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A REVIEW OF THE POTENTIAL OF AQUACULTURE AS A TOOL FOR INSHORE MARINE INVERTEBRATE RESOURCE ENHANCEMENT AND MANAGEMENT IN THE PACIFIC ISLANDS

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1 Introduction

1.1 General

In a number of Pacific Island countries, stocks of several inshore marine species of subsistence or commercial importance have been reduced or completely eliminated, mainly by fishing activities. This is particularly true of sessile or slow-moving invertebrates, including giant clams, pearl oysters, trochus, green snail, coconut crabs, and others. Where these stocks are still intact, growing levels of fishing pressure threaten to reduce them in a similar way. Other resources, such as sea cucumbers, are also increasingly threatened because of their relative ease of harvesting and the increasing profitability of collecting them.

In recent years, the concept of re-establishing these populations through the use of aquaculture or "ocean ranching" has been widely discussed (e.g. Kafuku 1986: Yamaguchi, 1988b). Aquaculture programmes have been conceived and, in some cases established with the specific aim, for example, of producing juveniles or adults for use in restocking programmes. Nevertheless, although aquaculture programmes for some species, notably giant clams, have been considered in some detail, no in-depth analysis of the overall applicability to the region of aquacultural resource enhancement (ARE) procedures has been carried out. Such an evaluation appears timely given the increasing prediliction of Pacific Island governments to become involved in this type of activity.

The intention of the paper is to promote discussion of the ARE issue. It is hoped that this in turn will provide guidance for collaborative work by the SPC Inshore Fisheries Research Project (IFRP) and the FAO South Pacific Aquaculture Development Project (SPADP) within the framework of the joint IFRP/ SPADP Reef Reseeding Project, as well as for other agencies.

1.2 Definitions

Aquacultural Resource Enhancement, ARE, is taken here to refer to a group of related techniques for the enhancement of natural populations of selected marine resources by the conduct of aquaculture. The term embraces all activities which involve:

- the deliberate placement, transplantation or restocking of juvenile animals that are;
    - produced in hatcheries; or
    - collected from natural habitats, and protected from predation for some part of their life cycle;
- the enhancement of natural recruitment by augmenting, concentrating or protecting broodstocks;
- increasing spat or juvenile settlement by providing artificial substrates (spat collectors, etc);
- reducing natural mortality by creating artificial habitats, shelters, or other forms of protection.

There is considerable overlap of these categories of ARE with each other and with more intensive forms of aquaculture, often with no clear boundaries. In some cases it is clear that ARE will only be warranted if it is supplemented by additional measures such as fishery regulation or management, or pollution control.

1.3 Rationale for aquacultural resource enhancement

The various fishery management situations in which the different types of ARE might be envisaged include recruitment failure caused by overfishing or other forms of natural broodstock depletion. However, ARE programmes are not only considered as a means of dealing with problems attribuatble to overfishing. Other reasons may include the mitigation of environmental damage (e.g. pollution or the destruction of spawning grounds), or the possibility that restocking could result in natural populations can be swelled beyond their normal limits because of, for instance, recruitment-limited population dynamics. ARE may also be beneficial where poor survival or settlement of planktonic larvae occurs because of an inadequate quantity or quality of settlement opportunities, or because of adverse larval transport caused by local current patterns or large distances between parent stocks and settlement sites.

This paper outlines some of the issues related to the concept of resource enhancement through restocking, ranching, and other aquaculture activities, suggests the possible benefits and limitations of such programmes, and indicates areas where further study may be needed. The subject area is confined to invertebrates, especially those found in the region. Fish ARE programmes, or those for temperate-water species in general, are only considered where the information illustrates general ARE principles, or is also relevant to invertebrates.

2 ARE experiences outside the Pacific Islands region

2.1 General

A number of countries have experimented with ARE programmes for various aquatic animals. These programmes have typically involved small scale transplantation or restocking of freshwater finfish (such as sturgeons, tilapia, common carp, Chinese carp, trout, black bass, perch, mullet) or coastal molluscs (oysters, cockles and mussels).

Much of the ARE activity that focusses on marine species is carried out in Japan, although some attempts have also been made in South-east Asia, the USA, and Europe. English-language documentation of the results of such programmes tends to be scattered and difficult to acquire. More focussed documentation is available in Japan, Thailand, China and other Asian countries, but is not published in English.

The following paragraphs present some information on these programmes and others outside the Pacific Islands region. The information is limited to a small number of cases and does not pretend to be comprehensive.

2.2 Japan

Japan has traditionally and aggressively promoted the principle of transplantation and restocking practices for freshwater fishery resource enhancement, mainly by a process of trial and error. Since about 1940 this has been extended to coastal marine resources. The Japanese term for this type of resource enhancement is *saibai-gyogyo*, which literally means "farming fisheries" or "sea farming". The amount of financial backing and the degree of official and popular support that such programmes receive is unique to Japan.

Early "sea-farming" attempts mainly relied on the mass release of large numbers of hatchery-produced juveniles. Target species were finfish (including sea bream, flounder, salmon, yellowtail and horse mackerel), crustaceans (including crabs and shrimps), molluscs (including several bivalves and gastropods as well as cuttlefish and octopus), and various other species (including sea cucumbers and seaweeds). More recently interest has grown in "marine ranching" of species found further offshore (including deep-water scallops, deep-bottom fish, and migratory species such as tunas). There has also been a trend towards more comprehensive systems of resource enhancement by the development of technical systems that permit a combination of environmental control, increases in juvenile production capacity, enhancement of the recruitment process, and a strict management regime.

Cowan (1981) gives an overview of Japan's ARE programme, which began in 1962 with the establishment of two government hatcheries on the Seto Inland sea. By 1987, 38 coastal prefectures were operating sea farming centres, with a further 14 national centres and many private or fisheries coopertaive hatcheries either operating or under construction (Matsuoka, 1989). In 1987 Japanese hatcheries were producing 49 million fish seedlings (36 species, excluding salmon), 393 million crustacean seed (19 species, including major prawn and swimming crab restocking programmes), 18 billion molluscs (28 species) and 18 million echinoderms (5 species). Practically all this production was for restocking purposes, sometimes in mitigation against overfishing, extensive foreshore reclamation, habitat destruction, and pollution, but mainly specifically targetted towards increasing production.

The techniques used for juvenile production tend to be intensive, and technically complex. Spawning may be natural (prawns, crab, bream) or artificially induced (abalone, salmon). Depending on the species, larvae are fed on a range of items including microalgae, rotifers, *Artemia* nauplii, minced trash fish, clam, krill, or artificial feed. Where live planktonic food is used, this too must be reared under controlled culture conditions. Water quality is maintained by filtration, aeration, irradiation, and the biological activity of marine bacteria or algae grown in the rearing water. Survival rates from hatching to release of juveniles vary from 5-50% depending on the species, hatchery techniques, and release age.

An important feature of Japanese juvenile releases is the use of intermediate rearing facilities, such as sea cages, artificial ponds in the beach zone, etc, where juveniles are on-grown to an age at which reasonable post-release survival rates can be expected. This also allows hatchery-reared animals to develop behaviour patterns (such as nocturnalism, food searching and capture, and burrowing behaviour in prawns) that will increase their chances of survival in the natural environment. In many cases this intermediate or ongrowing phase is protracted, and may last for months.

To further improve survival rates and enhance fishery production, artificial habitats have been used extensively in Japanese ARE programmes since 1980, when most restocking activities were incorporated into the later phase of "sea ranching" programmes. Habitat improvement is normally by the deployment of artificial reef modules, often specially formed concrete structures with internal cavities or gaps designed to provide appropriate forms of shelter to the animal in question. Special habitat modules have been designed for lobster, abalone, and many other species, and are deployed in large numbers at release sites. These modules may also be deployed independent of any juvenile release programme, as part of fishery habitat enhancement programmes that aim to improve natural recruitment or survival rates.
Restocking activities based solely on the production of juveniles are thus seldom carried out in isolation in Japan nowadays. As well as being supplemented by extensive juvenile ongrowing activities and habitat improvement, fisheries throughout the coastal areas of Japan - especially those being restocked - are subject to tight management controls through an extensive system of fisheries cooperatives.

Based on tagging programmes and the analysis of length-frequency data, together with statistical information on levels and distribution of commercial fishing catch and effort, some assessments have been made of the returns from various juvenile release programmes. Three examples from Cowan (1981) are as follows:

- tag-recapture investigations indicate recovery rates of 1-6% for kurama prawns (*Penaeus japonicus*) released at a size of 5-8 cm, and 35-41% for large prawns over 16 cm long. Combined data from gill netters and trawlers suggest recovery rates of 0.7-5.7%. In the Niigata prefecture, prawn catches per boat improved by a factor of 3.8 following the increase in juvenile restocking from 0.1 million to 1.1 million seed per year. However, this variation was within the normal range of fluctuation of the fishery and could not be directly attributed to the release programme without data over a longer period. In the Seto Inland sea, prawn releases over a 15-year period produced an apparent return to normal levels of total landings after a 7-year decline;

- a 4-year mark-recapture investigation on red sea bream (*Pagrus major*) by five Inland Sea prefectures recovered 8% of 206,000 released fish or their tags. Based on size-frequency data, other recovery rates ranged from 20% for second-year fish to 16% for third- and 5% for fourth-year fish. A general decline in landings was reversed in one location where intensive restocking was carried out. Since this reversal was not observed elsewhere it was attributed to the restocking programme. However, even using the most optimistic projections, the maximum contribution of hatchery output (4.3 million seed per year) to total annual catches was only 1.4%. To produce increases that could be reliably distinguished from natural variation would require the release of 5-10 million seedlings in the Inland Sea area alone. In this area the adult population has been estimated at 1.6-2.3 million fish;

- a 2-year tagging study on large (9-17 cm) blue crab (*Portunus trituberculatus*) indicated recapture rates of 22% for released animals, although the studies were hampered by lack of a suitable tag that will last through more than one moult. Reasonably distinctive size-frequency patterns in one area allowed researchers to calculate 1979 recovery rates of 4-13%, and to infer that 49-87% of the catch consisted of restocked animals.

By the early 1980's, Japan had been operating ARE programmes for some 15 years at an annual cost of over 4.6 billion yen (about US$ 40 million at the exchange rates of the time). After 1980, expenditure accelerated still further. Despite this degree of commitment, the results from many Japanese restocking activities still seem to be inconclusive. In many instances restocking alone has had no demonstrable effect on fishery yields despite being carried out for extended periods of time. This is at least partly due to the technical difficulties in studying the results of restocking and the masking effects of natural population variation.

Despite the lack of conclusive evidence of the general applicability of restocking programmes in fisheries management, there continues to be a widespread belief in the usefulness of ARE in Japan. The Japanese fishing industry in particular is convinced of the benefits of ARE.

2.3 Other countries

Most non-Japanese ARE experience concerns molluscs. Bivalves have been commonly used for restocking purposes in a number of countries because of the relative ease with which seedstock can be collected from the wild, and the tendency of these animals to remain in the area they are stocked. Restocking in these cases is normally in the form of put-and-take culture, in which wild seed are first collected by the use of seives or hand nets from mud or sand flats in the middle or low intertidal zones near estuaries. They are then restocked into grow-out grounds, sometimes after being reared intensively in tidal ponds.

Cockle restocking has been practiced in the Phetchaburi Province of Thailand since 1900 and the farming area reached a size of 1420 hectares in 1982 (Tookwinas, 1983). In Malaysia, cockle restocking was begun in about 1948 by a village leader, and since that time has spread rapidly to become the country's most important aquaculture industry (Ng, 1982). Broom (1985) summarised information on the restocking and culture methods used in Asian countries for three species of cockle, *Anadara granosa*, *A. subcrenata* and *A. broughtoni*. Chen (1976) described in detail restocking practices for cockle (*A. granosa*), freshwater clam (*Corbicula fluminea*) and hard clam (*Meretrix lusoria*) in Taiwan. Hard clams were introduced into Taiwan from Japan in the 1930's and have since spread widely into many sandy beaches and estuaries (Chen, 1984).

The table below gives information on bivalve ARE activities in the major Asian producing countries.

Species	Country	Seed size	Harvest size	Av yield (mt/ ha)	Reference
Razor clam (*Sinonovacula constricta*)	China	1 cm	5 cm	15-22	Nie, 1982
" "	China			12	Lovatelli, 1988
Small-necked clam (*Ruditapes philippinarum*)	China	0.5 cm	3.5 cm	18.7-45	Nie, 1988
" "	China			13	Lovatelli, 1988
Hard clam (*Meretrix lusoria*)	Taiwan	700-1000/kg	35/kg	1.13	Chen, 1976
" "	Taiwan			7	Lovatelli, 1988
" "	S. Korea			14	Lovatelli, 1988
(*Meretrix meretrix*)	China			15-30	Lovatelli, 1988
(*Venerupis japonica*)	S. Korea			7	Lovatelli, 1988
Cockle (*Anadara granosa*)	China	800/kg	2 cm (120/kg)	22.5-60	Nie, 1982
" "	China			7.5-20	Lovatelli, 1988
" "	Taiwan	5000/kg	100-200/kg	0.6-0.9	Chen, 1976
" "	S. Korea			10.5	Lovatelli, 1988
" "	Malaysia		2.5 cm	40	Ng, 1982
" "	Malaysia	4-10 mm	<3.18 cm		Broom, 1985
" "	Thailand	1,000-10,000/kg	4 cm	ca. 20	Tookwinas, 1983
" "	Thailand			11.27	Lovatelli, 1988
" "	Thailand			31	Saraya, 1982
(*Scaparca subcrenata*)	S. Korea			10.5	Lovatelli, 1988
(*Cyclina sinensis*)	S. Korea			15	Lovatelli, 1988

In southern California, several abalone hatcheries have been involved in producing juveniles for use as seed for restocking areas where natural populations have declined (Chew, 1984). Despite the relatively large scale of the restocking operation, it was not successful, probably because of predation on newly released juveniles, as well as emigration of adults from the restocked population (Hahn, 1989). In France, however, the construction of artificial concrete habitats in the intertidal zone resulted in recapture rates of restocked abalone as high as 40-50% 2.5 years after release (Hahn, 1989). In South Korea, coastal fishermen drop stones, rubble, and concrete blocks with internal cavities in the sea in areas that are favourable for commercial abalone species, in order to provide restocked juveniles with additional shelter from predatory starfish, fish, crabs and molluscs (Yoo, 1989). Lovatelli (1988) indicated total yields of 2.4 t/ha of restocked abalones, and 2.4 t/ha of restocked top shell *Turbo cornutus*, in areas enhanced in this way.

In the Caribbean there are commercially important fisheries for the meat and shell of the queen (or pink) conch, *Strombus gigas*. This species grows to over 18cm long and 845 g in weight at an age of about 2.5 years. Due to recent overfishing, restocking with hatchery-produced queen conch has been suggested. Hahn (1989) evaluated the restocking potential as poor because of expected high natural mortalities of restocked juveniles (at least 28 predators of this species are known), but recommended either transplantation or protected culture of adults. In the latter case, however, low conversion rates (20:1) of food (seaweed) to biomass, and the low meat yields (12%) per shell, make it unlikely that culture can be carried out cost-effectively.

Scallops are New Zealands highest-priced bivalve. In Golden Bay, a pilot scallop enhancement project using Japanese-style reseeding methods was successfully carried out between 1983 and 1987 (Bull, 1989). During this project, an evaluation was carried out of three different reseeding methods, two of which were considered to be economically feasible. In the "natural release" method, spat settle on collectors made of "Christmas tree" ropes. When they achieve a certain size they detatch themselves and drop to the sea floor where they continue to grow in the benthic habitat. When they reach 35-45 mm shell diameter they are dredged and transferred to grow-out grounds. In the "direct release" method, the spat settle and grow inside net collector bags whose mesh size is small enough to retain them once they reach a certain size. The scallops are thus unable to follow their natural settlement procedure, and remain in the bags where they continue to grow until they are deliberately released at an optimal size of around 10 mm diameter. The natural release method has been found to give better juvenile survival rates.

This operation is presently being commercialised and the seeding area expanded (Bull, 1989), with scallop beds in Tasman Bay, Marlborough Sound and other areas that have been depleted by commercial fishing over the past decade being seeded by the Ministry of Agriculture and Fisheries (Hilhorst, 1990). On-grown spat are reseeded onto known scallop beds for harvesting 2-3 years later. Some beds are allocated to commercial fishermen, others, closer to the shore, reserved for recreational collecting activities. Predation on spat by labrid fishes has been intense and has led to high levels of spat loss in some inshore areas.

Reseeding activities are funded partly from a fee levied on commercial vessels authorised to fish on the beds (20% of gross takings, equivalent to a charge of about NZ$14,000 each to 48 licensed vessels) and partly from public funds, negotiations for which are still under way. The operation is considered "costly" (Hilhorst, 1990).

The perceived success of this project has led to private farmers in New Zealand applying for licenses to reseed an area of 4,300 hectares in the Marlborough Sounds. If approved, a condition of the license would be the exclusion of other scallop fishermen from the area, which would set an unpopular precedent in capture fisheries management in New Zealand.

2.4 Evaluation of ARE programmes

Estimation of the contribution of stocked juveniles to the growth of a population or to the commercial catch continues to be difficult. Tagging of released juveniles is often only physically possible with animals above a certain size. In some cases small samples of hatchery seed need to be specially grown on for longer periods so that they can be tagged. Tagging in some cases can give approximate indications of recovery rates, as well as information about dispersal. Additionally, hatchery-produced animals in a catch can sometimes be distinguished from wild-grown animals by analysis of size-frequency data.

Polovina (1986) has attempted to apply standard yield-per-recruit and surplus production models to fisheries that are subject to restocking. He surmises that restocking will be most beneficial to fishery production in species which have a high asymptotic weight, and in situations where the ratio of natural mortality to growth (M/K in the Beverton and Holt yield equation) is small. This is so since the lower the ratio of natural mortality to growth the greater the survival of the released individual, and the greater the asymptotic weight the greater the weight (and thus presumed value) gained by the released individual.

3 Pacific Island species of interest

3.1 General

ARE is usually considered as a response to perceived declines in the abundance of species that are targets of fishing activities. Declines may result from overfishing, pollution, habitat destruction, or other causes, including natural ones. ARE is viewed as a conservation measure, and a way to restore the productivity of fisheries that appear to be in serious decline.

Resources that fall into this category in the Pacific Islands region at present, or can be expected to in the reasonably near future, are as follows:

Bivalve molluscs:	giant clams (*Tridacna* and *Hippopus* species)
	pearl oysters (*Pinctada margaritifera* and *P. maxima*)
Gastropod molluscs:	trochus (*Trochus niloticus*)
	green snail (*Turbo marmoratus*)
Crustaceans:	spiny lobster (*Panulirus species*)
	mangrove crab (*Scylla* species)
	coconut crab (*Birgus latro*)
Holothurians:	sea cucumbers (various species)

Several other species are of less widespread interest but are either locally overexploited or easy to produce in hatcheries, and may be potential ARE candidates. These include the blood cockle (*Anadara maculosa*) various other bivalves including ear shells, and the sea urchin *Tripneustes gratilla*.

Other than the crustaceans, all these species are slow-moving or sedentary benthic animals that are relatively easy to gather, and are thus highly vulnerable to intensive fishing. Ordinary harvesting practices can eliminate most or all individuals from a given area. The crustaceans, while somewhat more cryptic and elusive, are nonetheless prone to depletion because of their particular growth and recruitment characteristics.

The specific characteristics of each of the major groups above, and the considerations that would apply to ARE activities for them, are discussed in the following sections.

3.2 Giant clams (*Tridacna* and *Hippopus* species)

Munro (1989) describes the status of giant clam fisheries in the region and reviews the prospects for their enhancement in some detail. Of the 7 species of tridacnid (*Tridacna crocea*, *T. derasa*, *T. gigas*, *T. maxima*, *T. squamosa*, *Hippopus hippopus* and *H. porcellanus*) native to the region, stocks of at least three (*T. derasa*, *T. gigas* and *H. hippopus*) are thought to have been severely reduced by fishing pressure. In almost every Pacific Island country, stocks of one or more species of giant clam are reported to be overfished (sometimes to the point of extinction), either as a result of local fishing activities or due to poaching by Taiwanese clam-boats in some localities.

Following the realisations that giant clams grow faster than previously thought, autotrophic (self-feeding, due to the photosynthetic activity of symbiotic zooxanthellae), and easy to propagate under hatchery conditions, considerable research effort has been put into the development of aquaculture techniques for these animals. For some years, regional research centres in Palau, Australia and the Solomon Islands have been routinely producing giant clam juveniles by either low-intensity (tens of thousands) or high-intensity (millions) methods (Munro, 1989), and these have been successfully reared through several generations under a variety of different conditions. Juveniles produced by these centres, especially Palau, have been exported to other Pacific Island locations for purposes of restocking, grow-out trials, or broodstock establishment. Small nationally-operated low-intensity hatcheries have recently been established in some other Pacific Island countries (Federated States of Micronesia, Fiji, Marshall Islands, Tonga, Western Samoa), and more are planned for the future (e.g. American Samoa and Cook Islands). Some of these hatcheries have achieved successful spawnings, although mortality rates of larvae and newly-settled juveniles tend to be high (90% or more).

In some cases, the aim of establishing hatcheries is to permit the development of commercial giant clam culture operations, under which clams will be reared in high-density plots for ultimate commercial harvesting and sale. A great deal of work remains to be done on product and market development in support of this aim.

In the majority of cases, however, the aim, at least in the first instance, is to use hatchery-produced juveniles to reseed areas of reef known to have been over-harvested, or to re-introduce species that have been locally fished out. It is generally accepted that, in these cases, even if it could be done, simply regulating or banning fishing activities alone would not lead to stock re-establishment because of the particular reproductive characteristics of giant clams. Specifically, low densities of clams in an area result in poor spawning synchronisation, low fertilisation rates, and consequent poor recruitment. The short larval life spans of these species (6-8 days) also preclude larvae from travelling large distances and repopulating distant fished-out areas.

Experiments to establish commercial grow-out areas indicate that juvenile giant clams can be moved from hatchery tanks and placed in protected oceanic nurseries when they reach a size of 0.5-1.5 cm shell length, which, depending on the species involved and the growing conditions, might be achievable in 4-6 months. They are thought to become relatively safe from predators after reaching a shell length of about 10cm and at this time can be moved from nurseries to relatively unprotected areas.

Some measure of mortality rates in protected animals is given by Heslinga and Watson (1985). 12-17 mm (5 month old) clams kept in unfiltered seawater in raceways suffered a mortality rate of 5% per month, mainly caused by predation from muricid gastropods which entered the system as larvae. After transferral to sea-floor cages at a size of 30-40 mm (8-9 months old), 25% mortality was reported over the next 15-16 months. During the next 2-3 years 10% mortality occurred when the clams were kept in unprotected conditions. Adult giant clams in a reef enclosure in Papua New Guinea showed low mortality rates, ranging from 0-6% over a 5-year period (Munro and Heslinga, 1983).

In the case of unprotected animals, small (10-20 mm) clams placed in unprotected trays on reefs rapidly suffered total mortality due to predation (Heslinga et al, 1984). In the Cook Islands, 5 cm clams placed in unprotected conditions suffered 85% mortality during a three-year period, due to parasitic infestation (J. Dashwood, pers. comm.). Juvenile clams dispersed in a reef system might suffer a lower mortality rate as a result of being less concentrated, more protected, or better hidden, but this has yet to be demonstrated. The mortality rates of older animals kept under protected conditions can probably be taken to represent a lower limit to those that would be experienced by clams stocked onto a reef. Upper limits may be close to total mortality, but the actual rates that will be experienced cannot be known without further experimentation.

It would appear that reseeding reefs with very small clams taken directly from hatcheries will only be feasible if hatchery costs are low and hatchery output very great (Munro, 1989). Stocking reefs with clams that have been grown on to a length where mortality might be expected to be low (10-15 cm according to Heslinga et al, 1984) will require extended raceway or ocean nursery rearing, and the consequent development of economic systems for doing this (Munro, 1989).

If reefs are restocked by broadcasting seed or juvenile clams, it will be necessary to institute management measures to improve the chances of success. A minimum management measure will be the imposition of a size limit that permits at least some of the restocked clams to reach reproductive size.

Placing adult clams close together in high-density groups may improve natural reproductive success and enhance recruitment by improving spawning synchronicity and consequent rates of fertilisation (Chesher, 1989). Adults could be either hatchery produced or collected from the wild. In cases where aquaculture is for commercial purposes, high-density grow-out areas may also function to enhance natural recruitment if the clams are allowed to grow old enough to reproduce.

In wild populations of giant clams studied during a survey in Fiji, size frequencies are not normally distributed typically show a strong skewing towards the larger sizes (A. D. Lewis, pers. comm.). The under-representation of small animals appears to be a real feature of the population and not simply an artefact of the more cryptic habitat of the smaller size classes. The implication is that small animals are subject either to high rates of mortality or to very variable recruitment patterns. The individuals that survive beyond a certain critical size subsequently have much higher chances of survival, hence there is an accumulation of animals in the higher size ranges. If this "age-class packing" continues over a long period of time it will lead to dense populations of adults even though juveniles are rare. When such populations are harvested intensely, their recovery may not occur for years or decades, because of both the reduction in reproductive success associated with reduced densities of animals, and because of the length of time needed for the age classes to re-pack.

Irrespective of whether they are wild or being maintained under culture, giant clam populations are highly vulnerable to human interference and unauthorised harvesting and need to be protected from excessive depletion by limits or prohibitions on their exploitation. Devising locally acceptable and enforceable mechanisms, such as fishing bans or closed areas, for the protection of such concentrations has proved difficult in some areas where this approach has been tried (Fiji, Tonga, Western Samoa). A promising approach which is being pursued in Solomon Islands, Western Samoa, Fiji, Tonga and elsewhere, is to invest the responsibilities of managing and guarding (and ultimately, exploiting) broodstock and ongrowing populations in local communities or community groups.

Irrespective of the type of ARE undertaken, it is clear that it will need to be supported by management measures intended to protect the animals in question. These are likely to prove more difficult to enforce when fishing activity is dispersed and is primarily for subsistence purposes (Munro 1989).

3.3 Pearl oysters (*Pinctada margaritifera* and *P. maxima*)

Pearl producing bivalves of the genus *Pinctada*, especially *P. margaritifera* (black-lip pearl oyster) and *P. maxima* (gold-lip or silver-lip pearl oyster) have at one time been the basis of significant subsistence or commercial capture fisheries in all Pacific Island countries. *P. margaritifera* is a characteristic inhabitant of oceanic atolls and where conditions are favourable very dense populations may exist. Both species are also found in the coastal lagoons of high islands, although the natural distribution range of *P. maxima* is limited to the western part of the Pacific islands region. Factors affecting the suitability of any given area for pearl oyster growth and survival are not fully understood, but probably include water quality (salinity, temperature, nutrient supply), competition from other bivalves, presence of molluscivorous fish and other predators, and, in particular, hydrographic conditions affecting larval retention (rates of water exchange and current patterns).

The shells of these two pearl oyster species have been traditionally used for the fabrication of tuna fishing lures in many parts of the Pacific and because of this continue to have a high symbolic value even in areas where this type of fishing is no longer commonly practised. Additionally, overseas demand for pearl shell for use in decorative mother-of-pearl inlay work and button-making has existed for over two centuries, and has led to periods of very intense harvesting and export of shell which has in turn caused the depletion of pearl oyster stocks in many locations. For example, pearl oysters were reported to be practically extinct in Tokelau in 1957 (van Pel, 1957), and the pearl oyster population of Kiritimati in Kiribati appears never to have recovered from intensive harvesting in the late 1900's (Sims et al, 1990).

Areas of natural pearl oyster abundance are now few. Good stocks of *P. margaritifera* remain in some atolls of French Polynesia and the Cook Islands, where harvesting is controlled by fishing seasons and quotas. However these are under increasing strain as a source of wild material for aquaculture. *P. maxima* is still relatively abundant in some parts of the Solomon Islands and probably Papua New Guinea, frequently in deep water only accessible by the use of underwater breathing apparatus. Localised high densities of both species may occur elsewhere, particularly in remote atolls (southern Fiji, Federated States of Micronesia, Marshall Islands) and deep coastal waters around high islands. However, a recent upswing in prices for pearl shell has increased the profitability of harvesting these species, and the consequent threat to remaining wild stocks.

The reproductive characteristics of both species are similar and appear to mitigate against the recovery of wild stocks once populations have been driven below a certain level. The pattern of distribution of pearl oysters in a natural population is contagious (patchy), and appears to serve as a mechanism to improve fertilisation success by encouraging synchronous spawning among animals that are grouped together. Once the animals have been thinned out too much, spawning ceases to be synchronised and fertilisation rates are drastically reduced. Normal patterns of mortality appear to keep such reduced populations in a depressed state. If recovery is to occur, it may depend on a good recruitment year when conditions are optimal for fertilisation success, larval retention within the lagoon or coastal area, and early juvenile survival. Such a combination of conditions is likely to occur only rarely.

Since the mid-1900's, aquaculture of both of these species has been practised in the Pacific Islands region, and continues today in French Polynesia, Cook Islands and Fiji. Experimental culture activities are under way in Federated States of Micronesia. *P. maxima* is also cultured in Australia and South-east Asia. In all cases, culture techniques were introduced from Japan based on methods used with the Japanese pearl oyster, *P. fucata*. The main interest in culture is the production of pearls from shells that have had an artificial nucleus surgically inserted into the gonad. The methods used to rear pearl oysters are simple and involve only low technology and cost. However, the seeding technique is highly specialised and remains the domain of Japanese technicians, despite attempts to train nationals of other countries in the methods used.

The culture of *Pinctada* species for pearl production is now an economically important industry in Australia and French Polynesia, and is becoming so in the Cook Islands. The production of shell, and of young oysters for sale to pearl producers, are related industries in these locations. Other Pacific Island countries are becoming increasingly interested in the economic development potential offered by pearl oyster culture, especially for rural or outer island areas.

A major constraint on culture operations is the continued reliance on naturally produced juveniles. Despite years of experimentation, hatchery techniques for these species have not yet been successfully established in the region. There are at least two Japanese-operated hatcheries for *P. maxima*, and the successful closed cycle-production of *P. margaritifera* juveniles has been achieved at one hatchery in Japan and, more recently, in India (N. Sims, pers. comm.). Because of the commercial importance of these techniques, it is unlikely that information about them will become freely available in the region.

The issue of restocking pearl oyster populations is not clearly distinct from pearl oyster culture. Where wild populations have been reduced or eliminated by overfishing, there may be a desire to re-establish these populations to support local capture fisheries. Given the absence of readily available hatchery techniques at present, the only realistic option for ARE is to enhance the reproductive success of the wild population. This might be approached in several ways: by concentrating wild-collected adults to improve spawning synchronicity and fertilisation rates; by deploying spat collectors to provide improved conditions for larval settlement; and husbandry of the juveniles to improve early survival. The techniques used in such a stock re-establishment programme - harvesting of wild adults, deployment of spat collector lines, deployment of grow-out lines or trays, etc - would not be very different from those used in a commercial pearl oyster culture operation. A stock re-establishment programme that met with success could evolve into a commercial culture operation for shell and, ultimately, pearl production.

Attempts to restore pearl oyster stocks by re-introducing shell from elsewhere have been occasionally carried out. Examples include the attempted introduction of *P. maxima* into Suwarrow in the Cook Islands, and Christmas Island lagoon in Kiribati (Sims et al, 1990 in press), and into Tonga. These transplantation attempts have generally been unseccessful, and it seems that introduction of small numbers of adults is unlikely to be a feasible way to restock lagoons with pearl oysters unless supported by husbandry of the animals and, especially, collection and rearing of the spat they produce.

An important feature of commercial pearl farms is that they are not thought to significantly improve the process of natural recruitment. Pearl-oysters are protandrous (male-first, changing to female later) hermaphrodites. The surgery required to insert the artificial nucleus in the gonad of a pearl oyster results in sex-reversal of female oysters to males in 95% of cases. As a result, spawning success among operated pearl oysters is greatly reduced. As long as culture operations rely on juveniles collected from the wild, there will be an ongoing need for a separate viable adult broodstock to provide spat. This may be sustained by protecting wild adults from harvesting, by maintaining a culture operation for non-operated adults, or a combination of both.

3.4 Trochus (*Trochus niloticus*)

Trochus or topshell, *T. niloticus*, is a reef-dwelling gastropod whose shell is used for the production of mother-of-pearl buttons, and for other decorative purposes. A related but less heavy-shelled species, *Tectus pyramis*, is not used for commercial purposes in the region but appears to be gaining acceptance for button-making in Korea (K. Kikutani, pers. comm). The natural range of *T. niloticus* was originally restricted to larger continental lagoons of the Western Pacific, presumably because of the short larval life span of this species, which precludes extensive dispersal. However, numerous deliberate introductions have been carried out, some very recently (Gillett, 1988), and this species is now widespread in the region.

Trochus shell supports fisheries which may be small but which can nevertheless be important to the local economy. This is particularly true in small remote atolls where trochus populations have been established from introductions. Recent growth in demand for this species, and associated price increases, have led to increased harvesting pressure in many areas where it occurs.

Trochus are typically found in the surf zone of ocean reefs as well as in more sheltered but still well aerated lagoon waters. Feeding is by grazing on the algae that colonise dead coral surfaces. The animals are somewhat cryptic and are nocturnally more active, hence harvesting carried out at night tends to be more efficient. Spawning normally follows a lunar cycle in nature, and captive animals will continue to spawn in this manner. Reproductive success is though to be reduced and recruitment diminished when parent stock densities fall below certain limits as a result of poor spawning synchronisation (Bour, 1988).

Trochus larvae usually settle within a few days of fertilisation, metamorphosing in response to a chemical cue thought to be associated with reef algae (Heslinga and Hillmann, 1981). Young trochus achieve a size of about 10 mm shell diameter in about 2-6 months, growth varying widely with location (Bour, 1988). Captive spawning of trochus and the production of postsettlement juveniles has been achieved using simple hatchery techniques and low-technolgy equipment in Palau, New Caledonia and Vanuatu.

The investigation of large-scale juvenile production for restocking natural trochus populations has been advocated by several authors, including Bour (1988), who suggests that the young animals should be grown to a size of 25 to 30mm shell diameter before release. (Heslinga has suggested a release size of 10 mm or more). Bour argues that alternative management measures are difficult to implement, that trochus juveniles are easy to produce, at least on a small scale, and that the sizes of natural populations may be increased beyond their normal limits by restocking.

An important question when considering trochus restocking is that of the different habitat requirements of trochus of different sizes. Juvenile trochus appear to occupy a more restricted habitat than that in which adults are found. The need for smaller crevices in which to hide from predators (to which they are more vulnerable because of their lighter, smaller shells), together with less well-developed resistance to being dislodged by heavy surf, tend to restrict smaller trochus to the rubble-strewn reef flat typically found immediately behind the surf zone of oceanic reefs. Where the area of habitat suitable for juveniles is limited, this may act to constrain growth of the adult population, or its ability to recover from harvesting pressure. This question is of key importance to the issue of restocking of this species, and requires research attention.

Some experiments have been done to monitor growth and mortality in newly-released juveniles. A release in Palau led to total mortality within 48 hours as a result of predation (Heslinga, pers. comm. cited in Hoffschir, Blanc and Meite, 1989). described Four later experiments were carried out in Palau in which small trochus of various sizes were marked before release into sites that were monitored in the days following. The cryptic nature of the animals resulted in no more than a handful from being found again, and thus prevented an objective estimate of mortality. However, in each case substantial numbers of dead shells were discovered soon after the release (within 1 day and 1 month), indicating high initial mortality that may or may not have been sustained. Some dead shells had been crushed, presumably by molluscivorous predators, while others showed pinholes in the shells where they were thought to have been attacked by boring predatory gastropods. Hermit crabs were also noted as potential predators, based on observations of predation in culture tanks. (Kitalong, 1989, pers. comm.).

In New Caledonia, 5,000 juveniles were released at 20 different stations on the reef flat of Lifou island, where *T. niloticus* does not naturally occur. The juveniles were released into piles of coral rubble which had been gathered together on the reef flat to protect them and to make them easier to find later by discouraging their dispersal. Recoveries during subsequent monitoring visits allowed minimal survival rates to be estimated at between 20% and 70% (depending on the station) after 2 weeks, 8.4% (overall average) after 3 months (Hoffschir, Blanc and Meite, 1989) and 0.33% after one year (Hoffschir et al, 1990 [WP 8, this meeting]). Growth rates were typical and the authors were confident that this introduction would lead to the establishment of a viable population, with part of the cohort possibly spawning at the beginning of 1990, and the rest expected to reach reproductive age by the beginning of 1991.

Trochus at a size of 7.8 mm were released on reefs in Okinawa grew to an average size of 24.6 mm after 130 days at liberty. Post-release survival was found to be enhanced by introducing dead coral branches to the culture tanks and allowing the trochus juveniles to attach to them. The branches, with juveniles attached, were then placed on the reef, providing the small trochus with shelter and unbroken protection from predators (Tropical Zone Group, 1989).

Culturing trochus for purposes other than juvenile release programmes is unlikely to become a commercial activity in the near future given the value of the product, the specialised feeding requirements of this species and its relatively slow rate of growth. The economics of conducting trochus spawning and culture for ARE purposes will depend on the value of the local fishery, the economics of rearing the animals to a size at which post-release mortality is acceptably low, and the clarification of the relationship between juvenile habitat and adult population dynamics.

3.5 Green snail (*Turbo marmoratus*)

Green snail (*Turbo marmoratus*) is the largest of a group of turbinid gastropods found on Pacific Island coral reefs. Its heavy shell is sought after for mother-of-pearl and other decorative uses. Several other turbinids (*T. argyrostomus*, *T. crassus*) are used for subsistence food purposes in many areas. Green snails appear to share some biological features and similar ecological niches with *Trochus* species. In fact evidence of direct competition between *Trochus* and *Turbo* is presented by Sims (1985), who notes that residents of Aitutaki in the Cook Islands complained of a reduction in the abundance of the locally consumed small green snail *T. setosus* following the introduction of *T. niloticus*. However, apart from the cats-eye turban (*T. petholatus*) which is sometimes collected for the attractiveness of its heavy operculum, these smaller species are not presently of any commercial interest.

Like *T. niloticus*, *T. marmoratus* occurs in the surf zone of exposed reefs and in slightly less exposed lagoon areas, is restricted in its natural range by short larval life-span and associated dispersal phase, and has been deliberately introduced to several Pacific Island countries with the aim of establishing commercially exploitable populations. Although more valuable than trochus shell, green snail occurs in lower population densities, and is nowhere very abundant. It is partly for this reason that the details of its biology and population structure are less well-understood than are those of trochus.

Yamaguchi (1988) outlines present knowledge of green snail life history and describes attempts at captive spawning and juvenile rearing in Japan. Spawning has been induced by subjecting captive animals to physiological stress (keeping the animals in water that was allowed to become foul and then introducing clean sea water). The larval life-span is short and during this period feeding is not required, which is a major advantage from a hatchery viewpoint. Juveniles have been reared on various algal food combinations which has led to average growth to a size of about 20mm shell width after a year, somewhat less than typical trochus growth rates. This was felt to be less than the growth that would be expected in nature, since feeding conditions for the juveniles were not ideal.

The introduction of green snail to new habitats has not met with the same success as for trochus. Although a number of attempted introductions have been made, only one (to French Polynesia) appears to have been successful (Yamaguchi and Kikutani, 1989). These authors point out the difficulties of obtaining large enough quantities of wild adult green snail to enable further introductions, as well as the quarantine risks that this might entail, and suggest that captive spawning, juvenile ongrowing and subsequent release might be a more feasible approach to establishing new populations of this valuable species in island countries.

Present knowledge and experience of green snail culture is far less advanced than for trochus. However, experimental work is continuing in Japan and two private hatcheries in Okinawa and Tokunoshima have recently commenced seed production. Given the broad similarities between the two species, it is possible that the general principles of culture and ARE that apply to one will also apply to the other.

3.6 Spiny lobster (*Panulirus* species)

Several species of tropical spiny lobster or rock lobster are found in the region and form the basis of important fisheries, usually commercial. These include, in order of importance: *Panulirus penicillatus*, the double-spined rock lobster; *P. versicolor*, the painted rock lobster; and *P. longipes femoristriga*, the bluespot rock lobster. *P. ornatus*, the ornate rock lobster, is the basis of a very important fishery in Papua New Guinea but is of minor importance elsewhere, as are several other *Panulirus* species. These are described in some detail by Prescott (1988), and most of the biological information that follows is taken from this source.

Apart from the special case of the PNG trawl fishery for *P. ornatus*, fishing is normally by hand-collection or spearing while diving, usually at night when they are most active and range over the reef. Spiny lobsters, especially *P. penicillatus*, shelter in inaccessible caves and crevices in the daytime and are thus difficult to gather. Normal lobster habitat varies among species but typically involves well developed reefs with good live coral cover and adequate vertical or three-dimensional relief. Typical densities of *P. penicillatus* are around 100-150 animals per kilometre of reef edge (Prescott, 1988). Growth is resonably well documented in most species and has permitted estimates of natural mortality to be made, as detailed in Prescott (1988).

Although the larval and reproductive biology of tropical species have not been studied in detail, they are presumed to have similar characteristics to temperate water members of the same genus that have been studied. The sexes are separate, and no sex reversal has been observed. Reproductive activity continues year round close to the equator, but may be restricted to warmer seasons at higher latitudes. After mating the female incubates the eggs until they hatch, normally within 3 weeks to one month. The larval period is extended in palinurids, lasting between 4 and 22 months and typically being 3-9 months for *P. ornatus*. During this period the early larvae, called phyllosomata, grow through several stages, or instars, probably around 9, before moulting into a final pre-settlement stage, the puerulus. Phyllosomata may be carried many miles during this period: *P. penicillatus* phyllosomata have been found over 2000 nautical miles offshore of the nearest likely source of origin (the Galapagos Islands), and probably represent the most extreme case of extended larval life span and distribution among the tropical panulirids (Johnson, 1974).

During the puerulus stage of the lobsters larval life, constant, quite high swimming speeds (up to 46 cm per second) may be maintained. This stage in the lobsters life history probably plays an important role in determining recruitment to different fisheries. While lack of shelter may limit lobster abundance on some reefs, the majority appear to support lobster populations at levels below the carrying capacity of the reef. The rarity with which juvenile lobsters are observed suggests that rates of settlement are generally low, even taking into account the cryptic nature of the animals. Rates of larval recruitment probably vary significantly betwen different areas, with small remote reefs presumably receiving fewer recruits than reefs closer to areas with a large total population size and substantial reproductive output.

Although fishing activities have significantly reduced lobster densities in some areas, it is difficult to recommend meaningful management measures that may alleviate this situation. In most local fisheries in the Pacific Islands the animals mature before they are vulnerable to capture, hence regulation to protect berried females, although it exists almost everywhere, is probably not necessary. Likewise, given the continuous reproductive activity, seasonal restrictions are probably not justified, at least at lower latitudes.

As recruitment appears to be a potential limiting factor affecting the regions spiny lobster fisheries, juvenile release programmes for these species might be beneficial. However the complex and extended larval lives presumed for most of these species would appear to preclude the possibility of producing large numbers of juveniles through aquaculture. There may be a case for studying in more detail the larval development process of the tropical *Panulirus* species to assess their amenability to rearing, and to developing ways to enhance lobster recruitment through the use of spat collectors or other techniques that might enhance the natural juvenile settlement processes.

3.7 Mangrove crab (*Scylla* species)

Mangrove or mud crabs, are present in all Pacific Island countries where mangroves exist, and are used for subsistence purposes wherever they occur. In addition, they support commercial fisheries of varying importance in several countries including Papua New Guinea, Solomon Islands, New Caledonia, Fiji, Federated States of Micronesia and American Samoa, as well as in Australia.

Originally considered a single species, *Scylla serrata*, taxonomists now distinguish three species of mangrove crab (*S. serrata*, *S. oceanicus* and *S. paramamosain*) all of which are similar in appearance. The distributions of the three species and their relative fisheries importance is not well known at this time.

Adult crabs are found among the roots of mangroves or in burrows between them. Fishing is usually by hand-collection, but is also occasionally carried out using traps or nets. Regulations have been established in most countries to protect breeding adults and to conserve stocks. These include size limits, seasons, and prohibitions on the sale of soft-shelled (newly moulted) crabs or berried females. There are nevertheless concerns about the increasing amounts of mangrove crab landings in a number of Pacific Island countries, including Western Samoa and Fiji (Anon, 1988), and New Caledonia (Delathiere, 1988).

Due to the high value of mangrove crabs, interest in their culture has been consistent in recent years, and there have been numerous private ventures which have attempted to rear wild-caught small crabs to a saleable size. None of these appear to have achieved commercial success in the strict sense: although at least one mangrove crab "farm" operates in Queensland, Australia, its main income is from tourist visits. Recently, the Australian government has experimented with captive spawning and larval rearing of mangrove crabs, with a limited amount of success. A small number of larvae were reared through to juvenile crabs about two months old and released into the wild, although technical difficulties with the culture system resulted in mass larval mortality. It is expected that further trials will result in improved success with juvenile production (Hoshino, 1989).

There are nevertheless several major impediments to the physical and economic success of any type of culture activity based on mangrove crabs. The animals are aggressive and cannibalistic and this results in high mortalities unless they are stocked at low densities. Although technically omnivorous, the crabs prefer high-protein food rather than vegetable matter, and the rate at which they convert food to body weight is low. Because of these features, both food and habitat could become limiting to natural populations at fairly low densities, and would influence the success of ARE programmes. Habitat enhancement may allow higher population densities in the wild and could justify further examination. In more intensive culture activities, both food and artificially enhanced habitat would need to be provided, probably at unacceptably high cost.

3.8 Coconut crab (*Birgus latro*)

Coconut crabs, *Birgus latro*, are the world's largest land crabs, and are part of the hermit crab family. They are harvested everywhere they occur in the Pacific islands for subsistence and, sometimes, commercial purpose.

The life history of *B. latro* is reasonably well known, and is summarised by Fletcher (1988). Although adult crabs live in burrows in vegetated land areas, females release their eggs into the sea, at which time they hatch into zoeal larvae. The larvae undergo four moults, metamorphose into glaucothoe, and leave the water, taking up a terrestrial existence in gastropod shells, belying their hermit crab ancestry. The larvae continue to grow by moulting, ultimately shedding the shell and taking up an adult lifestyle. Adult growth is slow, and larger crabs may be up to 50 years old.

Recruitment of juvenile coconut crabs into adult populations appears to be a rare event and juveniles are seldom if ever observed in the wild. Adult populations suffer rapid depletion even when harvesting is only moderately intense. In some cases populations that have been severely reduced by harvesting do not show signs of recovery even after many years. In Vanuatu, Fletcher (1988) attributes this to high rates of larval loss due to sinking beyond the steep dropoffs that surround these islands, or to competition with other emerging hermit crab larvae.

The apparent role of recruitment in limiting coconut crab population size suggests that juvenile reseeding may be a viable option for supporting "fisheries" for these animals. Fletcher (1988) was able to rear larvae to the glaucothoe stage using only "very primitive apparatus", and suggests that more substantial levels of juvenile production could be achieved with a better rearing facility. He points out, however, that this is a long-term measure that should be considered alongside other activities, including improving public awareness of the threat to the coconut crab resource, and tighter regulation of harvesting based on size limits on quotas.

3.9 Sea cucumbers (various species)

Many species of sea cucumber are used to produce beche-de-mer, a cooked, dried and smoked product consumed in Chinese communities world wide. The Pacific Islands region has been a major supplier of beche-de-mer for over two centuries. A variety of species has traditionally been used for beche-de-mer production, and this is continually being added to as growing levels of demand and associated price increases alter the economics of processing and permit the use of previously low valued species. Conand (1989) reviews the development of beche-de-mer fisheries in the region. Additional information on some countries is contained in Anon (1990).

Traditionally important sea cucumber species are the larger, thick-bodied types including *Holothuria fuscogilva* (white teatfish), *H. nobilis* (black teatfish), *H. fuscopunctata* (elephant's trunk fish), *H. scabra* (sandfish), *Thelenota ananas* (prickly redfish), and *T. anax* (amberfish). These continue to be sought after and to attract the highest prices. However, apart from *H. scabra* (one of the few sea cucumbers that is also a subsistence foodstuff in some countries) these species tend to occur in relatively low densities in widely dispersed populations. They can and frequently have been fished out by local harvesting activities in many locations, particularly small islands and atolls without deeper inaccessible lagoon areas. There is little documentation on recovery rates of sea cucumber populations that have been depleted, but aneddotal information and observations suggest that populations may be able to recover to harvestable levels again remarkably quickly, in some cases within two years.

More recently, lower-valued sea cucumber species, previously only processed incidentally, are being harvested in large quantities in some countries. This group includes *Actinopyga echinites* (deep-water redfish), *A. lecanora* (stonefish), *A. mauritiana* (surf redfish), *A. miliaris* and *A. palauensis* (blackfish), *Stichopus chloronotus* (greenfish), and *S. variegatus* (curryfish). The relatively low value of these species is offset in some cases by the fact that they occur in dense, easily accessible populations in shallow water, and can be collected in large quantities. In Fiji, and possibly in New Caledonia, exports of low-valued beche-de-mer types now exceed exports of traditional high-valued types in terms of quantity if not of total dollar value (Preston, Vakamoce, Lokani and Viala, in press).

Several Pacific Island governments (Papua New Guinea, Tonga, Marshall Islands) are presently encouraging the development of beche-de-mer processing activities in order to take advantage of recent price increases for most product types. In other countries, production is increasing as a result of private enterprise without the need for government support. Processing, which is generally carried out at the village level in rural areas, provides income-earning opportunities to rural dwellers, often in situations where there is little or no developed infrastructure to support other economic activities. Consequently, there is a widespread desire on the part of

Pacific Island governments to see the sea cucumber resource exploited in a sustainable fashion rather than according to the "boom-and-bust" cycles that have characterised these fisheries, particularly those for the high-value species, in the past.

Despite several attempts to elucidate the basic biology of the commercial sea cucumbers of the region, little is known about reproduction, recruitment and growth in most species. Holothurians are notoriously difficult to tag, and tagging studies have generally not yielded a good understanding of movement, growth or mortality. Their contractile bodies are difficult to accurately measure in a standard way, and size frequency data do not lend themselves to analysis, since many populations appear to be unimodal and do not display expected patterns of modal progression. Fissiparity (the ability to reproduce by asexual division) in some species further complicates the analysis of length-frequency data. Holothurians often die or exhibit negative growth when kept in captivity, and studies of captive animals have not yet yielded good data on growth.

Despite these difficulties, research has been carried out and is continuing on key species within the region. Studies of the population dynamics of selected species have been carried out in New Caledonia (Conand, 1989). The reproductive seasonality of some species has been documented from New Caledonia (Conand, 1989), Papua New Guinea (Shelley, 1982) Fiji (Vuki, pers. comm.), Guam (Richmond, 1989) and the Federated States of Micronesia (Hopper, pers. comm.). Field studies of growth and reproductive behaviour are ongoing in Papua New Guinea (Lokani 1990, in press). More detailed studies of the reproductive biology of *T. ananas*, *A. mauritiana* and *H. fuscogilva* are presently under way in Guam (Richmond, 1989). Initial attempts to rear captive bred larvae of these species have been encouraging, and are being carried out specifically to assess their aquaculture and, ultimately, restocking, potentials.

In Japan, hatcheries for the Japanese sea cucumber *Stichopus japonicus* (which does not occur in the SPC region) have been operating for over 10 years and several ARE programmes are in operation for this species. At the present time, however, there is no established hatchery technology demonstrated to be capable of producing juveniles of, or of rearing in captivity, any of the holothurian species presently being exploited in the Pacific Islands region.

There is inadequate data on all aspects of holothurian biology and this prevents any realistic assessment of the true potential of these species for culture or ARE activities. Areas where additional information is required vary among species but include: fecundity and reproductive behaviour; factors influencing fertilisation, larval development (including feeding) and survival; larval settlement and recruitment; feeding and growth (including, for some species, density-dependent effects); and factors affecting natural mortality. Further research on these topics will be necessary before any type of sea cucumber culture can be envisaged.

4 Conclusions

A number of Pacific Island fisheries may benefit from ARE programmes. However, experience elsewhere, as well as our knowledge (in some cases quite limited) of the biology of the animals in question suggest that a cautious approach should be taken to ARE. Particular areas of concern that emerge from the information presented above are as follows.

ARE needs to be considered as part of an overall management approach and not as an alternative to management. Overseas experience all underlines the fact that simply releasing large numbers of juveniles into the fishery will not produce population increases unless the fishery is also subject to some form of management that allows the released juveniles to reproduce and thus make a contribution to population growth. ARE should be viewed as one of a set of management tools, and not as an easy way out of management. However, the development of aquaculture programmes for ARE purposes has the side benefit of improving the opportunities to study the species in question. This may in turn lead to a better understanding of the species' larval biology and early life history, which in turn may enable th development of meore effective management approaches.

The reproductive and larval biology of the species will be major determinants of whether ARE is likely to have biologically significant results. ARE is likely to be of most benefit to populations in which recruitment is a limiting factor. This may be because the population has been so reduced that reproductive success has been impaired (giant clams, pearl oysters, possibly trochus) or because specialised habitat requirements or larval life history characteristics impose a "filter" on the number of juveniles that are able to recruit to the adult fishery (tropical spiny lobster, possibly trochus).

ARE is likely to be most cost-effective for species that achieve large sizes (or high values) relatively quickly, and with low rates of mortality. Slow-growing species, or those that have a high ratio of mortality to growth, or those that do not achieve a large size or high value, will be less viable candidates for ARE from an economic viewpoint. Most organisms show higher rates of both growth and mortality early in their lives, and these drop in different ways as the animals age. In most cases the economics of ARE will be determined by the cost of raising the animals to the point where the ratio of mortality to growth falls to an acceptable level.

The contribution of ARE programmes to wild populations can be extremely difficult to assess. This has been demonstrated in well-funded, high-technology juvenile release programmes in Japan, as well as in experiments with trochus carried out within the region. In many cases there has been no demonstrable effect on yields from wild fisheries despite releases being carried out over many years, and the expenditure of large amounts of research effort and funding.

In summary, the issue of aquacultural resource enhancement is a "Pandora's Box" that contains as many potential dangers as it does benefits. The issues relating to ARE need to be assessed for each species in each situation, and it certainly should not be assumed that the success of any given ARE programme is a foregone conclusion. ARE is of potential benefit to a certain number of fairly specific situations. It will be necessary to evaluate each case fully in order to ensure that research and management effort continues to be well directed and that the use of available funding is optimised by ensuring that improvements in the management of the regions marine resources are real and not simply illusory.

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