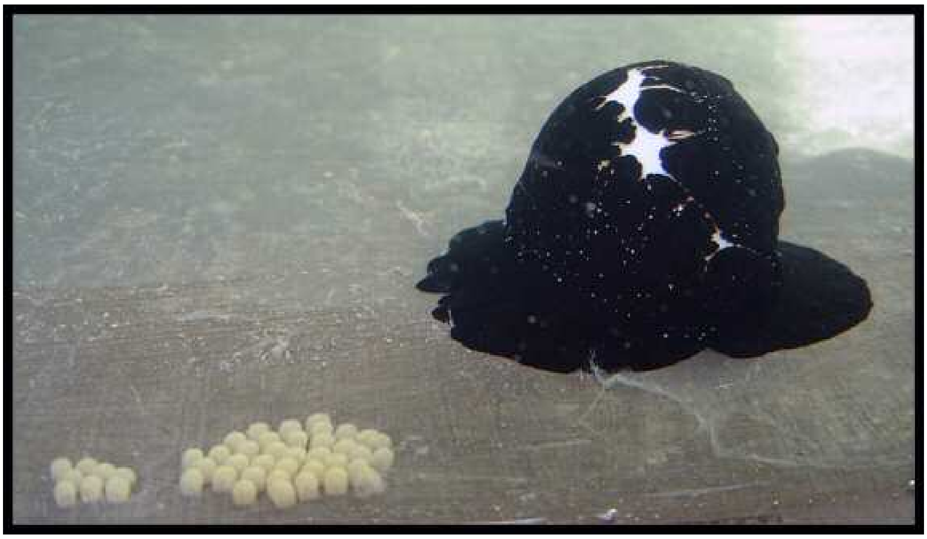

Figure 1. **Female *Ovula ovum* with capsule mass.**

(a maximum of ca 20 capsules per hour was observed), especially during the night, whereas the process was commonly slower during daytime (as slow as 1 to 3 capsules in 4 hours). An average of 86 egg capsules were deposited by a single female, with a maximum recorded of 102 capsules.

During spawning, the female covered portions of the capsule mass, or the entire mass, with its foot. No interaction with conspecifics was noted throughout the capsule-laying process, the other specimens remaining at a distance, usually more than 20 cm away. The females laid their capsules in a pattern of almost equally distanced rows (Fig. 1). Each whitish capsule was firmly attached to the substratum. The final shape of the capsule mass was usually rounded and the female moved away from it as soon as it was deposited. The capsules were translucent in the beginning, becoming yellowish and more opaque during the development of the embryos. Each capsule measured ca 4 mm wide and 5 mm high (Fig. 1) and contained between 150 and 212 embryos in an intracapsular fluid.

Development inside the capsule

Embryonic development began as soon as the capsules were laid. The survival rate varied throughout the various stages and was not uniform among the capsules. Most of the first egg capsules that were spawned contained several non-viable embryos. For example, the first third of the capsules showed up to 79% of non-viable embryos and larvae, and ca 25 ± 8% of the capsules spawned by each female eventually decayed without producing any pelagic larvae. The high percentage of abnormal development (irregular cellular divisions) among the first deposited capsules seemed to be associated with polyspermic fertilization, as revealed by microscopic examination. Moreover, between 20 to 31% of all oocytes in each of the last two-thirds of the capsules never developed. These oocytes showed no sign of fertilization or further cleavage.

Table 1 and Figures 2 and 3 illustrate the development of those eggs/embryos that developed normally. For detailed observation of the developing embryos, some egg capsules were collected at regular intervals from different spawns (n = 9) with a stainless steel scalpel. The first cleavage was completed ca 70 min after spawning and produced two rounded blastomeres of equal size (Fig. 2b). The 4-cell stage occurred 25 minutes later (Fig. 2c). The first micromeres appeared soon afterward, ca 160 min after spawning (Fig. 2d). Subsequent cleavage of the micromeres resulted in the formation of a cap of micromeres at the animal pole (Fig. 2e). The blastula stage was reached after ca 8 h and the early gastrula after 10 h (Fig. 2f). At that stage, the larvae developed their

Table 1: **Development of *Ovula ovum* under naturally fluctuating temperature (24 to 29.5°C), salinity and photoperiod. A new stage was usually considered attained when ca 50% of the individuals reached it.**

Stage	Time from egg capsule laying
Capsule laying	0
2-cell	70 min
4-cell	95 min
Cleavage stage	160 min
Blastula	485 min
Early gastrula	605 min
Gastrula	28 h
Hatching from fertilization envelope	63h
Late gastrula	72 h
Early trochophore	5 d
Trochophore elongation	6 d
Early veliger	8 d
Veliger	10–12 d
Late veliger	15–18 d
Free-swimming veliger (swimming at the surface)	20–22 d
Free-swimming veliger (swimming near the bottom)	22–25 d

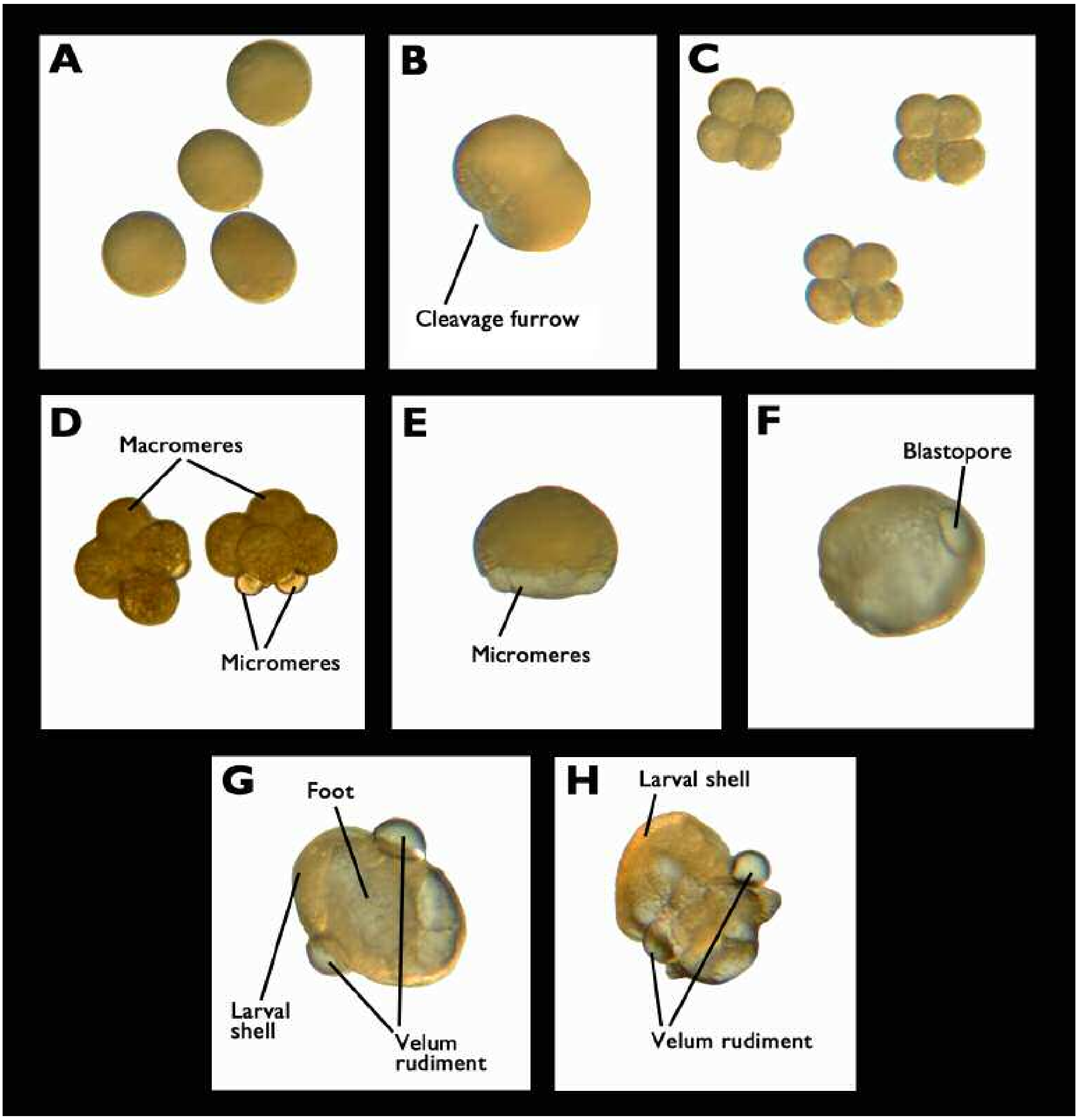

Figure 2. **Development of *Ovula ovum*.**

(A) Newly encapsulated eggs;
(B) 2-cell stage;
(C) 4-cell stage;
(D) and (E) cleavage stages showing the micromeres and macromeres;
(F) gastrula stage showing the blastopore;
(G) and (H) trochophore showing the larval shell, foot and velum rudiment.

first cilia. The gastrula hatched from the fertilization envelope after ca 63 h and started moving freely in the egg capsule. After harbouring an elongated shape for ca 72 h, the embryos slowly entered the early trochophore stage and were fully developed after 5 days. At that stage, the larvae started developing a foot and a larval shell, and the rudiment of a velum (Fig. 2g, h).

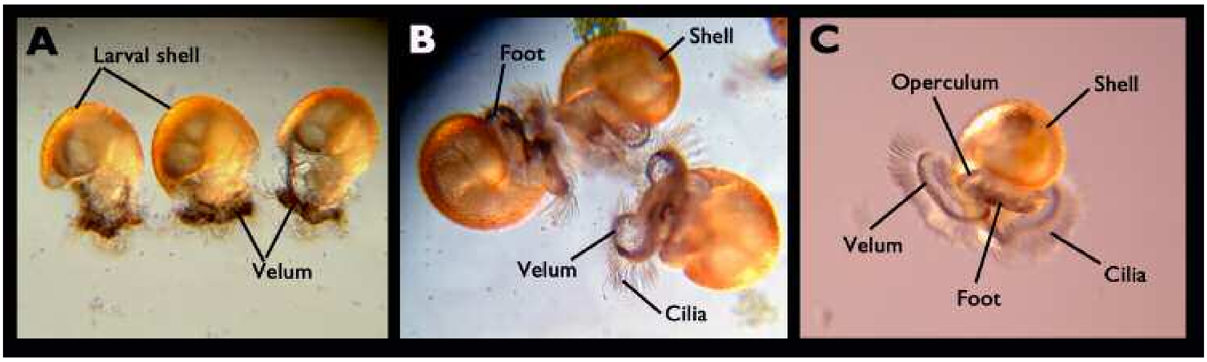

Figure 3. **Development of *Ovula ovum*.**
(A) Veliger larvae after ca 20 days of development just before hatching;
(B) and (C) free-swimming veligers after ca 25 days of development.
The larval shell, foot, velum, operculum and cilia are shown.

After 8 days, the larvae reached the veliger stage (Fig. 3). They started accumulating bluish-black pigments that were especially visible in the velum, whereas the foot possessed an operculum, and the cilia crowns were well developed. Furthermore, the shell became clearly visible and the heart was apparent through the transparent body (Fig. 3). On the outside, the stretched capsules seemed larger, measuring ca 5 x 5 mm.

Pelagic development

As the free-swimming veligers were about to emerge (Fig. 3a), several capsules were collected from different spawns and transferred to 50-L aquaria under similar environmental conditions. The veligers were left to hatch naturally (Fig. 3b, c). Densities were then adjusted to ca 1 larva per 50 mL of water. Due to unavailability of live microalgae at the time, various powdered preparations, such as *Spirulina* and Algamac, as well as ground green macrophytes were used to feed the larvae.

The free-swimming veliger larvae emerged after 20 to 22 days of development (Table 1). About 4 days later, all the larvae died on the verge of metamorphosis after spending some time swimming close to the bottom of the tank. Mortality was due to either the lack of appropriate food or settlement substrate. The investigation was thus terminated abruptly after 26 days of culture.

Acknowledgments

We would like to thank the team of the Marshall Islands Science Station (MISS) for their help during the laboratory work. This research was supported by the United States Department of Agriculture (USDA) under the College of Micronesia Land Grant programme.

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Nature gives a lesson in armor design

Source: Massachusetts Institute of Technology and http://www.physorg.com/news6647.html

The ocean is a perilous environment for a soft-bodied creature like a sea snail, so nature gives it an advanced nanostructured armor system that is stiff and strong yet lightweight. It's called a shell. Now Massachusetts Institute of Technology (MIT) scientists show that nature is indeed an expert nanoengineer.

Understanding the fundamental design principles of natural armor systems like shells may help engineers design improved body armor systems for humans in perilous situations, like soldiers and police officers. At MIT's Institute for Soldier Nanotechnologies, researchers are studying the structure and mechanics of the tough inner layer of mollusc shells, called "nacre" or mother-of-pearl, at extremely small, nanometer-length scales (a nanometer is a billionth of a meter).

In an upcoming issue of the Journal of Materials Research, Professor Christine Ortiz of the Department of Materials Science and Engineering, Professor Mary Boyce of the Department of Mechanical Engineering, and doctoral student Benjamin Bruet of materials science report their results. They show that nature is indeed an expert nanoengineer.

"The complexity we have observed in nacre at the nanoscale is quite amazing and seems likely to be a critical determinant of the toughness of the material," said Ortiz.

Nacre is composed of two relatively weak materials: 95 per cent calcium carbonate, a brittle ceramic, and 5 per cent flexible biopolymer. These materials are organized into a "brick-and-mortar" structure with millions of ceramic plates, each a few thousand nanometers in size, that are stacked on top of each other like rolls of coins. Each layer of plates is glued together by thin layers of the biopolymer. The MIT team has focused its studies on small nanometer-sized regions of the individual tiny plates.

"Even though the calcium carbonate is very weak and brittle on its own, one can get enormous increases in toughness through design at multiple-length scales," said Ortiz. "Understanding how the material is designed and functions at the smallest-length scales will be critical to learning how to create tough biomimetic synthetic composites."

Replacing the weak building blocks of nacre with stronger materials – in a similar design – has the potential to yield much tougher composites for use in armor systems or structural applications like automobile panels or plane wings.

Image: Kim Friedman, SPC

Trochus niloticus

The MIT team began its experimental studies by imaging the tiny plates cut from the nacre of *Trochus niloticus*, a sea snail, using a powerful instrument called an atomic force microscope. They found that each individual plate also had its own complicated nanostructure and was divided like a pie into separate sectors, with cylindrical beams running through the thickness of the plates, a fine surface of nanosized bumps, called nanoasperities, which were further organized into groups, and biopolymer molecules, only about 1 nanometer in height, traversing over and bound to the mountainous array of nanobumps.

They then used a diamond-probe tip only a few hundred nanometers in size in the Department of Materials Science and Engineering's Nanomechanical Technology Laboratory to push into the surface of an individual plate (a technique called nanoindentation) while "feeling" the force that resulted. "I was surprised to find that the tablets were both extremely stiff and strong at these length scales and that they resisted brittle crack formation and propagation even at exceedingly high forces," said Bruet.

Although scientists have studied the properties of nacre at the macroscale and microscale, Ortiz says that very little is known about its behaviour at the nanoscale, which is where structure and properties set the foundation for the material's overall behaviour.

The team is currently studying the nanoscale adhesion forces that exist between the ceramic plates and flexible biopolymer in the nacre, as well as the single molecule nanomechanical properties of the biopolymer. This research may shed light on the longstanding question of how to create durable interfaces in synthetic composites that can withstand high forces in water environments. Ortiz's group is also studying the nanostructure and nanomechanical properties of other natural materials, such as bone and cartilage.

"Nature uses nanoscale structural design principles to produce materials with superior mechanical properties," said Ortiz. "In many aspects, human engineers have yet to achieve the same skill. However, as nanotechnology methods advance, the creation of artificial nacre — and other kinds of high-performance armors — is becoming a more and more realistic goal."

Abstracts and publications on trochus and other molluscs

The remarkable population size of the endangered clam *Tridacna maxima* assessed in Fangatau Atoll (Eastern Tuamotu, French Polynesia) using in situ and remote sensing data

S. Andréfouët, A. Gilbert, L. Yan, G. Remoissenet, C. Payri and Y. Chancerelle

Source: ICES Journal of Marine Science 62(6):1347–1048.

Several lagoons of the Eastern Tuamotu Atolls (French Polynesia) are characterized by enormous populations of the clam *Tridacna maxima*, a species considered as endangered in many locations worldwide. This unique resource is virtually intact, until recently being impacted only by local consumption. Increasing exports to Tahiti's market (up to 50 tonnes of wet matter y^{-1}), combined with the relatively small size of these lagoons (<50 km^2), have raised significant concerns for agencies charged with management of lagoonal resources. In order to evaluate whether the current harvesting pressure threatens long-term sustainability of this resource, it is necessary to estimate the total number of individual clams present and also the fraction of that stock that is currently targeted by fishers, who generally collect clams in very shallow waters (<1 m), walking on the reef edges. Here, we present results for a pilot study evaluating this resource at Fangatau Atoll. Using a combination of data collected *in situ* and three remotely sensed images with different spatial resolution (1.5, 5.6, and 30 m), we estimate that the shallowest lagoonal areas (4.05 km^2 at depth <6 m) harbour five classes of benthic habitat with significantly different clam areal covers and densities. Considering the cover/density values for each habitat class, 23.65 ± 5.33 million clams (mean ± 95% confidence interval) inhabit these 4.05 km^2. Assuming that current harvesting techniques will be maintained in the future, the commercially available stock represents 44% of the population located on 1.18 km^2 of the shallow lagoon. A comparison of results from the three remote sensing platforms indicates that high resolution, broadband multispectral sensors (e.g. IKONOS, Quickbird) should provide the best existing platforms to conduct similar assessments elsewhere.

Stock enhancement programs in the United States affiliated Pacific Islands for economic development and food security

M. Nair

Source: Journal of Shellfish Research 24(1):330–331. January 2005.

There is a strong desire by many of the Pacific Island governments to develop income-generating local industry based on available natural resources, and to restock reefs where natural marine populations have declined. Some nations in the United States affiliated Pacific Islands such as the Republic of the Marshall Islands (RMI), Federated States of Micronesia (FSM), and the Republic of Palau also face increasing economic pressure as funding from their respective Compacts of Free Association with the USA diminishes. Farming marine and freshwater aquaculture organisms has the potential to provide export products, alleviate social pressure on threatened food species, and provide import substitutes for the US affiliated Pacific Islands. The economy mainly relies on foreign aid. Presently, there is emphasis on the development of marine resources, mainly marine aquaculture or mariculture, to meet future economic needs, become self-sufficient, and develop food security for its fast-growing population. Pollution-free water and biodiverse fauna of finfish and shellfish, of which several are endemic to the region, bless all the US affiliated Pacific Islands. Because the land area is minute compared to the vast ocean exclusive eco-

nomic zones, it means that in all these nations the natural resources are primarily marine. The nations' abundant and extremely biodiverse coral reefs provide habitat for robust fish populations and other marine life that support subsistence and commercial fisheries. However due to overfishing and bad and destructive fishing practices, several species have become overexploited and need conservation. There is also a strong desire by the national governments to develop revenue-producing local industries based on available natural resources and to restock reefs where natural marine populations have declined. The national and local governments have also initiated marine protected areas (MPA) to revive the fisheries. In addition to this, there are several stock enhancement programs, especially in shellfish like ornamental shellfish like trochus, black pearls, and giant clams, being undertaken successfully to restock the depleted reefs and in the MPA. Preliminary results have shown that these stock enhancement programs have been successful mainly due to the community participation in these activities. The success and popularity of such measures have prompted the governments to look into stock enhancement programs through sea ranching of hatchery-produced fish fingerlings of food finfishes like groupers, snapper, and other food fishes and several rare and endemic ornamental fish and shellfish species for food security, stock replenishment, and enhancement, thus paving the way for future economic benefits and community self-sufficiency and self-reliance.

Trochus resources: a new fishery for Tonga?

S. Malimali

Source: I. Novaczek (ed). 2005. Pacific voices: Equity and sustainability in Pacific Island fisheries. Suva: Institute of Pacific Studies, USP Fiji. 137–151.

Many Pacific island countries are exploring the potential of aquaculture for enhancing food security and marine exports. One of the most popular species for introduction has been the topshell, *Trochus niloticus* and, despite its experimental release in Tonga in 1992, information on the size of the stock and fishers' perceptions are limited. This study explores how fishers' activities, attitudes and livelihood options have influenced the trochus fishery establishment program in Kolonga village on Tongatapu. Observation, questionnaires, creel surveys and interviews were used for data collection over several months in 2003. The role of women in the fishery is a critical element, since day gleaning by women is the major fishing activity on the Kolonga reef. Day and night diving also occurs, but only by men. Females glean only for food, fishing 5–6 times per week. Trochus was found in only 8 of 79 catches inspected and had only been collected for home consumption. None of the fishers sold the shell, knew that the shell was marketable, knew that it had been introduced to Tonga, nor knew that harvesting it was banned. Trochus represented only 3% of the shells collected, but most fishers said they collected it. The basal diameter of trochus harvested from Kolonga ranged from 30 mm to 120 mm, with the majority being 50–90 mm. As the sexually mature size of male and female trochus is between 55 and 70 mm, some of the specimens observed were too small to have reproduced. Even small captures reduce the chance of a commercial fishery being established, and the trochus population could even become depleted to the point of local extinction. Recommendations for ensuring a viable trochus fishery in future include strengthening awareness programs, implementing community-based management measures and involving young people, women and elders (those most dependent upon reef gleaning) in local management systems.

Gender, generational perceptions and community fisheries management in Lelepa, North Efate, Vanuatu

J. Tarisesei and I. Novaczek

Source: I. Novaczek (ed). 2005. Pacific voices: Equity and sustainability in Pacific Island fisheries. Suva: Institute of Pacific Studies, USP Fiji. 186–208.

In recent decades there has been significant pressure on rural Vanuatu to join the cash economy. Communal sharing of resources has shifted to individual harvesting of marine resources for commercial gain, affecting gender roles, technologies used and fish stocks. The history of change in subsistence and small commercial fishing activities on Lelepa Island, north Efate, illustrates these developments. Researchers from the Vanuatu Cultural Centre collected data on traditional harvesting and management practices in 1999–2001. For this case study additional research was conducted in 2003 using observation and semi-structured interviews. While marine products remain the primary source of protein on the island they have also contributed to cash incomes, creating a dilemma for the community. For example, traditionally only women collected trochus but as it became commercially valuable men started to harvest it also and demand outstripped supply. Trochus is now uncommon. The introduction of spear guns, nets, reels and motor boats meant that by the 1970s Lelepa's other marine resources were also in decline. Green snail may be locally extinct. Beche-de-mer was fished out in the late 1970s. Many big fish, especially wrasse and grouper, are also now rare. Despite this the bulk of fish caught still goes for sale in Port Vila. Foreign companies have paid large access fees to collect fish, live corals and juvenile giant clams for the aquarium trade, but no monitoring of their activities has been done and it has had a detrimental impact on the emerging ecotourism industry. The paramount chief of Lelepa responded to these pressures by introducing traditional harvest bans and a marine protected area in the early 1990s. This was not popular with many fishermen and meant the end of fishing for elderly women. By custom, women have little say in village decision-making, but they are expected to provide food for their families and they also play an unacknowledged role in educating children about the protected area. Some species are recovering but violation of the ban by some small chiefs has led to problems of compliance and enforcement. Finding the balance between subsistence needs, economic development and resource conservation in Lelepa is likely to remain difficult and contentious.

Gender collaboration: a case study of local resource management in Safa'i village, Samoa

M.J. Siamomua-Momoemausu

Source: I. Novaczek (ed). 2005. Pacific voices: Equity and sustainability in Pacific Island fisheries. Suva: Institute of Pacific Studies, USP Fiji. 209–220.

Women in coastal communities across the Pacific have long been involved in many aspects of fisheries, but their role has often been undervalued or neglected in government plans and processes. This study explores gender roles in fisheries management and conservation in the village of Safa'i, a small, traditional community on the northern coast of Savai'i, the biggest island of Samoa. Safa'i has a population of around 250 and the village economy is based on subsistence and artisanal fishing and agriculture. Traditional fisheries management practices were based upon male chiefly authority and excluded women from consultation and decision-making. Problems occurred due to the lack of full community support and poor enforcement, exacerbated by population concentration in coastal areas. In 1995, the Samoan government introduced a fisheries extension program which gradually devolved powers and responsibilities for inshore fisheries management back to local communities. Safa'i joined this program in 2002. A cooperative management approach has established an institutional structure for the control of marine resources, enabling collaborative actions between the village leaders (matai) and the government. Shared decision-making involving both men and women was introduced and members of the Women's Committee were elected to sit on a Fisheries Management Advisory Committee. Consultation with women, matai and untitled men led to a fisheries management plan which has included: the creation of a marine protected area; bans on destructive fishing practices; enforcement of village rules and bylaws; restocking of reef and lagoon areas with giant clams and trochus; and workshops and training for villagers on fisheries management and conservation. Alternative activities such as penning fish for harvest and turtles for tourism and conservation have also been introduced. The plan is monitored and enforced by a committee consisting of men and women. Women's traditional fishing activities have been affected, as has their domestic routines, time allocation and family nutrition, but the changes will also benefit them. Safa'i has become very successful and the active collaboration of both women and men in fisheries management is seen as a key factor in achieving sustainable fisheries. Recommendations for further improvements made include: strengthening communications with village level women's committees and encouraging women's participation in workshops and training; using the women's committees to promote fisheries management; improving data on subsistence fisheries and women's involvement in fisheries; undertaking periodic reviews of fisheries management plans to determine the progress of women; and establishing a 'Women in Fisheries Association' in Samoa.

A 60-year isotopic record from a mid-Holocene fossil giant clam (*Tridacna gigas*) in the Ryukyu Islands: physiological and paleoclimatic implications

T. Watanabe, A. Suzuki, H. Kawahata, H. Kan and S. Ogawa

Source: Palaeogeography, Palaeoclimatology, Palaeoecology 212(3–4):343–354. (Sep. 2004).

We have constructed a 60-year stable isotope record from a ^{14}C-dated fossil giant clam, *Tridacna gigas* (6216 years BP), at its northernmost latitudinal limit in the geological past, on Kume Island, Central Ryukyu Archipelago, Japan. Stable oxygen (δ^{18}O) and carbon (δ^{13}C) isotopic analyses are combined with observations of growth lines seen on the inner shell layer. Sixty pairs of summer/winter growth lines, which preserve daily growth increments were observed in the inner shell layer. Two growth phases, characterized by a growth curve and isotopic profiles, are clearly recognized throughout the growth history of this specimen. No significant shifts in average values of the two isotopic ratios were detected during its growth history, although the growth rate varied widely from 1 to 15 mm/year over 60 years, including after the onset of sexual maturity. Spectral analysis of the fossil *Tridacna* δ^{18}O time series implies that decadal variability observed in the North Pacific Ocean during the past hundred years also existed 6000 years ago. Our study implies that fossil giant clams are one of the best means of inferring isotopic records of annual to decadal climate variations. Giant clams have the advantages of a dense shell, high growth rate, long lifespan, and geographically and geologically broad distributions.

Dimethylsulfoniopropionate in six species of giant clams and the evolution of dimethylsulfide after death

R.W. Hill, J.W.H. Dacey, S.D. Hill, A. Edward and W.A. Hicks

Source: Third International Symposium on Biological and Environmental Chemistry of DMS (P) and Related Compounds, Rimouski, Quebec, Canada 26–28 September 2002. Canadian Journal of Fisheries and Aquatic Sciences 61(5):758–764.

Substantial accumulation of dimethylsulfoniopropionate (DMSP) is documented in tissues of all six of the common species of giant clams (Tridacnidae). Results include measures of DMSP concentrations in siphonal mantle, byssal mantle, adductor muscle, and gill tissues obtained by gas chromatography of alkalized extracts plus evidence of DMSP from mass spectrometry. Formation of dimethylsulfide (DMS) by tissues after death is documented. The tridacnid clams maintain symbiotic associations with populations of dinoflagellates, which live in the enlarged siphonal mantle. It was postulated that because of their association with dinoflagellates, the clams would chronically accumulate DMSP to high concentrations. The results show that DMSP occurs at over 30 nmol degree kg^{-1} in many tissues of tridacnid clams, meaning that these clams accumulate DMSP to the highest documented tissue concentrations in the animal kingdom. DMSP at such concentrations could affect multiple properties and functions. Of particular interest for this research was to assess whether postmortem breakdown of DMSP is responsible for the rapid development of potent off-odors and off-tastes that have blocked the commercial success of giant clam aquaculture. High concentrations of DMS produced in the day after death probably account for the peculiar perishability of giant clam tissues.

Effects of copper and decreased salinity on survival rate and development of *Tridacna gigas* larvae

E. Blidberg

Source: Marine Environmental Research 58(2–5):793–797. (August-December 2004).

Giant clams (Family: Tridacnidae) are endangered species distributed in the Indo-Pacific region. In this study, survival rate and development of *Tridacna gigas* larvae were studied for three days in ambient water (32 psu), copper (2.5 µg Cu^{2+} L^{-1}), reduced salinities (25 and 20 psu) and the combination of copper and 25 psu salinity. No significant differences were found in larval development between treatments. The survival rates decreased considerably with reduced salinities although the combination of copper and reduced salinity gave synergistic effects. As a consequence, this could limit population growth of giant clams in coastal areas and could also explain the absence of larval settlement on reefs close to harbours or river mouths. More research is needed to understand the basic requirements and stress tolerance in giant clam larvae for reef restoration and other management actions to be successful.

Successful seeding of hatchery-produced juvenile greenlip abalone to restore wild stocks

C.D. Dixon, R.W. Day, S.M.H. Huchette and S.A. Shepherd

Source: Fisheries Research 78: 179–185. (2006)

Seeding of hatchery-produced abalone has the potential to enhance or maintain wild populations and ensure the viability of fishing grounds, but survival of outplanted juveniles has been poor in many previous seeding experiments. In our study hatchery produced *Haliotis laevigata*, age 18 months with a mean size of 28 ± 3 mm, were released at eight sites in South Australia. Because a pilot study showed significant increases in survival 2 months after release in reefs with two layers of boulders compared to a single layer, six reefs were established at each site, each with two boulder layers and approximately 6 m^2 in area. Juveniles were anaesthetised prior to individual tagging and then given 5 days to recover on settlement plates within cages. The cages were transported in cool boxes, opened and placed between boulder layers by divers within 6 h of leaving the hatchery. Six months after seeding almost all juveniles were in cryptic positions between boulders, but 9 months after seeding 17% of abalone were emergent at 56 ± 7 mm. Estimated minimum survival after 9 months was poor at two sites (0 and 23%) but at six sites survival ranged from 47 to 57%. Empty shell collections accounted for 10% of seeded juveniles during this period. A second seeding a year later at one site resulted in similar survival after 3 months. These results compare very favourably with previous seeding experiments, particularly considering the range of sites seeded and the number of reefs within each site. This was probably due to careful site selection, careful handling of seeded juveniles and the provision of a suitable, cryptic environment to reduce mortality. Poor survival at two sites appeared to be due to the presence of large numbers of predators soon after seeding.

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