Current paradigms in trochus management and opportunities to broaden perspectives

by Raymond P. Clarke & James N. Ianelli
National Marine Fisheries Service and
National Oceanic Atmospheric Administration

Introduction

Trochus (*Trochus niloticus*) are coral reef-associated, gastropod molluscs that provide the basis of important inshore fisheries in many areas of the Pacific (Indo-Australian archipelago, Melanesia, Micronesia and, more recently, Polynesia). Trochus, or topshell, have aragonite shells which are the primary raw material for mother-of-pearl buttons and decorative inlay work. The meat is edible and is typically cooked, dried or occasionally canned for consumption. Annual demand for raw trochus shell is estimated at between 3,000 and 5,000 t (Bour, 1990). Most raw material is exported to processors in Japan, South Korea or Taiwan.

Dalzell & Adams (1994) estimate that 80 per cent of all harvests from inshore fisheries in the South Pacific are taken for subsistence purposes. They also note that most of the commercially important inshore invertebrates are harvested for export markets. Trochus fisheries thus form a substantial opportunity for social and economic development in Pacific Island countries. Indeed, much of the literature related to nearshore Pacific Island marine resource development has focused on trochus.

Trochus have been translocated to at least 70 new settings during the past 65 years (Eldredge, 1994). Typically translocations have been supported by public sector (government) initiatives. However, the fact that several early trochus transfer activities were also undertaken by independent fishermen indicates that the resource has long been perceived to have excellent development potential (e.g. in Guam, as noted by Smith, 1987).

Examples of economic success stories for trochus reseeding programmes (also referred to as translocation) are perhaps best exemplified by the Aitutaki fishery in the Cook Islands (Sims, 1988). Adams (in prep.) estimates that between 6,500 and 12,000 t of trochus have been harvested over the past 50 years due to successful transplanting programmes. As successful translocations occurred, research flourished, leading trochus to become one of the most well-studied inshore fishery resources in the Pacific (cf Preston & Tanaka 1990).

Experience with the resource dynamics has increased over the years (see Bour, 1990 and Nash, 1993 for reviews) and a number of truly innovative investigations on alternative approaches to managing the resource have begun (e.g. Nash et al, 1995). However, while trochus reseeding programmes have been a clear fishery development success, examples of success in managing sustainable trochus fisheries are much less common.

A cursory review of the literature provides a number of cogent examples of dramatically variable landings. If landings are viewed as proxies for abundance, then populations have changed dramatically, given that fishery landings have fluctuated by at least three orders of magnitude (Figure 1).

Many people have concluded from these trends that, because trochus are sessile invertebrates, they are extremely vulnerable to exploitation and easily overfished. Fortunately, one of the more encouraging aspects of trochus management is that mistakes, such as overfishing, can potentially be corrected through trochus transplant programmes.

However, responsible resource management policy implies that steps should be taken to harvest the resource at a sustainable level while maximising social benefit and minimising costs. With the substantial and growing amount of marine resource management experience, we feel that a review of trochus fishery management is timely.

To undertake such an analysis, we reviewed historical trends and drew from examples of trochus management techniques applied throughout Micronesia during the 20th century. Micronesia has the longest proactively managed and documented (in English) trochus fishery in the Pacific.

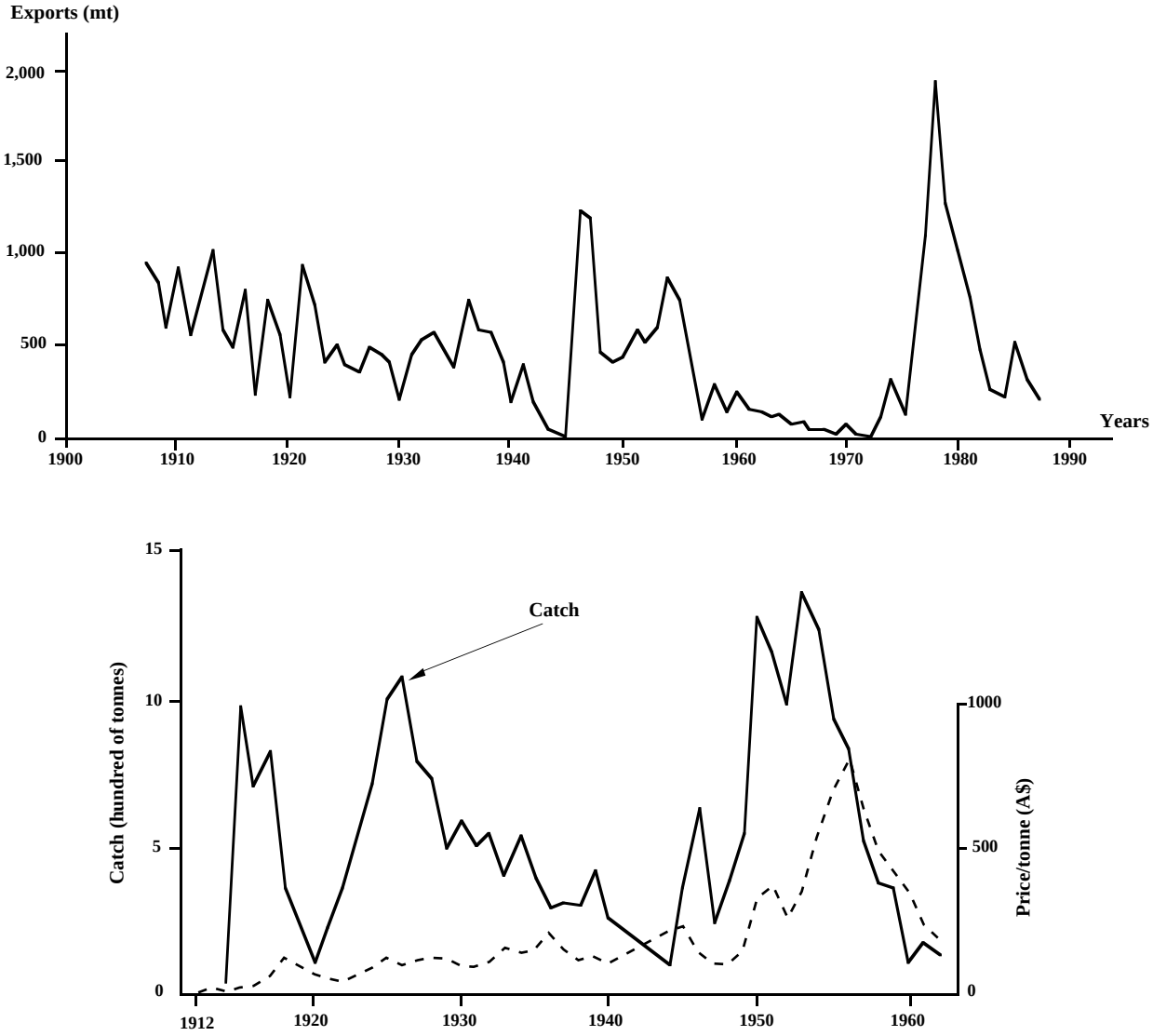


Figure 1: Trochus landings for New Caledonia (top) and Australia (bottom)
Source: Bour, 1990

Overview of Micronesian Trochus Fisheries Management

Republic of the Marshall Islands (RMI)

Trochus were introduced into the Marshalls during 'Japanese times' (1915–1945) and now appear to be established on at least six atolls (Jaluit, Majuro, Ailinglaplap, Arno, Mili, Enewetak). At least four surveys have documented the trochus fishery in the Marshall Islands (McGowan, 1957a and 1958; Wright et al, 1989; and Curren, 1993) with the latter two concentrating on Enewetak Atoll. Trochus were initially translocated to Jaluit Atoll via an ocean liner and were later spread to least seven atolls (Eldredge, 1994 and Gillett, 1991). Historical records of harvests in the Marshall Islands are especially poor and warrant further investigation (Smith, 1992a).

The harvest of trochus in the Marshalls Islands is currently regulated by the Marine Resources (Trochus) Act of 1983 (P.L. 1983-15§1). The origins of the Act are linked to US Trust Territory of the Pacific Administration (TTPI) laws and apply to all internal and territorial waters of the Marshall Islands. The Act makes the Cabinet of the President responsible for declaring harvesting seasons for trochus anywhere in the Marshall Islands, and each harvest period (season) is not to exceed three months in any twelve-month period. Only citizens of the RMI are allowed to harvest trochus,

and consideration is afforded to customary law regarding access.

In addition, no shell with a basal diameter of less than 7.6 cm (3 in) is to be harvested. The transplanting of trochus requires a written permit from the Minister of Resources and Development and there is provision for the removal and transplanting of trochus in the event of a disturbance (i.e., construction) at cost to the responsible party.

Currently the actual implementation of the Act is decentralised, with control given to the local atoll or its representative, either a democratically elected Atoll Council or a mayor. The local atoll government, typically an Atoll Council, decides when to initiate a trochus season. For logistical purposes, the season is timed according to appropriate tidal fluctuations (in late northern summer in the RMI). The Atoll Council then makes a request to the Nitijela, the legislative body of the RMI, through its representative Senator, who obtains the permission of the Cabinet. The Cabinet will set the season timing (initiation date and length) and may provide specifics on areas to be harvested or other restrictions (such as locations for buying). Typically the recommendations from the Senator or the Atoll Council are accepted without modification.

Despite trochus shell's apparent economic significance as an export income-earner, ranking second or third behind copra and aquarium fish through most of the 1980s, records of the level of removals and the amount of effort expended are lacking. Smith (1992a) reports that 'accurate production figures are not available' and there is no resemblance between existing records, even on production from a specific atoll such as Enewetak (eg, compare Wright et al 1989, with Curren, 1993 or see Smith, 1992a). The only 'consistent' records are those from the RMI Office of Planning and Statistics (Table 1).

Smith (1992a) indicates that open seasons, each for the maximum period of three months, were approved in 1987 on all atolls for the period between August and October, in 1989 for Enewetak only between September and November, and in 1990 for Enewetak for the same period as in 1987. There have been no harvests on Enewetak since 1990, despite a survey by Curren (1993) in 1992 recommending, as did Wright et al (1989), that a 100 t quota be established. The lack of an ensuing harvest on Enewetak is as much due to concern for the resource as to general lack of confidence that fishers will obtain a fair price. The lack of a coordinated buying scheme is also believed to have inhibited the initiation of harvests on

Table 1: Estimated trochus production and value for the Republic of the Marshall Islands, 1987–1994.

Year	US$ (000) [1]	Weight (mt)	Location
1987	179,000	100	Enewetak
1988	350,000	150	Enewetak
1989	467,000	145	Various
1990	179,000	100	Various
1991	176,000	?	Various
1992	176,000	?	
1993	0	No landings [1]	
1994	0	No landings	

[1] provided by D. Jack, MIMRA, 1995

Source: RMI Office of Planning and Statistics, with weight and location data from Smith, (1992a) and Curren, (1993)

other atolls, such as Ailinglaplap (K. Hart, pers. comm.). Sources at MIMRA indicate that there has been no harvest of trochus during the past two years. Based on the research and recommendations from Wright et al (1989) and Curren (1993) the RMI sustainable trochus harvests appear to be in the vicinity of 100 t annually.

Federated States of Micronesia (FSM)

According to a variety of sources, trochus naturally occurred in the FSM only in Yap proper. It has been harvested commercially at least since 'German times' (1898–1914) (Smith, 1992b; McGowan, 1958; Asano, 1938 as translated by Izumi, 1987). The trochus resource apparently had particular value to the Japanese and was the subject of substantial translocation efforts between the late 1920s and the 1940s.

The Japanese began translocating trochus from Palau to Chuuk Lagoon in 1927, with efforts continuing at least until 1931. After this, based on what was apparently observable success, the Japanese Government undertook an aggressive translocation programme in many of the islands and atolls in the FSM, with seed stock coming from either Palau or Yap proper.

Current records of FSM transplants can be found in a number of sources (Gillett, 1991; Bour, 1990; Nash, 1993; Smith, 1992b; Eldredge, 1994; Izumi, 1987). By the end of the 'Japanese times' most of the high islands and many of the populated atolls had undergone trochus transplantations by the Japanese. To a lesser extent these efforts continued under the US Trust Territory of the Pacific Islands (TTPI) administration (eg, to Kosrae) (Smith, 1992b).

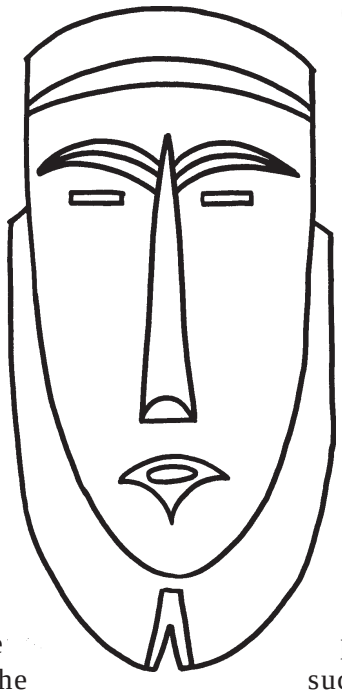
Trochus introductions were re-started in earnest in the early 1980s as a result of regional research on trochus, based mainly in Palau. The Pacific Fisheries Development Foundation, located in Honolulu, Hawaii, undertook a number of trochus reseeding projects in the mid-to-late 1980s, mainly focusing on the outer atolls of Chuuk, Pohnpei and Yap States. These efforts continued into the 1990s, and there are plans to expand the translocations in late 1995 in some areas of the outer atolls of Yap State.

It appears that at least through 'Japanese times', and later under US administration, the trochus resources of the FSM were managed under regulations that were regional in scope. For a considerable portion of the Japanese period there appears to have been a minimum size limit of 7.6 cm, which, according to Asano as quoted in McGowan (1958), was based on 'experience'. In 1937, the minimum size was raised to 8 cm based on 'research' but, as McGowan (1958) states, this 4 mm increase 'failed to have long term results'.

The Japanese also employed seasons ranging from two weeks to one month and in 1922 declared a moratorium on trochus fishing throughout the region. But the results of the moratorium were ambiguous, as landings data from Palau and Yap indicate; the catches in the following year were 'quite high' in Palau but were clearly not so in Yap (McGowan, 1958). However, these data are difficult to interpret without information on effort levels.

After World War II the first trochus management documentation by US authorities can be found in the reports for the US Commercial Company (USCC) *circa* 1946. Bascom (1946) reports that trochus had not been exported from Pohnpei prior to the war, and there was no evidence that the Japanese prohibited trochus fishing at any time (but it was assumed that they would have once an export trade had been established). In the absence of any data specific for Pohnpei, an open season in May and June 'which the Japanese allowed in other parts of the Carolines' was adopted by the USCC and a minimum size of 8 cm invoked.

Hall and Pelzer (1946) report for Truk (Chuuk) that, despite substantial efforts by the Japanese administration in trochus seeding, they appeared not to have 'profited greatly from this work'.They recommended that the pre-German pattern of vested reef ownership be re-established to ensure equitable and efficient trochus harvests in Truk.



Management 'under the principle of a sustained yield economy, subject to regulations passed for reasons of conservation' was the recommended management objective. But in May 1946 the US Government notified the chiefs of Truk that it considered all trochus beds to be the property of the US since they had been planted by the Japanese and were considered the property of the Japanese South Seas Government prior to the war. The USCC's first season, and in turn first commercialisation of the resource on Pohnpei, occurred in June 1946 when Okinawan and Truk 'natives' collected large quantities of trochus; 50 per cent of this had to be rejected because of worm damage or other defects.

The first region-wide review of the trochus resource was by Smith (1946, 1947) who reviewed all marine resources in Micronesia and their use just after the end of the war. Smith reported that the collection of trochus was done by the 'natives', who were permitted to harvest individuals over 7.6 cm in base diameter (note difference from USCC size of 8 cm reported above) during a two-week period during May or June.

None were collected between 1942 and 1946, but 100 t were purchased by the USCC during 1946. McGowan's work (1958) provides the basis for much of the management employed by the TTPI Administration through most of the 1960s, 1970s and 1980s. On the basis of his two and a half years of research in Micronesia, McGowan breaks management regimes down into three basic categories: moratoriums, seasons, and minimum size limitations. He does not endorse moratoriums and is ambiguous on the appropriate minimum size regulation, while recognising the need for seasonal openings / closures. The 7.6 cm (3 in) size employed by that time in the FSM (and Micronesia in general) was not endorsed as being effective but nor was an increase from 3 in to 4 in because of an anticipated 55 per cent decline in landings based on length-frequency analysis.

Declines in trochus population, and in turn of landings, recorded during the 1950s were attributed by McGowan to the lack of large individuals, leading to what he interpreted as reduced spawning stock biomass, and to densities that were reduced to the point where spawning was unsuccessful.

This hypothesis resulted in the recommendation that sanctuaries be implemented; by 1958 there were sanctuaries reportedly established in Yap, Truk (Chuuk) and Pohnpei (along with Palau). The TTPI management regime was later reviewed by Parkinson (1980) who found that the trochus sanctuaries were 'sited in fairly arbitrary fashion' (in Palau and Chuuk in particular). He also reported there was little or no enforcement of these areas.

Modern management (late 1970s to 1992) of trochus in the FSM, by state, is reviewed in detail by Smith (1992b); therefore, only relevant sections are reported here. Each state in the FSM is responsible for managing inshore resources, and while there is an FSM code dealing with trochus exploitation (Title 23, Section 108-115) this code is regarded as unnecessary, except for Chuuk State where the current management regime is ambiguous.

Yap State

Yap State, in which trochus occur naturally, has the longest record of exploitation in Micronesia (along with Palau) and historical landings have had to be compiled from a number of

sources (Figure 2), yet significant gaps remain. During the later 1980s there were a number of proposals to build a trochus hatchery on Yap proper, but a feasibility study questioned the long-term benefit of such a facility (Uwate, 1986; Heslinga, 1988).

Yap State currently manages trochus under Title 18, Section 1009 of the State Code, which calls for the Governor to determine harvest levels, areas and seasons. Practically speaking, the Yap State Marine Resources and Management Division of the Department of Resources and Development works closely with the Governor's Trochus Protection and Harvest Review Committee to determine actual regulations.

For 1994, the basic regulatory framework involved minimum and maximum size limits of 7.6 and 10.2 cm respectively, a season lasting at most one week, registration of all harvesters (who must be FSM nationals), a non-transferable US$ 5.00 permit fee, a ban on scuba-aided collection and acceptance by buying stations of live specimens only. These same regulations are applied to the outer atolls, but the actual season may vary according to particular conditions, typically associated with the scheduling of appropriate transport of buyers and product (Smith, 1990). Currently viable fisheries are known to occur on at least two outer atolls (Ulithi and Woleai), and it is believed that fisheries may soon be initiated on a number of additional outer islands.

Also under consideration by Yap State is the creation of a centralised, government-supported Trochus Marketing Authority. This Authority is envisioned to have sole buying and selling rights of the trochus resource in Yap, with the objective of 'close-coupling the cost of managing the resource with the economic benefits generated by the resource'. The proposed Authority is to be made up of five Directors, with a manager and a secretary. It will be responsible for resource assessment and the introduction of new management schemes (e.g. Individual Transferable Quotas, ITQs), the purchasing and marketing of all trochus products, and, research, along with any future reseeding efforts. These activities would be defrayed through 'the buying and selling of trochus... less the cost of operations'. The current status of this proposal is unknown.

In 1994, the total trochus harvest was 32 t, valued at approximately US$ 70,000. A target of 25 t was anticipated to be harvested, but the 7 t difference was landed because of inability to comprehensively monitor and control harvests during the open season (J. Fagolimul, pers. comm., 1995). For Yap proper, the long-term sustainable yield has been tentatively

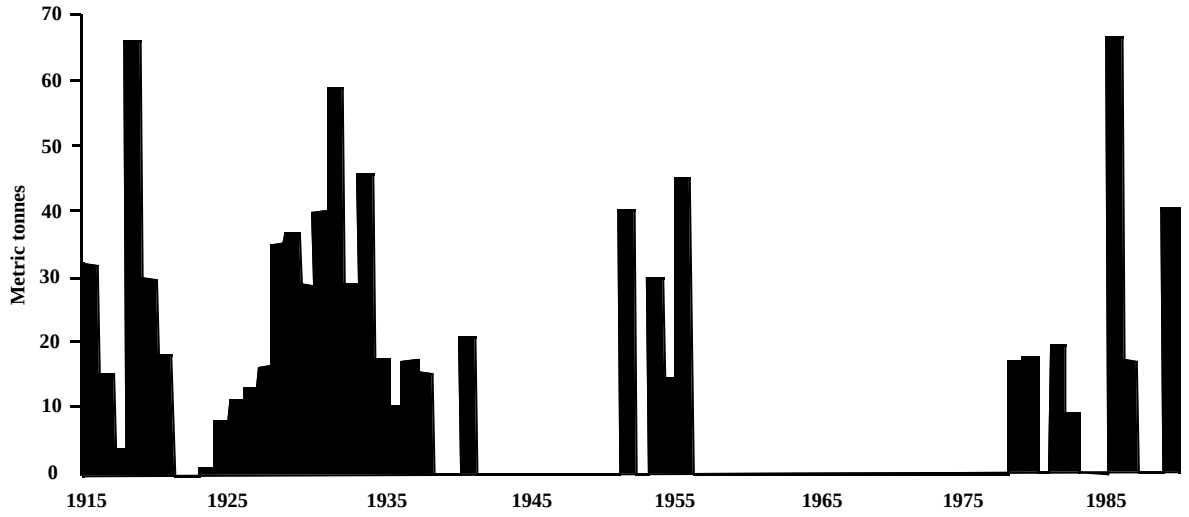


Figure 2: Time trend of Yap trochus harvests

Sources: Asano, 1939; McGowan, 1958; Smith, 1947; Smith, 1990.
Note: Yap MRMD indicates 32 t harvested in 1994.

estimated at 23–25 t, based on historical landings. With the addition of sustained harvests at Ulithi and Woleai Yap State landings could exceed 30 t annually (J. Fagolimul, pers. comm., 1995).

Pohnpei State

In Pohnpei State, the trochus fishery was first exploited after World War II. Historical landings were compiled from a variety of sources and are depicted in Figure 3.

Currently in Pohnpei State the Director of the Conservation and Resource Surveillance designates open seasons (not to exceed 60 days), and the areas in which harvesting may take place. Specimens between 7.6 and 10.2 cm (3 and 4 in) basal diameter are the only size allowed to be harvested and the use of scuba equipment is outlawed. Specimens must be brought alive to buying stations, where a receipt is issued detailing the number of live, dead, and undersized trochus landed and designating the volume that may be sold for cash.

All trochus are cleaned by the producers. There are no data available on how much of the meat is sold or consumed, but it is believed that much of the meat is not utilised (Curren, pers. comm.). Pohnpei has several sanctuaries, but the integrity of these areas has been compromised during several recent harvests (Smith, 1992b).

Pohnpei is relatively unique in the FSM in that it uses discrete seasonal openings in an attempt to limit catch in the face of continually increasing effort and declining abundance. Based on density surveys, a Total Allowable Catch (TAC) is estimated, along with anticipated effort (number of harvesters), to determine *pro forma* the time needed to harvest the TAC. The length of the season is modified accordingly and recent trends show a dramatic decline in duration (Table 2).

Table 2: Pohnpei trochus season (in days) and relative production in weight and value in US$, 1986

Year	Days	mt/day	US$/day
1984	30	4.51	7,450
1985	No harvest		
1986	20	9.07	23,000
1987	No harvest		
1988	3	62.70	168,666
1989	No harvest		
1990	1	86.00	862,000
1991	0.33	185.00	?
1992*	0.25	144.00	?
1993	No data		
1994	No data		

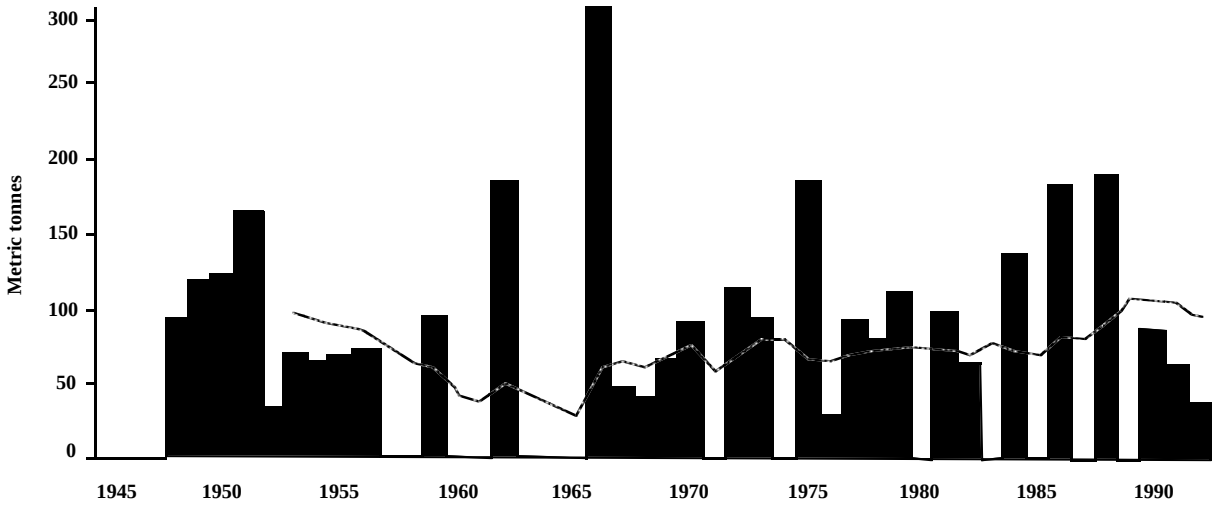


Figure 3: Time trend of Pohnpei harvest. Bars represent estimated landings, line represents a moving average of removals.

Sources: McGowan, 1958; Smith, 1992b; Parkinson, 1980

The Pohnpei State Government, through its Marine Resource Division, in conjunction with the Pacific Fisheries Development Foundation, supported trochus hatchery and juvenile release research in the late 1980s, but the results appeared not to have been cost-effective and were discontinued in early 1993. No estimates of the long-term sustainable harvest were made, but historical data indicate that the trochus resource of Pohnpei State is potentially one of the largest inshore fisheries in all of FSM. Figure3 suggests that 50–60 t annual harvests may be sustainable over the long term, depending on the various management tools employed, but this is suggested as a very provisional target.

Kosrae State

For Kosrae, the Director of the Department of Conservation and Development regulates the time, place and method by a permit system, but the actual harvest is monitored by the Kosrae Marine Resources Division. Kosrae has a minimum-and-maximum size regulation (7.6–10.2 cm), all harvesters must be registered, no scuba equipment is allowed, and seasons are typically less than two weeks.

There is a sanctuary on Kosrae that is reportedly used for restocking or seeding other areas on the island. Trochus hatchery work has reportedly gone on at the FSM National Mariculture Facility in Kosrae for several years now, but no details were obtained for this study. Smith (1992b) reports that, between 1984 and 1992, four trochus harvests occurred (1984–8.1 t, 1985–16.1 t, 1988–10.2 t and 1992–5.5 t). No long-term estimates of sustained harvest were obtained, but the stock appears to be expanding and 8–10 t per year may prove a sustainable target in the short term.

Chuuk State

In Chuuk State, trochus is managed under the vestiges of the TTPI code; however, new management and regulatory regimes may have been instituted recently. The TTPI regime involved a minimum size of 7.6 cm, and seasonal openings between May and September. Chuuk had several sanctuaries during the 1980s and between 1986 and 1992 no legal trochus season was declared (Smith, 1992b). The status of the resource is unknown, but in recent years there have been proposals to build a trochus hatchery in Chuuk to mitigate against overfishing. No long-term landing data were compiled and no estimates of the long-term sustainable harvest were found. A cursory review of Smith (1992b) reveals that landings have fluctuated recently between 0 and 110 t, suggesting that 30–40 t per year may prove a viable target for sustained harvests.

While the FSM has implemented a set of relatively wide spectrum of management strategies, fisheries' staff is still facing overfishing problems. For example, virtually every state in the FSM has enforcement problems (Smith, 1992b). In fact, this problem is not unique to the FSM; it represents one of the major costs incurred for all management regimes, as highlighted in the discussion section below.

Republic of Palau

Trochus are found naturally in Palau and have a long history of being exploited. Reports (e.g. McGowan, 1958) indicate that exploitation occurred on a regular basis in the late l900s; however, harvest records date to the early twentieth century and are particularly strong for the period referred to as the 'Japanese times' (Figure 4).

During this period the Japanese appeared to manage the fishery with minimum size and season limitations, along with enforcement by the central government and local village systems (Gail & Demambez, 1958). Motoda (1938) reported during this period that only 'natives' were allowed to harvest trochus, for the 'protection of native life'.

The fishing season was initially restricted to between May and June and the fishing grounds were restricted to particular areas 'according to the circumstances'.

Minimum size regulations of 7.6 cm (3 in) were imposed. Harvesting was by 'bare' diving and sometimes the meat was eaten but 'not usually'. The fishing season was limited to July, August and September in 1916, but shifted to May and June in 1921. While the fishery ap

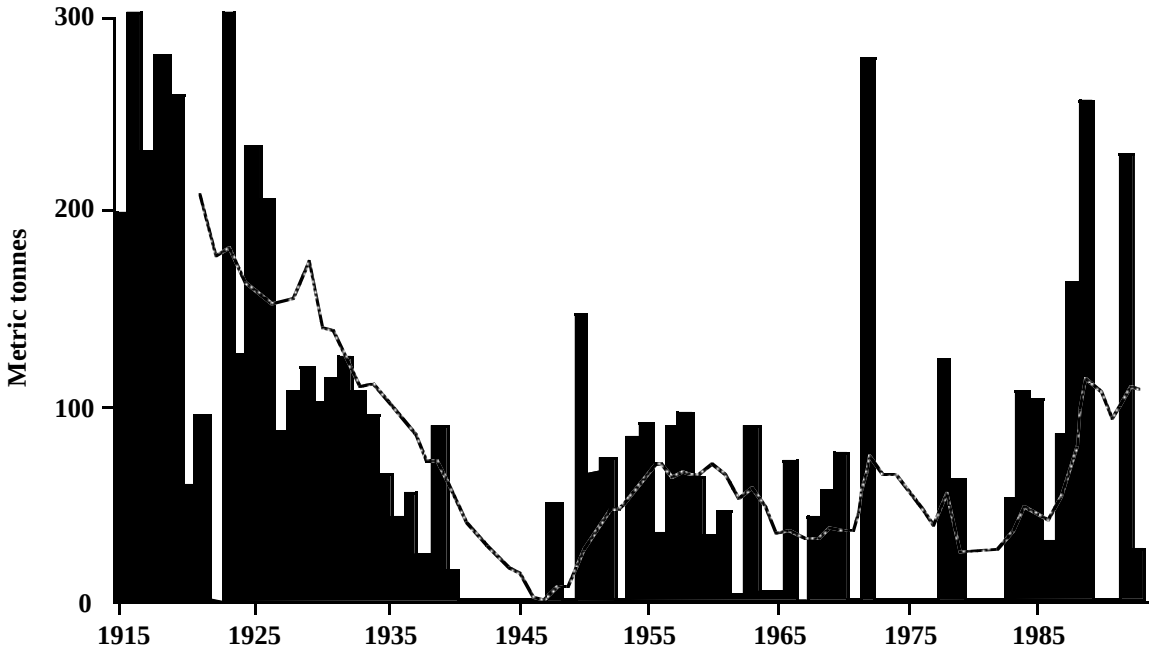


Figure 4: Time trend of Palau harvest. Bars represent estimated landings, light line represents a moving average of removals.

Sources: McGowan, 1958; Heslinga, 1981; Nichols, 1991; Smith, 1947; and Parkinson 1980

pears to have been actively monitored and proactively managed during Japanese times, catches fluctuated considerably and there were problems similar to those reported today. For example, Motoda (1938) reports that in March 1937 a vessel from Takao, Formosa (Taiwan) was apprehended by the South Seas Government (Japanese) for poaching trochus. The vessel carried 20–30 Loochoo fishermen, who were reportedly on their way to trochus fishing grounds in the Koringal Islands, Great Barrier Reef or New Caledonia.

After World War II, trochus management fell to the US administrators of the Trust Territories, as cogently summarised by McGowan's extensive work in 1956–58. McGowan's proposal to establish a sanctuary system on each island or atoll was implemented in the 1960s in most of the TTPI (Truk, Pohnpei, and Yap). This management tool was based on what, at the time, was hypothesised to be the importance of a short-term, lecithotrophic larval span and allele effect in the eventual recruitment success of trochus.

It was recommended that one sanctuary be established for each five miles of barrier reef (McGowan, 1958). Sanctuaries were eventually established in several states in Palau by members of the 'local Conservation Division' (Heslinga et al, 1984).

When Palau became a Republic in 1980, trochus management and monitoring responsibilities which were formerly vested in the TTPI Administration were devolved to the state level (of which Palau has 16), but the Palau Marine Resources Division (PMRD) was (at least in theory) available to assist each state by providing advice on the appropriate levels of harvest, population assessments and the establishment of sanctuaries. During this period also, a moratorium system in which a particular state or village stopped collecting trochus for more than one year was established in several states; e.g. Kayangle in 1979, Angaur and Ngeremlengui in 1980, Koror, Kayangle, and Peleliu in 1983 (Heslinga et al, 1984).

Trochus sanctuaries were one of the first examples of modern use of the sanctuary concept as a management tool in Micronesia (though they have a long history in traditional management systems—see Johannes, 1981, 1991). However, the effectiveness of the modern trochus sanctuary system in Palau was investigated in the early 1980s and found to be of questionable

merit, partly because surveys indicated that trochus densities were greater outside sanctuaries, in areas open or subject to fishing, than within them (Heslinga et al, 1984). This was hypothesised at that time to be caused by sub-optimal habitat within the designated sanctuary areas.

Heslinga et al (1984) emphasise the importance of placing an effective sanctuary in proximity to appropriate authorities (whether modern or traditional) to allow effective and efficient monitoring and enforcement. The sanctuary concept could have performed better in Palau (specifically Koror State) if the sanctuary areas that McGowan originally recommended had been established and enforced.

However, the recommended areas were based on biological considerations and apparently did not take into account cultural or socio-economic factors (Heslinga, pers. comm., 1995). The effectiveness of sanctuaries has always been dependent on enforcement, which has been problematic, especially in the urban centres, as recently documented by Johannes (1991).

During the late 1970s and early 1980s, enforcement of existing management regulations was noted as particularly difficult; e.g. in a number of locations in Palau trochus were fished to 'extinction' (Heslinga, 1981a).

In 1979, 20 per cent of the trochus harvested in Palau were below the 7.6 cm minimum size and, despite a one-month fishing season, many fishers routinely collected trochus out of season and hid the shells until they could be legally sold.

Commensurate with the tenor of the times in several areas in the Pacific, Heslinga (1981a, 1981b) alludes to the prospects of aquaculture and reef reseeding or artificial enhancement to augment overfished stocks in Palau. Heslinga notes that:

> 'efforts to protect trochus stocks through conventional regulatory measures have been only marginally effective in the Pacific where enforcement capabilities are almost universally inadequate' and
>
> 'reseeding of selected reefs should be investigated as a potential means of conserving this valuable resource'.

At that time the complete biology of the species was not fully understood, nor had it been reared on a consistent (much less commercial-scale) basis anywhere in the Pacific. Artificially augmenting trochus stocks was partly justified because of the socio-economic importance of trochus to remote Pacific Islands. For example, Heslinga (1981a) indicates that the 1979 ex-vessel price in Micronesia of US$ 0.55 / kg represented 'a 500% increase in the last decade'.

Stock augmentation by rearing juveniles for release on to reef flats was also investigated, because the fishery had considerable socio-economic benefits: the skill, capital investment, and technological levels for participation in the fishery were relatively low and appropriate for rural Pacific Island settings. Research during the early 1980s explored the feasibility and cost-effectiveness of trochus mariculture as a management option. Consistent production of hatchery-reared trochus was quickly attained (Heslinga, pers. comm., 1995).

However, during the late 1980s the effectiveness of releases, as well as a concrete demonstration of cost-effectiveness, continued to elude researchers in Palau . In 1992 the PMRD shifted emphasis away from the mariculture / reef augmentation approach, since research and empirical evidence indicated that 'conventional methods of management were considered a more cost effective approach to managing Palau's trochus fishery than artificial stock enhancement through mariculture'.

Recent personnel changes at PMRD have apparently resulted in the re-evaluation of this policy, in that efforts are now under way to restart trochus propagation activities at the Palau Mariculture Demonstration Center and a stock augmentation programme is expected to be in place by the end of 1995 (D. Otobed, pers. comm., 1995).

While investigations on artificial rearing were increasing and hatchery methods were being further developed in the early 1980s Palau's trochus fisheries underwent severe declines (see Figure4). Much of the lack of control over the fishery during this period could be attributed to the decentralisation of management authority. The individual states of Palau had difficulty effectively managing the trochus resource 'as concerns about the ability of the resource to sustain itself arose as the fishing pressure increased throughout the 1980s'.

In August 1989, these concerns led to the passage of legislation by the Third Olbiil Era Kelulau (OEK) (Under the Palau National Code title: Environmental Protection, Subchapter IV: Trochus) which returned control to the central government and initially established a three-year harvest moratorium in all states (except Sonsorol and Tobi States). Subsequent Executive Orders and OEK legislation established seasons, typically of one month, and confined harvest rights to Palauans, while maintaining the 7.6cm minimum size. Koror State still maintains six sanctuaries, while at least one other state (Ngaraard) has established at least three.

Palau's Ministry of Resources and Development (of which the Division of Marine Resources is part) is currently responsible for monitoring the status and harvests of the trochus resource. The most recent trochus survey was conducted by PMRD in 1991 and encompassed surveys (via visual census) in eight states. From standardised transects using visual census, Ngiramolau et al (1991) estimated there were 40.9 km^2 of optimal trochus habitat in Palau, with densities of 12,400 trochus per km^2. Using an average weight of 0.32kg (0.7 lb) per trochus they estimated total biomass at 160 t.

Application of a 40 per cent exploitation rate to this estimated biomass gives a potential sustained yield of 64 t. Nigiramolau et al suggested that an export quota be established, based on a pre-fishery assessment, allocation of the quota between buyers, and the utilisation of the trochus meat being discarded.

The data suggested that the 1989 harvest of 257t was excessive, as had been the 1985–1989 average harvest of 130 t. Ngiramolau et al report that, during the 1989 season, fishers worked day and night and many undersized shells were harvested. They also indicate that remote sensing (satellite imagery) will be used in the future to better quantify habitat for trochus, in order to refine these data. This initiative has seen little subsequent progress.

In 1992, at the direction of the OEK, the first trochus season in three years yielded approximately 250t (see Figure4) (the exact figure ranges from 229 to 265 t). Most (76%) was sold as raw (uncleaned) shell for approximately US$2.65 / kg. The harvest was composed of 86 per cent shells between 7.6 and 10.2 cm in diameter, indicating the importance of first-year recruits to the fishery. Of particular interest is the fact that 1,438 individuals (10% of the population) sold trochus on 2,214 occasions to two local buyers, with an average of 83 kg or US$220 per transaction (or US$335 per individual). The total harvest brought in US$645,000 (ex-vessel).

With the exception of Koror State, which has obvious logistic advantages, the importance of the trochus harvest is demonstrated by the fact that the more remote states harvested and sold

proportionately greater amounts of trochus per transaction. The reported catch rate of 9.1 kg / fisher / hour (or US$24 / hr) compares favourably with the estimated rate of 2.3 kg / fisher / hour for the period 1936–1941. The higher catch rate was attributed in part to increased numbers of trochus, but also to the fact that the use of larger boats with larger engines has made even the most remote areas accessible to harvest.

The 1992 harvest had a reported export value of US$1.1 million. Trochus was Palau's second leading export item, after tuna. PMRD records indicate that, for the 1992 harvest, only about 300 kg of trochus meat entered the standard commercial marketing channel; it was sold for US$1.00 per pound. Approximately 600 kg were exported as personal luggage by air carrier. Additional quantities may have been sold commercially and an unknown quantity was harvested for subsistence consumption.

In 1993 a fishing season was declared by the OEK, but only two states (Koror and Peleliu) chose to open the resource to fishing, with 29 t valued at US$59,000 being harvested (no export value is reported). There were no trochus harvests during 1994. Currently no major changes are expected in the management of the trochus resources in Palau. A season is currently underway in Palau (June), with fishing effort reported as high (N. Idechong, pers. comm.).

Guam

Trochus was introduced to Guam from Saipan in the l950s, reportedly by private fishers, and has become widespread in most reef areas. Little information was found on the historical aspects of trochus management in Guam after introduction, but the management regime during the 1960s most likely resembled that found in other US Territories. In 1989, trochus regulations were revised to take into account the growingly different stakeholders participating in the fishery.

Currently, the regulatory regime in Guam is unique for Micronesia in that it is broken into commercial and recreational / subsistence seg

Table 3: Commercial and subsistence trochus harvests, Guam, 1979–1995

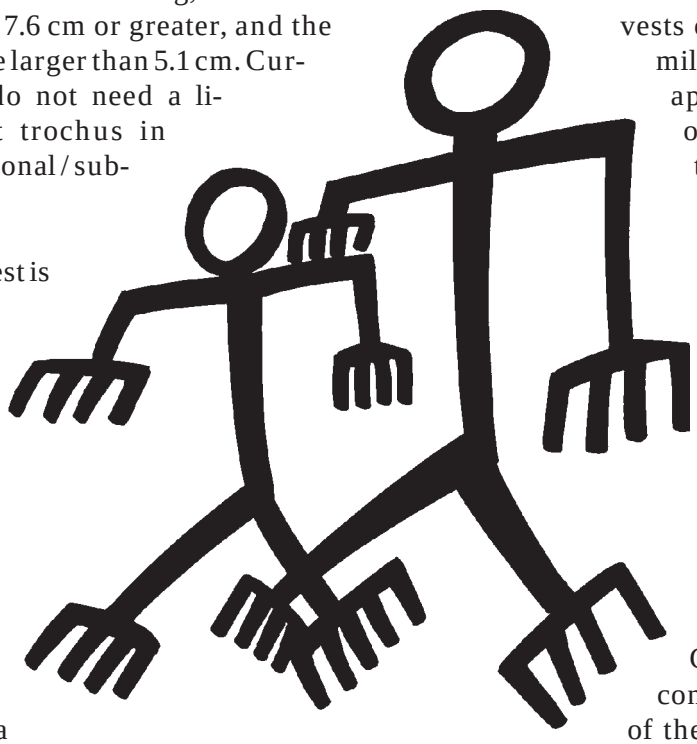
Recreational/subsistence [1]		Commercial		
Year	**Weight (kg)**	**Fishers**	**Seasons**	**Pieces**
1979	1,661			
1980	1,025			
1981	961			
1982	4,730			
1983	700			
1984	7,300			
1985	1,430			
1986	1,350			
1987	840			
1988	n / a			
1989 [2]	900	9	1 May – 15 June	10,300
1990	982	7	1 – 28 May	10,300
1991	690	6	1 May – 5 June	10,110
1992	n / a	7	1 May – 20 June	10,000
1993	n / a	6	1 May – 27 June	10,000
1994	300	0		0
1995		0		0

[1] Recreational / subsistence landings based on creel surveys. Numbers should be taken as indicative, rather than absolute measure of landings.

[2] Prior to 1989, regulations for commercial and recreational harvests were identical.

Source: Guam Division of Aquatic and Wildlife Resources.

ments. Regulations allow year-round harvesting for home consumption, as long as no more than 22.7 kg (50 lb) of wet weight are harvested per person per day. Of the 22.7 kg, at least 18.1 kg (40 lb) must be 7.6 cm or greater, and the remainder must be larger than 5.1 cm. Currently residents do not need a licence to harvest trochus in Guam on a recreational / subsistence basis.



Commercial harvest is restricted to animals larger than 10.2 cm (4 in) and is regulated by the requirement for a permit (cost: US$ 25) from the Guam Division of Aqua-tic and Wildlife Resources. There is an island-wide quota (10,000 pieces), which does not fluctuate from year to year and is based on what is believed to be the long-term sustainable harvest, but there have been no recent efforts to adjust or modify the quota.

All shells are to be collected from outside the reef margin and there is a 50-piece-per-day limit. Prior to 1989 the commercial harvest of trochus is believed to have been small, with the majority of the commercial fishers being Korean or Filipino (G. Davis, pers. comm., 1995). Recent commercial and recreational / subsistence landings are shown in Table 3. On the basis of the 10,000 piece limit, Guam is capable of producing 3–4 t of trochus each year.

Commonwealth of the Northern Mariana Islands (CNMI)

Trochus were originally brought from Palau to Saipan during 1937–38 by the Japanese and reportedly were very successful in spreading and reproducing (Asano, 1938), so much so that by the early l950s specimens were being transported to Guam for translocation efforts there. Commercial fishing in Saipan occurred approximately 13 years later, with trochus being transported to several other islands (Rota, Tinian and Agrihan) in the Mariana.

McGowan (1958) reported harvests of 2.3 (short) tons per mile of reef in Saipan, with approximately 13 miles of good habitat, for a total harvest of 30t in 1956. He related these high production rates to the relatively unexploited conditions, and noted their remarkable similarity to those seen in other Micronesian trochus fisheries (eg, Palau, Yap, Chuuk, Pohnpei) during peak production years.

Commercial harvests continued through most of the 1960s and 1970s, although records specifically for the Marianas are not available; Marianas harvests are believed to be reported with total TTPI harvests (Adams et al, 1994).

During the US TTPI administration the minimum size limit of 7.6 cm was in effect, as well as seasonal openings / closures. Due to what was apparently heavy fishing pressure during the late 1970s and early 1980s, a moratorium on trochus fishing was established in 1982 by the CNMI Division of Fish and Wildlife.

In 1986, regulations were modified and two sanctuaries were established (around Garapan channel and Tank Beach), along with the establishment of a permit system for the commercial harvesting, buying or selling and a catch report.

The effectiveness and enforcement of current laws appear problematic; for example Adams et al (1994) report that 14.65t of trochus were imported to Japan from the 'Marianas Islands' in 1989, indicating a significant breach of the commercial moratorium, but they also allude to the fact that this report may represent transhipping from another port of origin.

Despite the moratorium, it appears that exploitation levels near population centres in the CNMI are considerable and that trochus are typically kept if found during reef fishing or gleaning activities by local residents. Adams et al (1994) note, that while effort was diffuse, it was difficult to control and that trochus were at best 'moderately abundant in areas far from shore, near sharp coral or urchins or close to Government offices'.

There have been at least two assessments of trochus resources in the Northern Mariana Islands (McGowan, 1958); however, both appear to be qualitative in nature and neither is based on statistically verifiable results. In 1994, the South Pacific Commission completed a survey and resource assessment of the trochus stocks in the areas of Saipan, Rota and Tinian using a team of experienced biologists employing predominantly transect methods. The results indicated that the trochus resource at any location was not 'dense' and appeared to be 'maximally' exploited (Adams et al, 1994).

Substantial fishing pressure, along with lack of appropriate habitat, were proposed as limiting factors in many portions of the Mariana Islands, and a precautionary approach was recommended for the few reserve areas in which trochus were found in moderate numbers. The report estimates that a harvest of 11–13t/year may be sustainable from the three areas combined, with the caveat that this number includes all sources of harvest mortality.

The DFW has formulated a number of general recommendations as a result of the 1994 survey. They exclude commercial harvest and the use of artificial breathing devices, maintain the 7.6 cm minimum size, require all harvesters to obtain a licence from DFW, allow 10 pieces to be harvested daily (and a maximum of 200 in possession), and require that catch-and-effort information be supplied to the DFW. For Saipan specifically, seasons are limited to October and November, with a maximum of 100 licences and fishing confined to a particular area. For Rota, two one-month seasons are recommended, along with area closures and a limit of 50 permits. For Tinian, a season in August and September is recommended, along with limits on the areas fished and a limit of 50 licences. The current status of these recommendations is unknown and it appears that no commercial production can be expected from the CNMI in the near term.

Discussion

We begin our discussion by attempting to draw on the experiences of the different fisheries management practices presented in the first section in order to formulate management alternatives. Much of this work follows on from accepted parameters (Nash, 1993 and Bour, 1990) and trochus management tools described in the Micronesian case studies. We review the costs and benefits of the various methods employed, attempting to evaluate possible tradeoffs. Finally, we review the various indirect management measures applied.

Trochus landings for those areas in Micronesia where data exist or were compiled appear to mimic more pan-Pacific trends. Landings are extremely variable, suggesting that market conditions and resource constraints place compelling demands on fishery managers to control exploitation. This has been done using a variety of direct and indirect methods. During most of this century, trochus management in Micronesia has been relatively consistent, involving seasonal openings, minimum size regulations and, more recently, a variety of other measures. Current management measures are summarised in Table 4.

Quotas

There are several factors which affect direct quota management systems. Since many natural marine populations display a high degree of variability in stock size and recruitment, information on the current absolute abundance is often critical. Experience in Micronesia, from the inception of exploitation, has included workers attempting to determine stock size. More recent efforts have focused on the importance of recruitment. For trochus, Nash (1993) reports that quotas are commonly based on apparent historically sustainable harvests. This appears to be the case in Guam, Palau and Yap. In fact, this rough-and-ready approach is used for species in many parts of the world, espe

cially where little is known about absolute abundance and key biological parameters are poorly estimated.

Using biological parameters given by Nash (1993), we performed a simple modelling analyses of trochus harvest rates based on some basic demographic information. We assumed a fixed instantaneous natural mortality rate of 0.3 (Nash cites a range between 0.1 and 0.77). Growth was modelled to follow a trajectory (with variability) as shown in Figure 5.

Table 4: Summary of current fishery management regulations for trochus (*Trochus niloticus*) in Micronesia and the Cook Islands (Aitutaki Atoll).

Country	Min.size (cm)	Max.size (cm)	TAC	Seasons	ITQ	Sanctuaries	Moratorium	Permit	Live inspection	Rec./subsis. regulations[1]
FSM										
Chuuk	7.6			X		X	X			X
Kosrae	7.6	10.2		X		X	X		X	
Pohnpei	7.6	10.2		X		X	X		X	
Yap	7.6	10.2		X				X	X	
Palau	7.6			X		X	X			
RMI	7.6			X			X			
CNMI [2]	7.6			X			X			X
Guam	5.1	10.6	X	X				X		X
Cook Is.	8	11	X	X	(IQ)	X	X	X	X	

[1] Recreational / subsistence regulations

[2] Includes currently proposed regulations

Adapted from Nash (1993)

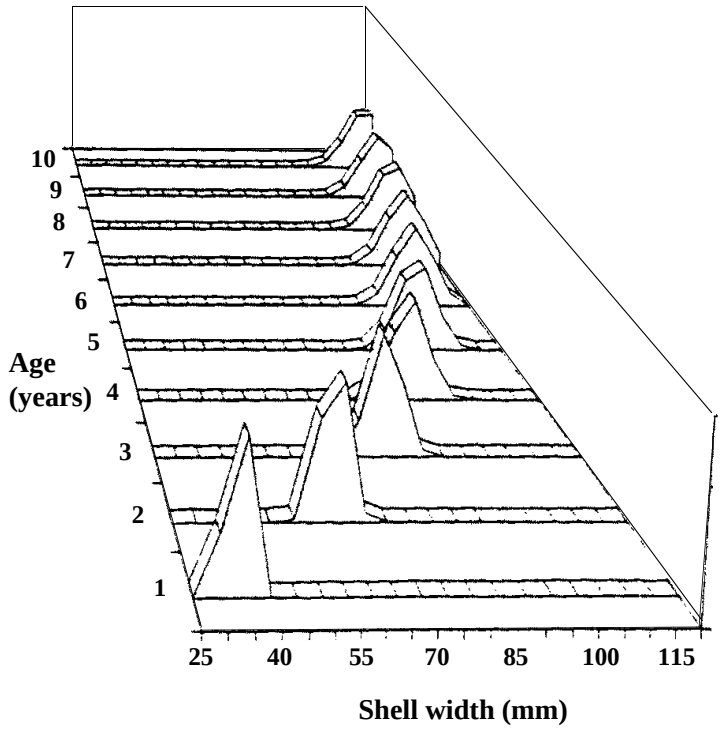


Figure 5: Generalised age-size relationship for trochus, based on Nash (1993); average basal diameters of 33, 58 and 76 mm for 1, 2 and 3 year-old trochus respectively

Furthermore we then assumed that trochus mature with size, as depicted in Figure 6.

From this combination of parameters, calculations using various minimum size limits make it possible to evaluate the reduction of spawning output per recruit caused by different harvest rates. Note that this type of calculation is independent of any stock recruitment relationship.

For example, if exploitation represents 40 per cent of Age 3 and older trochus, and a minimum size limit of 8 cm is used, this results in a reduction in spawning output per recruit of about 44 per cent of unfished levels. Taking into account data for any species of groundfish stocks around the world, and given the assumptions of natural mortality, etc. this rate would probably provide sustainable yields.

A major pitfall with this approach is that uncertainty about the harvest rate is usually greatly overshadowed by uncertainty about the absolute abundance.

For example, if the figure of 40 per cent was applied to an estimated stock size of one million individuals when the true stock size was only half as big, there could be severe implications. In these situations it is ideal to evaluate decisions on setting harvest levels by making careful analyses of the consequences of being wrong!

Risk assessment is currently one of the major areas of emphasis for heavily-exploited, temperate-water resources. In instances where numerous demands are placed on fishery resources by varied and numerous stakeholders, not only one must determine appropriate levels for quotas, but also the inherent risk involved in the various levels of exploitation taken as given in many fisheries.

Size regulations appear to be a simple, yet important trochus management tool. Our case studies show that size regulations (along with seasons) have been the most universally accepted trochus management method in Micronesia. This also appears to be the case for other regions of the Pacific.

Size limits have a sound biological basis in that, if done properly, they can conserve spawning stock biomass above critical levels.

Growth rate and size at sexual maturity of trochus vary substantially, both between and within sites (Nash, 1993). We consider that universal recommendations of minimum size limits are inappropriate and that trade-offs in financial yield and biological yield per recruit should be evaluated for specific situations.

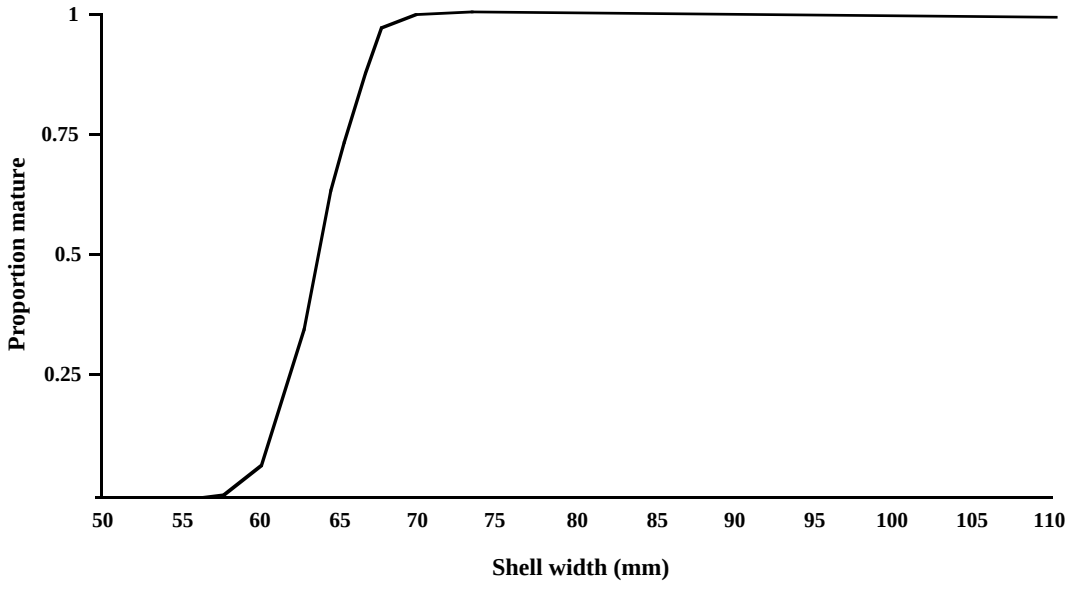


Figure 6: Assumed relationship between the proportion of the population that is mature and size, for trochus-based data published by Nash (1993)

In Micronesia, the minimum size for trochus harvests has been amazingly consistent across the region, at 7.6 cm for almost 90 years. The first application of this technique by the Japanese was based on 'experience'.

The more recent literature indicates that this size is not unreasonable given maturation and growth patterns observed in trochus. Importantly, the harvests in these regions have been highly variable but remained at a relatively consistent level until recently. Clearly, size limits are an effective conservation tool.

However, if fishing mortality is too high, population densities can drop to levels where the population is not able to replace itself even with size limits in place. If an adjustment is believed to be warranted, a movement from 7.6 cm to 8.0 appears to be one option and has been recommended by some (Bour, 1990).

Economic factors need explicit consideration when size limit regulations are being established. Trochus shell buyers and button blank producers prefer shell as small as 6.4 cm and not much larger than 11.5 cm (Philipson, 1989; Adams et al, 1992).

Nash (1993) suggests a size-limit-only approach to trochus management. Under high levels of fishing pressure (which appear to exist throughout Micronesia) the minimum size should be in the range of 11.0 to 12.0 cm. Such large minimum size limits would render trochus exploitation uneconomic for all but subsistence fishing. This could be viewed as a way of nominally 'having a fishery' while effectively calling for a moratorium.

Options for developed economies such as the CNMI and Guam are a little different from those for developing countries. In developed areas the importance of commercial trochus fisheries is relatively minor.

In the CNMI, for example, where stock abundance appears to be low (Adams et al, 1994), perhaps a recreational / subsistence only fishery may be the best path for recovery (with a high size-limit regime). As has been realised in many areas of the world, greater social benefit can be sometimes derived from reducing or eliminating commercial catch rather than recreational or subsistence fisheries.

The use of maximum size limits occurs in at least in three areas within Micronesia and appears to be a recent phenomenon. Historically, market conditions limited the take of large trochus (> 14 cm) because the quality of the shell decreases due to sun bleaching, deterioration by boring organisms, and reduced button production per unit area. This economic constraint appears to fit well with the animals' increasing fecundity as correlated to age (or size).

However, while the fecundity of the trochus increases at a geometric rate relative to basal diameter (below 110 mm), maximum size limits are believed to contribute only marginally to spawning stock biomass–especially in heavily exploited fisheries.

In areas where stocks are severely depleted, a reduction of maximum size limits is not recommended. In these cases, the minimum size limit should be increased and other measures to reduce the total catch are preferable. The current maximum size of 10.2 cm in Yap, Pohnpei and Kosrae may have questionable economic and biological implications, particularly if the total catch is quite high relative to stock size.

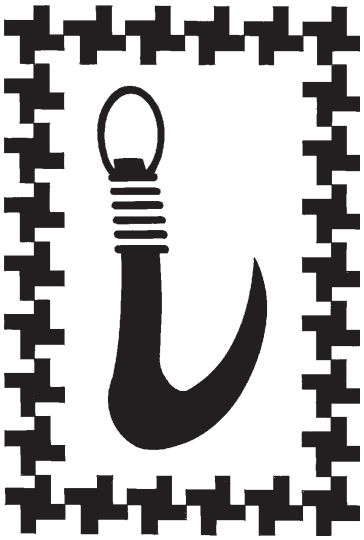
Seasons

Seasons or openings were historically applied by the Japanese in Micronesia to protect trochus from what was felt to be critical periods related to defined spawning events. The Japanese undoubtedly applied this regulation as a result of experience in other, temperate-water fisheries where this behaviour is more typical. However, even in Japanese times a desire to control effort seems to have been one of the reasons for seasonal openings.

The historical data reveal that exploitation rates were potentially great enough to drive the resource to very low abundance levels or extinction. Secondly, as the reproductive biology of trochus has become more apparent with the work of Heslinga and others, the use of seasons has gained region-wide salience as an

essential tool for maintaining the biological integrity of trochus resources. Nash (1993) reviews behavioural characteristics related to spawning in trochus and concludes that a quota-managed fishery (TAC) based on reproductive conditions alone would be difficult to support and, due to the frequency of spawning in most locations, impossible to manage.

Of concern is the contemporary use of seasons to attempt to limit ever-increasing effort. As is demonstrated in the case of Pohnpei, the ability of the local population to harvest the resource is tremendous. Short fishing seasons make it impossible to monitor and in many instances enforce either size limits or TAC. This trend is not unique to Pohnpei; it has been documented in the Cook Islands (Sims, 1988; Nash et al, 1995) and has been reported in Palau and Yap.



In both Yap and Palau, a good portion of the Marine Resources Division staff, plus resources from other agencies (public health and safety), is required to control and monitor trochus seasons. The cost is considerable and several fishery managers have stated that trochus seasons are a real drain on departmental resources. An additional lost opportunity (and as such a cost) is the reported waste of considerable volumes of trochus meat. It has been reported for Pohnpei that the smell of rotting trochus coincides with any opening.

Moratoriums

Moratoriums or complete bans on fishing have been applied since at least 1922 in Micronesia with varying degrees of success. Some commercial fishing moratoriums have been induced, such as that between 1940 / 41 and 1946 as a result of the war, while others have apparently lasted 6–7 years (Chuuk), with a duration of one to two years being more common. The complete cessation of fishing or elimination of seasonal openings is usually a response to either actual or perceived overfishing.

Heavily overfished populations may require several years to return to levels or population densities deemed appropriate for exploitation. The appropriate population densities will vary from place to place. Adams et al (1992) cite, levels of at least 100 exploitable shells per hectare of suitable habitat and up to 300 per hectare for areas 'that are not heavily fished'.

It was noted that in Aitutaki, densities must reach 600 per hectare before the Island Council authorises a harvest. With few exceptions, densities throughout Micronesia appear to fall between the lower threshold (100) and that reported as a minimum level for exploitation in the Cook Islands (cf Smith, 1992b; Curren, 1993; Adams et al, 1994).

Moratoriums provide a convenient tool for resource managers. They are relatively easy to enforce and monitor. If rigidly enforced, they are the most effective biological way to allow a resource to recover. They also have intuitive appeal to resource users. Despite a recent three-year fishing ban, many fishermen in Palau indicated that they would support a moratorium if it ensured healthy recovery of trochus stocks (Johannes, 1991). There have also been instances in which fishers have voluntarily refrained from requesting a trochus season, despite being eligible to do so, reportedly because of concern for the resource (Idechong, pers. comm.).

However, the imposition of a moratorium may bring significant social and economic costs. As demonstrated for Palau, trochus are a rather egalitarian resource–a wide array of individuals typically partakes in trochus fishing. At

least at the production level, benefits are typically spread throughout the community. In several locations within Micronesia, trochus fishers are from the lower portions of the socio-economic stratum of society. Many depend on trochus harvests as an important windfall or pulse income, defraying schooling, clothing or housing costs. Trochus income may also provide resources important for religious or cultural events.

Of additional concern is what is referred to by economists as the time-value of money or 'discounting effects'. This premise relates to continually rising prices or the high rates of inflation in most areas. It basically implies that a dollar today is worth more than a dollar next year or two years from now.

In Pacific insular settings inflation rates of 10 per cent per year for imported products are not uncommon. In the case of a three-year trochus moratorium, a fisherman needs to receive at least 31 per cent more for his landings in Year three than Year one, all other factors being equal. And the problem is that all other factors do not remain equal, thereby making a precise calculation of the costs and benefits of moratoriums impossible.

However, the conceptual tradeoff is more straightforward: the health of the trochus stock, and its intrinsic ability to grow (or recover), versus the socio-economic needs of the stakeholders most dependent on the fishery. A precautionary approach dictates error on the side of caution to ensure the health of the resource.

Sanctuaries

Sanctuaries differ from area closures in that it is assumed that no exploitation whatsoever occurs within a defined area. The effectiveness of sanctuaries as a management tool for sessile invertebrates depends on better survival rates (due to lack of harvests) and the likelihood of increased abundance both within the area designated and potentially in the exploited population. Increased abundance within the sanctuary is envisioned to provide greater spawning output which would propagate to fished areas via larval dispersion.

The effectiveness of sanctuaries therefore also depends on oceanographic conditions and habitat. The biggest impediment to sanctuaries as an effective management tool is the difficulty of keeping the area free from fishing. Often, the economic and social costs of establishing sanctuaries is underestimated by resource managers.

Trochus sanctuaries are intuitively appealing and have been implemented in several locations throughout Micronesia. McGowan first advocated the use of sanctuaries as a management tool for trochus in response to what was felt to be low adult abundance and reduced probability of successful spawning (fertilisation).

Subsequent research has confirmed the importance of threshold levels of adult densities to ensure reasonable fertilisation rates (allele effect). However, while the 'solution' of sanctuaries has intuitive appeal, their effectiveness in practice during the past 35 years has been, at best, limited.

In several settings in Micronesia trochus sanctuaries have been established in areas that had been hypothesised to be areas of sub-optimal habitat, as was demonstrated for Palau. Furthermore, the integrity of the sanctuaries appears to be continually compromised (Palau, Pohnpei, CNMI). This is especially disconcerting given the fact that trochus were either introduced or not heavily exploited by traditional peoples.

Imposing sanctuaries appears to impart significant social costs, without a commensurate demonstration of benefit. This finding has significant implications in areas or situations where resources have been intensively utilised by traditional or contemporary cultures. Smith (1992b) suggests that the establishment of sanctuaries in Yap proper would be inappropriate due to current tenure practices.

This contrasts with Pohnpei's open-access inshore fisheries, where sanctuaries are often violated by poachers during seasonal openings and have had to be abandoned to reduce conflicts (Smith 1992b).

Associated with the cost of completely foregone benefits of traditionally exploited resources, is the need to address the question of marginal effectiveness, both ecologically and economically. Or, simply stated, how large and how far apart do trochus sanctuaries have to be to ensure maintenance of appropriate levels of spawning stock biomass?

Some (McGowan, 1958) suggest one sanctuary of undetermined size for every five linear miles of barrier reef but we, like Heslinga et al (1984), conclude that this is a rather 'arbitrary' recommendation.

Heslinga et al (1984) recommend that if sanctuaries are to be at all effective, whole reefs (channel to channel) be designated as such. These considerations appear to have as much to do with limiting enforcement and monitoring costs as with biological matters. Evaluations of marginal cost and benefit are scarce for tropical inshore fisheries. Nonetheless, responsible resource management policy, in the face of varied demands by constituents, requires this type of analysis.

Our review of the literature on experiences in Micronesia for trochus over the past 35 years suggests that the effectiveness of sanctuaries is inconclusive. While they are a biologically attractive means of managing the resource, the costs of effectively implementing sanctuaries in many areas may outweigh benefits, particularly if other management options are available.

A final caveat: our review has focused on the use of sanctuaries for trochus under exploitation. Clearly sanctuaries have other applications and potentially wider benefits that are not amenable to cost/benefit analysis (e.g. biodiversity considerations).

Stock replenishment—hatchery rearing and juvenile releases

Nash (1993) proposed two possible management objectives for hatchery rearing of trochus: seeding reefs depleted from overfishing and to compensate for overfishing in the absence of other conservation measures. In Micronesia, stock replenishment through the release of hatchery-reared juvenile trochus has been of questionable effectiveness. Hatcheries in general are mitigation measures for poor management practices or habitat degradation. In many cases the number of juveniles released has had an undetermined or unrelated effect on subsequent fishable stock levels. That is, natural mortality at critical life history stages, coupled with poor settlement timing, has limited the impact of hatchery-reared individuals on the adult population.

Thus, with technical effectiveness still unproven, the economic effectiveness cannot be addressed. Experience, especially in Palau and to a lesser extent in Pohnpei and Kosrae, suggests that the overtaxed capital and human management resources of typically small marine resource divisions are best allocated to alternative methods of trochus management, as opposed to being spent on a trochus hatchery for reseeding purposes.

There is an intrinsic appeal to artificial rearing, in that it provides demonstrable proof to stakeholders that 'something is being done' in the event of stock depletion or overfishing. Fishery administrators must weigh the benefit derived from public perceptions against the drain on departmental resources. In addition to direct costs to support rearing activities, there are also costs associated with monitoring releases and enforcing regulations promulgated to ensure survivability until recruitment into the fishery.

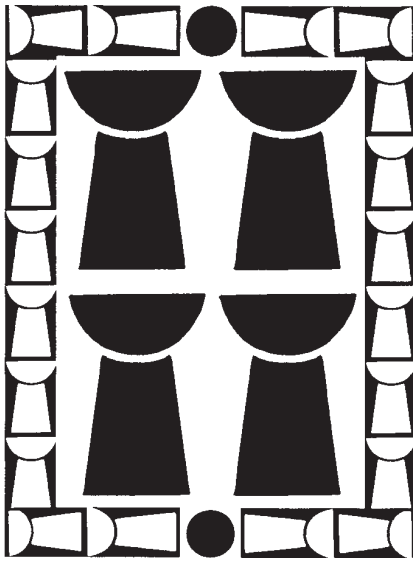
Even in instances where international donors are willing to assist either technically or financially, resource managers must examine the opportunities foregone, when considering the development of hatchery programmes for trochus. If hatchery techniques are to be pursued, we suggest this be done collaboratively, in regional centres, where costs and risks can be spread over a number of potential benefactors.

We should reiterate that while hatcheries have not led to demonstrable results in terms of augmentation of fishery production, there have been clear secondary benefits through the determination of basic biological factors useful for management.

With the considerable body of literature demonstrating the effectiveness of translocations (though there have been numerous failures) within Micronesia and Pacific-wide, if in fact augmentation is required, it is best carried out using adult trochus (> 8.0 cm) in a passive programme.

The costs of translocations, while not insignificant, are discrete and not of the recurrent variety needed to support a hatchery. Experience in Micronesia suggests that it may take between 6 and 10 years, possibly up to 15 years, to establish a new fishery.

Translocation programmes also incur long-term costs. Often it is essential that a complete moratorium or ban be imposed on the harvest of any trochus after translocation or reseeding takes place (cf Gillett, 1994). This regulation requires assiduous enforcement which can be obtained on a least-cost basis in instances where traditional systems are still active. In those areas where traditional systems of control and governance are no longer active, or are only marginally effective, the central government will incur enforcement costs.



These costs may prove significant and should be taken into account in the planning process. Translocation or reseeding programmes appear to be most successful in areas where the people understand that short-term yields must be foregone in order to attain a sustainable productive fishery in the future. Therefore an information and education programme is critical to the success of any attempts to initiate new fisheries or rebuild depleted ones.

There are costs associated with the monitoring of both augmentation and translocation programmes. For translocation programmes the cost is relatively discrete and there is a growing body of literature on methods (cf Nash et al, 1995).

However, releases of juvenile trochus require more rigorous procedures, particularly to monitor the pre-recruit phases, and may also require commensurately greater resources.

Finally, from a biological perspective, the merit of transplanting trochus to different areas to mitigate overfishing of the local stock may be questionable, given genetic problems. For example, genetic diversity can help organisms adapt to specific habitats, tidal conditions, water temperatures. Also, maintaining genetic diversity can also help to combat diseases and maintain unique spawning characteristics. Little is known of these processes in trochus. However, this is a fertile area for future investigation.

Other management methods and considerations

While trochus has been demonstrated to be a relatively important and equitably distributed cash crop for Micronesia (e.g. Palau), there are certain tendencies that should be avoided, such as over-capitalisation. In some developed economies large investments have been made in vessels and equipment to harvest trochus resources, with few alternative means of generating income. With the need to service large capital investments comes a tendency to fish at levels beyond those sustainable.

This situation is not unique to trochus; there is a plethora of examples where fisheries evolve to situations in which total costs equal or exceed total benefits and resource levels are driven extremely low.

A derivation of this trend has been experienced in several Pacific settings. For example, button-cutting factories require between 100 and 150 t of trochus shell per year (depending on the number of machines that must be supplied).

In settings in which these factories have been built, there have been 'strong pressures' to have seasons each year along with reduced minimum size regulations (Adams et al, 1992). The need to recoup the investment puts pressure on the resource and typically drives stocks to much lower densities. Pohnpei had a button factory, but it recently closed, reportedly due to lack of constant supply.

Our review suggests that there are no settings in Micronesia which can support a button factory with purely local stocks. Therefore, we suggest that efforts to expand trochus fishery benefits would be best spent optimising management to suit local conditions and to coordinating with regional organisations, such as the Forum Fisheries Agency, to determine appropriate markets and pricing schedules.

This broaches the final issue in our discussion: that of the role of government in the actual sales and transaction of trochus fishery products. With the considerable variability of annual volume coming from the various sites within the region, as well as in aggregate, there will be inherent variability in the economic and social benefits potentially derived from the resource.

One tendency is for government to assume the role of buyer, in an attempt to provide better and more equitable prices to producers. Local and national governments do have a role to play in the management, enforcement and monitoring of trochus activities in attempts to maximise local benefits. However, government and, in turn, marine resource divisions should assiduously avoid getting involved in roles traditionally left to private enterprise.

The Trochus Marketing Authority proposed for Yap State presents an extreme example. With an estimated annual production of 30 t, the gross value of the resource is clearly insufficient to provide the basis for an independent board with exclusive purchasing and marketing powers. Even if trochus production were to grow (as a result of expanded translocations), experience in the region has been that, while governments qualify and certify buyers, the premise that a part-time government board will time markets and provide better prices to producers, without additional subsidies, is questionable.

Governments' most appropriate role here may be to monitor fishery activities and enforce regulations, while promoting or fostering competition by encouraging a reasonable (and manageable) number of interested buyers. Regional fishery organisations appear to have a role also in information dissemination, management advice, and training. To this end, the *SPC Trochus Information Bulletin* is a very good example of coordination and information on activities. A more frequent 'Infofax' detailing world prices, market trends and available responsible buyers, might also be of value to producing countries.

Summary

The history and current experience of trochus fishery development and management in Micronesia appear to mimic wider trends in other Pacific Islands countries. Micronesia provides tremendous variety and richness in terms both of the trochus fisheries and of the societies exploiting them. In this study we have attempted to highlight these nuances.

There is an incredible volume of research that has been carried out on trochus; this was in part why it was chosen for this study. More recent efforts by W. Nash, W. Bour, T. Adams, and others provide a wealth of information and act as model studies for other inshore

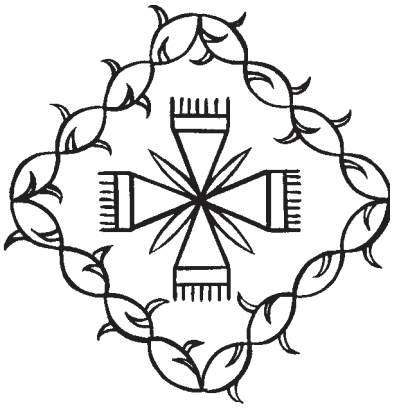
marine resources. Here we use trochus fishery experiences in Micronesia as a case study to broaden management perspectives, while adding to this considerable pool of knowledge.

However, for Micronesia there is considerable variation in the volume and quality of the data available for analysis. Efforts must be redoubled in a number of areas to better monitor and document current fishery trends—even the most basic types of data may be difficult to obtain. Initiatives by the Pacific Island countries and the Forum Fisheries Agency to compile eclectic reports and data sources are an especially good start to this end. The utility of marine resource departments' annual reports cannot be overemphasised. These data provide the basic tools required for sustainable fishery management.

It appears that Micronesia, as a region (excluding the CNMI) is currently capable of producing 300–310 t of trochus per year on a sustained basis under current management regimes. Most of the current management tools employed appear to focus on the biological attributes of the fishery. While this has ensured the ecological sustainability of the resource, it appears that adjustments can be made to optimise management.

Policy-makers and fishery managers need to look beyond biological factors and incorporate long-term economic and social considerations into management regimes. Our review suggests that a number of management tools, while theoretically valid, have been of questionable utility when one broadens the perspective to include social and economic factors.

The use of sanctuaries and artificial augmentation programmes may require re-evaluation, especially when effectiveness and enforcement costs are included in the decision calculus. The heavy dependence on seasons to maintain appropriate levels of spawning stock biomass has been demonstrated to be of questionable long-term merit. An effort must go into rationalising the quota between users. Moratoriums are effective but potentially incur heavy costs to those most in need. The establishment of trochus button factories should be evaluated in terms of competitiveness and the ability of the local resource to support the vital jobs which are created.



Size limits have proven useful to fishery managers because they are easy to understand and enforce, are amenable to incremental change, and can be modified given other (economic and social) considerations. However, there are drawbacks—as the Micronesian experience demonstrates they cannot be relied on at least for trochus to ensure sustainable nor consistent harvests. In the case where the market demands smaller, potentially sub-adult specimens, there are continual downward pressures on the minimum sizes.

All measures impose costs, as well as providing some benefit. The real questions have to do with tradeoffs; and these are what we have attempted to highlight.

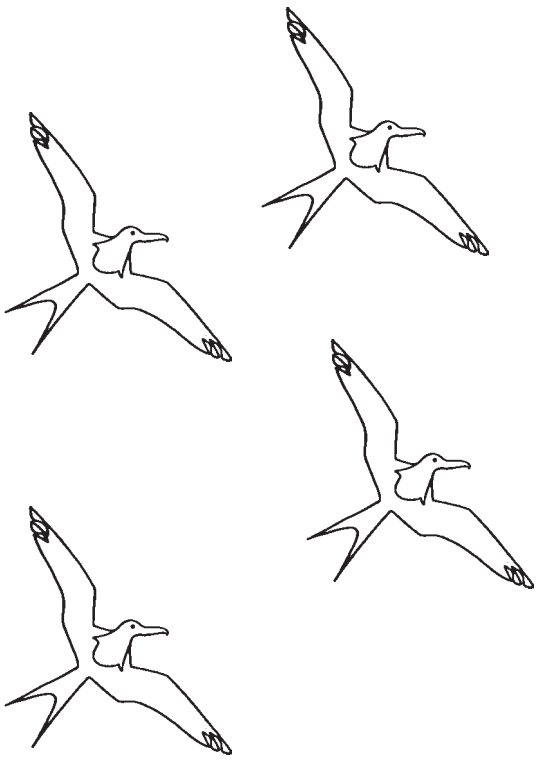
Proper management of trochus resources can provide a model for other inshore resources. They provide a real opportunity for resource managers and governments to provide benefits for all stakeholders. Government clearly has a role to play in the management of trochus fisheries, as does the private sector. However tendencies by either to enter into the other domain should be viewed with caution. In most of the areas of Micronesia today we believe that central authority is required for sustainable fishery management.

For many settings there has been an irreversible movement toward modernisation, which has seriously compromised the ability of traditional systems to manage the resource effectively. Parochial interests have proven too

strong to revert to traditional forms of management. Therefore, modern management regimes will probably continue; governance regimes must be modified accordingly.

For the more economically developed portions of Micronesia, the complete cessation of commercial harvests may be appropriate, given the alternatives and demands placed by the various resource users. Where traditional systems continue to be exercised, marine resource agencies should look to these as possibilities rather than constraints. These systems need to be supported and encouraged. The opportunity for community-wide quotas, determined cooperatively by modern and traditional methods, divided under traditional means, represents an alternative that may provide considerable benefits at minimum costs.

The Aitutaki fishery should continue to be monitored both economically and socially, as well as biologically. Some have recently suggested the appointment of 'fish wardens' from the local community of fishers (Adams et al 1994; Johannes, 1991). These options warrant further investigation. Central governments and fishery divisions need to support local efforts to assist in managing their resources. By doing so, all involved will benefit.



References

Adams, T., C. Aldan, V. Alfred, I. Bertram, A. Bukurrou, J. Cruz, T. Flores, L. Ilo, F. Rasa, R. Seman, & J. Taman (1994). Assessment of the Northern Marianas trochus resource and recommendations for management of the fishery. Draft Report of CNMI/SPC fisheries survey team to the Chief of the Division of Fish and Wildlife. 36pp.

Adams, T. & P. Dalzell (1994). The Present status of coastal fisheries production in the South Pacific Islands. South Pacific Commission, Twenty-fifth Regional Technical Meeting on Fisheries, 14–18 March 1988, Noumea, New Caledonia, *Working Paper* 3.

Asano. N. (1938). Experiment of trochus transplantion on Saipan Island. In Japanese: English translation in Izumi, 1987. *Nanyo Suisan Jijo*: 2(3), 662.

Asano, N. (1939) Guidelines for a trochus production survey and transplantation. *South Seas Fisheries News* 4(1):273–279. Translated in summary form in: Izumi, M. 1987. Summary translation of trochus research from the South Seas Fisheries News, 1937–1939. *FAO/UNDP Regional Fishery Support Programme Document* 87/2, Suva, Fiji.

Bascom, W.R. (1946). Pohnpei: A Pacific economy in transition, Vol. 8. US Commercial Company, Economic Survey of Micronesia, Honolulu, 287 pp.

Bour, W. (1990). The fishery resources of Pacific Island countries. Part 3: Trochus.

Curren, F. (1993). A study of the Enewetak trochus resource with recommendations for management and marketing. Unpub. Rep. Pacific Island Network, University of Hawaii Sea Grant Program. 48 pp.

Dalzell, P. & T. Adams (1994). The present status of coastal fisheries production in the South Pacific Islands. *Working Paper* 8. Twenty-Fifth Regional Technical Meeting on Fisheries, South Pacific Commission, 14–18 March, 1994, Noumea, New Caledonia.

Eldredge, L.G. (1994). Perspectives in aquatic exotic species management in the Pacific Islands. Volume I: Introduction of commercially significant aquatic or organisms to the Pacific Islands. *Inshore Fisheries Research Project Technical Document* 7. South Pacific Commission, Noumea, New Caledonia.

Gail, R. & L. Devambez (1958). A Selected annotated bibliography of trochus (*Trochus niloticus* Linn.) *South Pacific Commission Technical Paper* 111, 1–18.

Gillett, R. (1991). Pacific Island trochus introductions. Workshop on trochus resource assessment, development and management, Port-Vila, Vanuatu, 13 May – 2 June 1991. 6 pp.

Gillett, R. (1994). Trochus survey at Fakaofo, Tokelau. Inshore Fisheries Research Project Document. Unpublished. South Pacific Commission, New Caledonia.

Hall, E.T. & K.S Pelzer (1946). The economy of the Truk Islands: An anthropological and economic survey. Vol. 7. US Commercial Company Economic Survey of Micronesia. 114pp.

Heslinga, G.A. (1981a). Growth and maturity of *Trochus niloticus* in the laboratory. *Proceedings of the Fourth International Coral Reef Symposium*. Vol. 1:39–45.

Heslinga, G.A. (1981b). Palau trochus project report, September 1981. Micronesian Mariculture Demonstration Center, Koror, Palau.

Heslinga, G.A & A. Hillman (1981). Hatchery culture of the commercial top shell *Trochus niloticus* in Palau, Caroline Islands. *Aquaculture* 22:35–43.

Heslinga, G.A., O. Orak & M. Ngiramengiar (1984). Coral reef sanctuaries for trochus shells. *Marine Fisheries Review* 46(4):73–80.

Hilborn, R. & C.J. Walters (1992). Quantitative fisheries stock assessment. Chapman and Hall, New York. 570pp.

Izumi, M. (1987). Summary translation of trochus research from the South Seas Fisheries News, 1937–1939. *FAO/UNDP Regional Fishery Support Programme Document* 87/2, Suva, Fiji.

Johannes, R.E. (1981). Words of the lagoon: fishing and marine lore in the Palau District of Micronesia. University of California Press. 245 pp.

Johannes, R.E. (1991). Some suggested management initiatives in Palau's nearshore fisheries and the relevance of traditional management. Unpublished report. Palau Marine Resources Division.

McGowan, J.A. (1956). Current status of the trochus industry in Micronesia. Unpublished report. US Trust Territory of the Pacific Islands Doc.

McGowan, J.A. (1957a). Trochus studies in the US Trust Territory. *SPC Quarterly Bulletin* 7(2):22–23.

McGowan, J.A. (1957b). Trochus research in the Trust Territory. *Micronesian Reporter* 5(1):14–15.

McGowan, J.A. (1958). The trochus fishery of the Trust Territory of the Pacific Islands. A report and recommendations to the High Commissioner, US Trust Territory of the Pacific Islands, Saipan. 46 pp.

McGowan, J.A. (1959). The *Trochus niloticus* fishery of Micronesia. *Veliger* 1(4):2628.

Methot, R.D. (1990). Synthesis model: An adaptable framework for analysis of diverse stock assessment data. *Int. North Pac. Fish. Comm. Bull.* 50: 259–289.

Motoda, S. (1938). Useful shells in Palau Islands (Palau no Yuyo Kairui). *Journal Sapporo Society Agriculture and Forestry (Sapporo Norin Gakkaiho)*, Year 31, No. 4b, pp 315–324.

Munro, J.L. & S. T. Fakahau (1993). Management of coastal fishery resources. In: Nearshore marine resources of the South

Pacific. Forum Fisheries Agency, Honiara, Solomon Islands.

Nash, W. J. (1993). Trochus. In: Nearshore marine resources of the South Pacific. Edited by Andrew Wright and Lance Hill. Institute of Pacific Studies, Suva. pp. 451–496.

Nash, W., T. Adams, P. Tuara, O. Terekia, D. Munro, M. Amos, J. Legata, N. Mataiti, M. Teopenga & J. Whitford (1995). The Aitutaki trochus fishery: A case study. *Inshore Fisheries Research Project Technical Document* No. 9. South Pacific Commission, Noumea, New Caledonia.

Ngiramolau, A., B. Mechol & H. Renguul (1991). Assessment of *Trochus niloticus* populations in Palau. *Palau Marine Resources Division Technical Report* No. 91.2

Nichols, P.V. (1991) Republic of Palau marine resource profiles. Forum Fisheries Agency Profiles. *Forum Fisheries Agency Report* no. 91 / 59.

Parkinson, B. (1980). Trochus resources survey. UNIDO Mission Report. 24 pp.

Preston, G.L. & H. Tanaka (1990). A review of the potential of aquaculture as a tool for inshore marine invertebrate resource enhancement and management in Pacific Islands. *Information Paper 5*. Twenty-second Regional Technical. Meeting on Fisheries, South Pacific Commission, 6–10 August, 1990, Noumea, New Caledonia.

Sims, N. (1988). Trochus research in the Cook Islands and its implications for management. SPC Workshop on Pacific Inshore Fishery Resources, Noumea, New Caledonia, 14–15 March, 1988. *Information Paper 37*, 13 pp.

Smith, A. (1990). Final report on the 1990 trochus harvest for Yap and Ulithi, with recommendations for future harvesting. 39 pp.

Smith, A. (1992a). Republic of the Marshall Islands marine resources profiles. *Forum Fisheries Agency Report* No. 92 / 78. 90 pp.

Smith, A. (1992b). Federated states of Micronesia marine resource profiles. *Forum Fisheries Agency Report* No. 92 / 17.

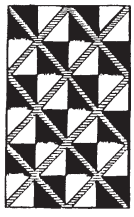
Smith, B.D. (1987). Growth rate, distribution and abundance of the introduced topshell *Trochus niloticus Linnaeus* on Guam, Mariana Islands. *Bull of Mar. Sci.* 41(2):466–474.

Smith, R.O. (1946). Survey of the fisheries of the former Japanese Mandated Islands. Vol. 10. US Commercial Company Economic Survey of Micronesia. 92 pp.

Smith, R.O. (1947). Fishery resources of Micronesia. Fish and Wildlife Service Fishery Leaflet 239.

Uwate, R.K. (1986). Trochus / giant clam hatchery feasibility study, Yap State. Pacific Fisheries Development Foundation Project. 6 pp.

Wright, A., R. Gillett & R. Alfred (1989). Results of a survey at Enewetak and Bikini Atolls with suggestion for Fishery Management. *South Pacific Forum Fisheries Agency Rep.* 89 / 20, 19 pp.



NOTE: This and the following five articles were presented during the SPC/FFA Workshop on the Management of South Pacific Inshore Fisheries which was held in Noumea in June/July 1995. Two volumes of country and background papers from the Workshop will be published by SPC in early 1996.