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Pearl Oyster

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FFA Report 92/63

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CHAPTER 12

PEARL OYSTER

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I. INTRODUCTION

Two species of the pearl oyster genus *Pinctada* (Table I) are commercially significant to the South Pacific. The black-lip pearl oyster, *Pinctada margaritifera* (Linnaeus, 1758) ranges from Baja California to the Eastern Mediterranean Sea (Jameson, 1901; George, 1978: Table II). Black-lip shell is fished throughout the region and black pearls are cultured in French Polynesia, the Cook Islands, Fiji and Okinawa. *P. maxima* (Jameson, 1901), the gold-lip or silver-lip, ranges from Burma to the Solomon Islands. It is cultured for white pearls in Australia and South East Asia. Gold-lip has also been cultured at various times in Papua New Guinea, Solomon Islands, Palau and Tonga (George, 1978; Uwate, *et al.*, 1984). The two species are distinguishable by colour (Hynd, 1955); *P. margaritifera* has a black external shell surface and black non-nacreous border, where *P. maxima* is yellow, gold or silver.

The winged, or brown-lip pearl oyster, *Pteria penguin*, is fished for shell in the Solomon Islands (Philipson, *unpubl. data*). It can produce half pearls, although early culture trials in Tonga were unsuccessful (Uwate, *et al.*, 1984). A smaller species, *Pinctada maculata* (Gould, 1850), is also found through the Pacific Islands (Hynd, 1955), and is fished in some areas for the small, baroque natural pearls. The shell is of no value, however, and there is little potential for culture of the species. *P. albina* (Lamarck, 1819), is cultured in Shark Bay, Western Australia (Hancock, 1989) and *P. radiata* (Leach, 1814) culture is being trialled on the Australian Great Barrier Reef. However the potential for culturing these species in the Pacific Islands is not known.

INSERT TABLE I AND II

II. LIFE HISTORY AND POPULATION BIOLOGY

HABITAT

P. margaritifera occurs in lagoons, bays and sheltered reef areas to around 40 m depth, but is most abundant just below low-water. Strong byssal threads attach the oyster to rocks or other oysters. *P. maxima* is occasionally found on reef flats but its greatest abundance is between 10m and 60m on the open shelf areas of continents and large islands (Hynd 1955). *P. maxima* juveniles are anchored by byssal threads, but lose their attachment in later life.

Pearl oysters are non-selective filter-feeders (Mansour and Gabal, 1980; Nasr, 1984; Chellam, 1987; Jacob, *et al.*, 1980). High turbidities may exclude *P. margaritifera* from closed lagoons or from areas of heavy terrestrial run-off. Temperature limits both species to warmer tropical regions.

Lagoon water quality influences sizes, growth rates, and shell colour and quality in *P. margaritifera* (Galtsoff, 1933; Anon, 1956c; Ranson, 1957; Domard, 1962; Service de la Peche, 1970). Strong currents also promote faster shell growth (Kent, 1890, 1893; Galtsoff, 1933; Kafuku and Ikenoue, 1983).

REPRODUCTION

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P. maxima and *P. margaritifera* generally reach maturity at two years of age. Initially, the majority are males, but protandric sex changes usually result in an even sex ratio by the fourth or fifth year (Millous, 1977).

Temperature is the main influence on sexual development and spawning patterns (Tranter, 1958b; Millous, 1980; M. Coeroli, *pers. comm.*). Spawning is usually not limited to distinct seasons and protracted spawnings may occur throughout the year. The period of greatest spawning intensity for *P. maxima* is summer (Tranter, 1958b). *P. margaritifera* usually exhibits two periods of maximum spawning (Tranter, 1958a; Coeroli, *et al.*, 1982). Marked seasonal temperature changes produce more discrete spawnings in higher latitudes.

RECRUITMENT

The planktonic larval stage in *P. margaritifera* may extend to four weeks (Coeroli, *et al.*, 1982), but is somewhat shorter (around three weeks) in *P. maxima*. The larvae are obligate planktotrophs after one or two days. *P. margaritifera* and *P. maxima* larvae have relatively narrow physiological tolerances. Larvae settle out onto suitable available substrate, but retain some motility before beginning to secrete byssal threads.

Age-fecundity patterns, density-dependant effects, and larval and juvenile survival rates are not well understood. Larval drift patterns are difficult to predict, and wind-driven eddies may cause highly patchy spat-falls in enclosed lagoons. Spat-collector records for *P. margaritifera* (Coeroli *et al.*, 1982; Cabral, *et al.*, 1985; Sims, *unpubl. data*), and observations of wild stocks (*e.g.*: Hornell, 1914; Alagarswami, 1977) suggest that recruitment fluctuates from year to year. Crossland (1957), however, obtained consistently high *P. margaritifera* spatfalls, throughout the year, over a fourteen year period on collectors in the Red Sea.

GROWTH

Growth rates vary markedly between individuals, and between locations (Chellam, 1978; Yoo, *et al.*, 1985; Sims, 1990b). Representative von Bertalanffy parameters are around $K = 0.52$, and $L_{\infty} = 155$ mm for cultured *P. margaritifera* (Sims, 1990 b). L_{∞} is between 200 mm and 250 mm for *P. maxima* (Sagara and Takemura, 1960; R. Dybdahl, *pers. comm.*).

The rapid initial growth results in shell diameters of between 100 - 120 mm after two years in *P. margaritifera* (Coeroli *et al.*, 1982; Sims, 1990b), and 100 - 160 mm for *P. maxima* (Sagara and Takemura, 1960; R. Dybdahl, *pers. comm.*). Subsequent growth consists mainly of increasing shell thickness, with the oyster continuing to secrete nacre (the pearl material) throughout its life.

Growth rings have been found in shell sections of *P. maxima* from North-Western Australia (R. Dybdahl, *pers. comm.*), where there is a marked annual temperature variation. Rings have not been found in shells from other locations or in other pearl oysters (Hynd, 1955; Chellam, 1978; Sims, 1990b).

MORTALITY

Pearl oysters suffer greatest mortalities as larvae and immediately after settlement. Predation in the plankton is high and many spat are carried by currents away from suitable benthic habitats. Juvenile predation produces skewed or bimodal size-frequencies (Galtsoff, 1933; Sims, 1989). The large growth processes in juvenile *P. maxima* and *P. margaritifera*

are for protection from predators (Crossland, 1911), and are lacking in the smaller, faster-growing *Pinctada* species.

Predation by fish, octopii and gastropods is the main cause of natural mortality (M) in adults (Herdman, 1903; Shipley and Hornell, 1904; Allen, 1906; Crossland, 1911, 1957; Reed, 1966; Intes, 1984). Intes (1984) used $M = 0.1 - 0.2$ as an approximation for *P. margaritifera*, with a life-span of up to fifteen years. Sims (1990b) estimated natural mortality of *P. margaritifera* at 0.11.

Shell borers include sponges (*Cliona* sp.), bivalves (*Lithophaga* sp.) and polychaetes (*Polydora* spp.) (Coeroli, 1983; Reed, 1966; Crossland, 1957). *Polydora* infested 75 percent of *Pinctada margaritifera* cultured in Palau (Takahashi, 1937). Older oysters are more prone to borer attack, but regular shell cleaning can reduce the problem on farms (Mohammad, 1972; 1976).

III. THE FISHERIES

PEARL SHELL FISHERIES

P. margaritifera and *P. maxima* are the largest species in the genus, with thick nacreous shells (Mother-of-Pearl, or MOP). Pacific Islanders traditionally used pearl shell for fish hooks, tools and ornaments (Hedley, 1899; Beaglehole and Beaglehole, 1938; Skinner, 1935; Macgregor, 1935; Buck, 1932). Today it is used in jewelry and the button industry.

Commercial fisheries for black-lip shell have flourished periodically throughout its range. The most productive lagoons are in the Tuamotu-Gambier Archipelago of French Polynesia and the Northern Cook Islands. Black-lip shell is also produced in notable quantities in Solomon Islands, Fiji, and Papua New Guinea (Table III).

INSERT TABLE III

Methods: Free-diving is still the main method used in most Pacific fisheries. Shot-lines are used in Polynesia to aid descent and ascent, allowing some divers to reach 40 m (Sims, 1989). Hard-hat and hookah diving machines were once widely used, but their use is now generally proscribed.

Markets: The South Pacific and Australia provide perhaps one quarter of all MOP, including trochus shell (Philipson, 1989). Worldwide annual production of MOP from pearl oysters is around 1,200 tonnes (*ibid.*).

Annual pearl shell production from the South Pacific region is valued in excess of US\$1 million. The value of pearl shell has increased over the past decade. Black-lip shell from Solomons Islands, for example, has increased from US\$741 per tonne in 1981 to US\$5,531 per tonne in 1989 (Skewes, 1990). The long-term prospects for continued high returns are good, with the limited supply making price declines unlikely.

Expanded production of button blanks within the region could double the value of shell exports as most shell is currently exported unprocessed (Philipson, 1989). In addition, some potential for export of dried pearl oyster meat to the South East Asian market exists.

PEARL CULTURE

Natural pearls are rare in *P. margaritifera* and *P. maxima*, but both species produce large cultured pearls. Pearl culture developments have wide-ranging benefits to farmers, island communities and national economies, yet require minimal capital or technical support. In the Cook Islands, one local family began spat-collecting and shell culture in 1982. By 1990, there were more than one hundred local farms on Manihiki alone (Sims, 1990a).

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Pearls are the ideal export commodity: they are non-perishable, shipping costs are negligible, and lucrative markets are well established.

Methods: Pearl culture was first developed by the Japanese early this century (Matsui, 1957; George, 1978; Hollyer, 1984). The general principles of culture and grafting were first "kept in absolute secrecy" (Wada, 1953 in George, 1969), but have since become more widely known (Tranter, 1957; George, 1969, 1978; Mizuno, 1983; Coeroli and Mizuno, 1985). Techniques for spat collection and culture have been described for *P. maxima* (George, 1978; Dybdahl and Rose, 1986), and *P. margaritifera* (Crossland, 1957; Reed, 1962, for the Red Sea; and Service de la Peche, 1970, Coeroli, *et al.*, 1984, and Sims, 1988a and c, for Polynesia). (Also *P. fucata martensii*, in Kafuku and Ikenoue, 1983, and Hollyer, 1984; and *P. fucata*, in Alagarswami, 1987).

Black-lip culture techniques for the Pacific were first developed in French Polynesia. Spat-collectors consist of bundles of local hardwood, nylon rope, gauze or plastic sheet strung on sub-surface lines (Fig.'s 1 and 2). Juveniles are also collected from wild stocks by diving. Adults are placed in panel-net pockets, or drilled and tied to lines. These are then suspended from platforms on the bottom, or from floating rafts or bouy-lines (Fig. 3).

INSERT FIGS 1, 2 and 3

First seedings occur around two years of age. The pearls are harvested after 18 months or two years, when the nacre coating on the bead is around 2 mm thick. Individual oysters may be reseeded and can produce up to three pearls during their life. Experienced Japanese technicians generally provide best results, and are still used widely throughout the industry.

Markets: Current annual production from the Australian and French Polynesian culture industries is valued respectively at over US\$70 million and US\$40 million (based on Japanese import values, 1989: Table IV). The Cook Islands industry is currently worth US\$4 million annually.

INSERT TABLE IV

Demand for pearls is increasing. Black pearl values could further improve as expanded production increases product awareness.

IV. RESEARCH PRIORITIES

Prevention of overfishing and evaluation and development of pearl culture are priorities for most Pacific Island countries with pearl oyster stocks (see Table III). Routine survey techniques are required, and spat-collector and growth trials need to be conducted.

SURVEY METHODS

Earlier surveys were usually conducted by test fishing, with highly subjective results. Refinement of SCUBA and hookah survey methods has permitted objective assessment of stocks of *P. margaritifera* in Polynesian lagoons (Intes and Coeroli, 1982; Intes, *et al.*, 1986; Sims, 1989, 1990b), and *P. maxima* in Australia (Penn and Dybdahl, 1988; K. Colgan, *pers. comm.*). Densities, distribution, and age- or size-structure of populations and descriptions of associated benthic assemblages and bottom-types are among the primary objectives of most surveys.

Objective surveys can provide baseline measures of abundance, but permanent survey sites are needed for monitoring stock changes. Objective surveys are inappropriate for regularly determining sustainable harvest quotas. Results are inherently imprecise because of the wide variability in densities between randomly selected sites (Sims, 1989, 1990b). Permanent sampling sites remove the between-site variability, but both fishing and

recruitment remain highly patchy. Large sample areas are therefore needed to detect changes in abundance, particularly under moderate fishing pressures, or over short periods.

GROWTH STUDIES

Shell dimensions: Shell diameter (dorsoventral measurement, or D.V.M.) is a simple measure to use in the field and is a good indicator of growth performance. Coeroli and Mizuno (1985) validated the use of D.V.M. in comparative culture trials by relating shell growth to pearl nacre deposit rate and value. Although heel depth usually increases linearly with time, it is also affected by environmental influences (Sims 1990b). Both D.V.M. and heel depth vary within the same age-class, even when cultured under identical conditions.

Growth trials: Tagging in mark-remeasure growth studies is easy for pearl oysters: shells are drilled as for culture, and the tags tied through the hole. Underwater glues do not stick well to the smooth exterior shell surface. Theft and predation can cause problems in growth trials, but protected areas, co-operative farmers, enlightened officials and public education can all minimise losses.

Growth is often underestimated in tagging trials because of the high frequency of non-nacreous border loss. Negative growth may occur in individuals or with small sample sizes, probably due to grazing or predatory fish breaking the shell border. Exclusion experiments are difficult because restricted water movement may cause slower growth (Nicholls, 1931).

Linear increments can only be used to compare growth between trials for single age-classes. For oysters of unknown or mixed ages, confidence limits and significant differences for von Bertalanffy growth parameters and ϕ' (Pauly and Munro, 1984) have been determined by comparing Ford-Walford plots (Sims, 1990b). Use of the Beverton-Holt model of optimum yield-per-recruit is validated by the observance of the cube law of length and weight (Galtsoff, 1931; Coeroli, 1983; Fig. 3, in Sims, 1990b).

POPULATION DYNAMICS

Permanent survey sites are best for long-term monitoring of stocks. Catch data can be extrapolated to give fishing mortalities, but real measures of natural mortality and recruitment require survey sites set up in protected areas.

The patchy patterns of spat-falls across lagoons and over time make it difficult to predict the best times and locations for collector deployments. Collector trials are useful in lagoons of unknown potential but research should otherwise simply document results from commercial collectors. Suitable collector materials have already been identified (Coeroli, *et al.*, 1984), and further developments are probably best left to the initiative of farmers.

Under normal conditions, larger, more fecund oysters should maintain an even sex ratio in the wild. Pearl implantation may disrupt the normal reproductive development of oysters (M. Coerloi, *pers. comm.*), and the degree and pattern of protandry may vary for different situations.

FISHING IMPACTS AND PRODUCTION

Sustainable yields for the Tuamotu-Gambiers atolls in French Polynesia have been estimated using approximations of original abundances (Intes, 1984). Effort and fishing power are difficult to quantify, however, making production records, catch-per-unit-effort and test-fishing data all poor indicators of virgin abundance.

Knowledge of the distribution of fishing effort and impacts is useful for establishing reserves

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or closed areas. Effort is always difficult to quantify as catch rates vary widely between individual divers and between sites. Diver-hour is probably the best unit. Mandatory logbooks (in licensed fisheries) or creel census surveys can be used where divers are less willing to disclose catch information.

There is usually no attenuation of fishing effort (and oyster densities or sizes) away from villages because of the high value of the catch. Where free-dive fishing is heavy, shell densities and diameters generally increase with increasing depth. Heavier fishing also produces smaller average sizes over successive years (Sims, 1990b).

Although pearl shell traders are often reluctant to provide production data, they can be a good source of information for village- or island-based fisheries. Estimates of the percentage of stocks fished each year can be calculated from this data when it is used in conjunction with surveys. Customs and export data can also be useful providing information such as the island of origin and weight of shell by grade is included.

V. DEVELOPMENT AND MANAGEMENT

PEARL OYSTER STOCK MANAGEMENT

Early pearl shell fisheries regulations throughout the Pacific were based largely on "guesswork" and "arbitrary" closures (Russell, 1958, p 58; and Anon, 1960). Overfishing was often justified by claims of better growth rates and improved shell quality at lower abundances (Anon, 1956a; Anon, 1956b; Anon, 1959; Noakes, 1959; Powell, 1960; Anon, 1961). In some cases, black-lip stocks have been fished to below self-sustaining levels, and haven't recovered since (*e.g.* Suvarrow Atoll, Cook Islands: Sims, 1989; and Kiritimati Atoll, Kiribati: Sims, *et al.*, 1989).

As growth overfishing should not be the major concern, management should ensure protection of broodstocks and continuing recruitment. Reserve areas, quotas, and other restrictions on effort should be applied rather than minimum size limits.

Permanent reserves: Permanent reserve areas are clearly beneficial. Dense aggregations of large, highly fecund oysters ensure ongoing recruitment to wild stocks and spat collectors. Spawning is more synchronised and fertilization rates are higher. Reserves should be located in areas of high natural densities and close to villages to allow constant community surveillance. Reserves should preferably be on the windward side of lagoons: Millous (1977) found higher reproductive activity there in Takapoto, French Polynesia and the retention of larvae within the lagoon is improved.

Although protected reserve areas have been widely used in traditional fisheries, and are more readily incorporated into modern management (Sims, 1990c), they have not always been supported by divers or island communities. A breeding reserve in Manihiki, Cook Islands, has been ineffectively enforced because the benefits to the stock were not apparent to the local community. While densities increased in French Polynesian reserves over the short-term, recruitment to wild stocks or spat-collectors did not increase (M. Coeroli, *pers. comm.*). Reserves only reach full reproductive potential, with maximum fecundities and densities, after many years. Benefits from periodic closed seasons and rotational closures are therefore limited and long-term or permanent closures are preferable.

The main objection to reserves is usually that dense older shells will foster infestations of 'worms' and other borers. Borers are rarely host-specific, however, and there has been no evidence of increased prevalence in the shell catch due to proliferation of oysters in reserve areas.

Harvest seasons and quotas: Harvest seasons and quotas can be used to restrict effort, but are often applied arbitrarily. The logistical and manpower requirements make annual pre-

harvest surveys on each island an impractical way to determine harvest durations or quotas. Seasons or quotas can be set in advance, using production data and standing stock figures from earlier surveys, but conservative estimates of abundance and sustainable yield should be used. Predicted catch rates should allow for unforeseen increases in shell price or number of divers causing rapid increases in effort.

Enforcement of harvest quotas and seasons is invariably difficult. Actual catches may far exceed quotas due to hoarding of shell or poor monitoring.

Rotational closures have been used throughout French Polynesia (Alexander, 1902; Intes, 1984) and in Penrhyn, Cook Islands (Sims, 1989). In French Polynesia, harvests were rotated between islands. Rotations cause less economic detriment than total closures, but are of less benefit to the stock. Fishing effort is concentrated, rather than reduced.

Live shell quotas limit the taking of stocks for farms in French Polynesia (Intes, 1984) and gradual reductions in quotas have encouraged greater reliance on spat-collectors (M. Coeroli, *pers. comm.*). Farm numbers are also limited by individual quotas in Western Australia, primarily to protect wild stocks (Dybdahl and Rose, 1986; Malone, *et al.*, 1988).

Size limits: Although minimum size limits have been used extensively in pearl shell fisheries, their benefits have not been demonstrated. Limits for *P. margaritifera* have been set at 120 and 132 mm in the Cooks Islands, and 130 mm for most of French Polynesia. *P. maxima* size limits are 115 mm in Torres Strait (Yamashita, 1986) and 120 mm in North Western Australia (Dybdahl and Rose, 1986). However, theoretical optimum size at first harvest may be as small as 110 mm D.V.M. (Sims, 1990b), because of the high juvenile mortalities in the wild, slow shell weight growth, and heavy fouling of older shells. Protection of small oysters is also of little benefit to reproductive capacities, because of their slow, protandric development, and lower fecundity.

Enforcement of size limits has always been difficult. Divers are often unsupportive, perceiving that stocks are overfished when abundance decreases, not when sizes decrease. Juveniles are often "banked" until they attain minimum legal size, or undersized shell is crushed and sold as fragments.

Size limits are also not workable where juveniles are taken for farm stocks. In French Polynesia, a smaller limit of 11 cm is set in Takapoto lagoon (the chief source of spat), compared with 13 cm elsewhere. Size limits apply only to MOP shell in Western Australia (Dybdahl and Rose, 1986). Larger oysters also cannot be taken for MOP on the main pearling grounds south of Broome (R. Dybdahl, *pers. comm.*). Similar maximum size limits could provide some protection to broodstocks, as in trochus fisheries (Bour, *et al.*, 1982; Sims, 1985, 1988b), but again would be difficult to enforce.

Gear limits: *P. margaritifera* broodstocks in deep water can be protected by the prohibition of diving machines, hookah rigs and SCUBA gear. Restriction to free-diving also maximises employment; an important consideration for island economies. Gear restrictions are impractical in *P. maxima* fisheries, as hookah rigs are used exclusively.

Gear limits by themselves are not sufficient protection for black-lip stocks. Despite widespread claims of unfished *P. margaritifera* stocks beyond 40 m (Gug, 1957; Hynd, 1960; Domard, 1962; Intes, 1982), there is no evidence of natural reserves of abundant, large oysters below the range of free-divers (Intes and Coeroli, 1982; Intes, *et al.*, 1986; Sims, 1989).

STOCK ENHANCEMENT

Early spat-collection and cultivation trials were intended primarily to preserve natural stocks through decreasing fishing pressure, increasing settlement success and reducing

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juvenile mortality (Ranson, 1955, 1957; Crossland, 1957; Hynd, 1960; Reed, 1962).

Spat from collectors can be used to re-establish over-exploited stocks, or supplement stocks in reserve areas. Remaining adults can also be aggregated in protected areas to enhance reproductive efficiency. Stock enhancement may be especially useful in open lagoons, where planktonic larval losses and predation are heavy.

Introductions should be used to reseed depleted stocks only where other enhancement methods have proven unsuccessful. Broodstock aggregation and spat collector programmes are more beneficial in the long term. Ongoing transshipments to pearl farms in other lagoons may be commercially viable, but should be carefully controlled (see "oyster transshipments" below).

Transshipments aiming to establish self-sustaining wild stocks in new areas are not likely to be successful. There are no records of introduced pearl oysters becoming established in islands where they were not previously common. With such a long larval stage, pearl oysters were widely dispersed, and stocks became established in all lagoons with suitable habitats. It is therefore unlikely that introductions can overcome the natural limits to distributions.

PEARL OYSTER CULTURE ISSUES

Culture industries in Japan, Australia and French Polynesia have all suffered from over production and overcrowding resulting in heavy mortalities (George, 1978; Hollyer, 1984; Dybdahl and Pass, 1985). Many of the causes, such as disease and pollution, can be improved by better farm management.

Overfishing is also still a problem where farms rely on wild stocks. Spat collectors (as in French Polynesia) and hatchery production (as in Japan) can alleviate these pressures.

Disease control: Persistent, heavy mortalities among pearl farm stocks have occurred in most culture industries, severely limiting profitability. Disease and pollution problems have plagued the Japanese industry since 1962, with over-production resulting in "very high mortalities" and "low quality pearls" (George, 1978, p 41; Hollyer, 1984). Recurring disease problems have accompanied the Australian and French Polynesian culture developments. Stressed or diseased oysters result in low retention rates and poor quality pearls. In addition, mortalities produce greater pressures on wild stocks. In French Polynesia mortalities have spread to wild *P. margaritifera* and other bivalve populations (e.g. *P. maculata*, *Tridacna maxima* and *Spondyllus* sp., M. Coeroli, pers. comm.).

The causative organisms and nature of pearl oyster diseases are still poorly defined. The marine bacteria, *Vibrio harveyi* was identified as a pathogenic agent in *P. maxima* in north western Australia (Pass, et al, 1987). Bacteria (possibly *Vibrio alginolyticus* and/or *Beneckea vulnifica*) are also associated with mortalities in *P. margaritifera* in French Polynesia (Coeroli, 1983), but these may be secondary infections.

Onset of disease is associated with stressing of the pearl oysters, through either transportation from collection site to farm, thermal shock during transshipment, overcrowding of oysters on farms, careless handling practices or the grafting operation itself. Oyster stresses are often linked to overcrowded conditions (Dybdahl and Pass, 1985; Reed, 1985, Lowe, 1986; Pass, et al, 1987). Matsui (1958, p. 526) noted that "the continuous use of the same ground often causes a serious decline in ... production (and) quality", but that the removal of faecal deposits beneath farms helped recovery.

Depletion of phytoplankton in surface waters may impose limits on farm capacities (Intes, unpubl. m.s.), but is unlikely to be the principal cause of ongoing mortalities. The boom in farming in Takapoto, French Polynesia, produced an estimated 1000 percent increase in

demands on surface water primary production (*ibid.*). Unexploited stocks of *P. margaritifera* would have also been concentrated in the shallows, however, with presumably similar impacts on phytoplankton levels. Carrying capacities for *Pinctada* spp. are difficult to model (Dybdahl and Rose, 1986) because of the many unknown physiological and ecological parameters. Further study of pearl oyster feeding and filtration rates is required (see Mansour and Gabal, 1980; Nasr, 1984; Jacob, *et al.*, 1980), but is not a priority for the Pacific Islands.

Farm management practices: Mortalities can be prevented by careful transshipment, stocking and handling practices (Coeroli, 1983; Dybdahl and Pass, 1985; Pass, *et al.*, 1987), but are difficult to control once established. Losses were substantially reduced in Australia following the adoption of new farming procedures (Pass, *et al.*, 1987). Most farms in Polynesia are now shifting from banks and fixed platforms to long-lines, with lower densities, better circulation, and limited detrital build-up on the underlying lagoon floor. Survivorship there has consequently improved (M. Coeroli, *pers. comm.*).

Oyster Transshipments: Transshipments between islands should be carefully controlled to limit the spread of diseases. Oysters stressed by transshipment are more likely to succumb to disease-causing pathogens (Dybdahl and Pass, 1985; Pass, *et al.*, 1987). The disease problems in French Polynesia appear to have been spread among the atoll lagoons by commercial shipments of spat from Takapoto (Reed, 1985).

Transshipments should also protect genetic identities of different lagoons (Blanc, 1983; Blanc *et al.*, 1985; Wada, 1986a and b; Wada, 1987). The diversities between lagoon stocks are increasingly significant for selective breeding trials (Wada, 1987), as hatchery techniques are further developed. Fast-growing oysters could be bred for preferred pearl colours and greater resistance to disease and implantation stresses. Transshipments should therefore be over the smallest possible distances, and in one direction only.

Farm stocks: Pearl farms require continual supplies of oysters from either divers, spat collectors, or hatcheries.

Diving: Where stocks are already overfished for MOP, farming produces further declines. The expansion of farming in Manihiki, Cook Islands, was accompanied by an 18 percent decrease in stock abundance over one year (Sims, 1990b). Catch quotas are still the main limit to growth in the Australian industry (Malone, *et al.*, 1988). Fishing for farm stocks has been gradually phased out in French Polynesia, however, encouraging greater use of spat collectors.

Spat collectors: *P. margaritifera* culture in the South Pacific has developed largely due to successful spat collection. The required materials are inexpensive and readily available, and the methods are simple. Settlements average 50 spat per bundle for hardwood brush collectors (*Pemphis acidula*: AQUACOP, 1982) and reach over 300 per collector for optimum locations and materials (Coeroli, 1983). Over 80 percent of farm spat were taken by collectors in French Polynesia in 1988 (M Coeroli, *pers. comm.*) and spat collectors will work in any lagoon with natural stocks.

Collectors for *P. maxima* have been less successful, with heavy fouling often occurring (Rand Dybdahl, *pers. comm.*). Spat which settled showed poor survival and growth (Dybdahl and Rose, 1986).

Hatchery culture: Commercial hatcheries for *P. maxima* are reported from Torres Strait, Western Australia, Indonesia, Japan and the Philippines. *P. margaritifera* hatcheries provide sufficient stocks for three black pearl farms in Okinawa (M. Yamaguchi, *pers. comm.*). Although the technology is still largely proprietary, some recent successes with black-lip have been reported (Alagarswami, *et al.*, 1989). A hatchery in French Polynesia is now consistently producing 300,000 black-lip spat per year (M. Coeroli, *pers. comm.*).

The physiological and nutritional requirements of the larvae and their long planktonic period make pearl oysters difficult hatchery subjects. Logistical and maintenance problems may make large-scale pearl oyster hatcheries impractical on isolated atolls. Where these constraints can be overcome, small hatcheries could provide spat for farm culture and for reseeding depleted stocks.

Farming and grafting research: As with hatchery developments, advances in farming or grafting techniques are usually considered proprietary. These refinements are best left to private farmers. Demonstration of the correlation between the pearl quality and shell growth (Mizuno, 1983; Coeroli and Mizuno, 1985) allows farming sites and husbandry methods to be evaluated using simple growth trials (*e.g.*: Yoo, *et al.*, 1986; Sims, 1990b).

Despite the expense of hiring experienced technicians, the more reliable results justify their employment in developmental farming stages. It is difficult to obtain training for local seeding technicians, and this should only be a priority in Pacific Islands after farming is well established.

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Fig. 1	A spat collector line in Manihiki, Cook Islands, weighed down by a heavy spatfall of <i>P. margaritifera</i> .
Fig. 2	A single collector from the same spat-line.
Fig. 3	Long-line culture of black-lip pearl oysters in Manihiki, Cook Islands.

Table I. Species of the pearl oyster genus *Pinctada*

SPECIES	SYNONYMS	DISTRIBUTION
<i>margaritifera</i> (Linnaeus, 1758)	<i>cumingii</i> "Black-lip"	Indo-Pacific: from Mexico to Tanzania and Red Sea
<i>maxima</i> (Jameson, 1901)	<i>margaritifera</i> "Gold-lip" "Silver-lip"	Australia South East Asia P.N.G., Solomon Is.
<i>maculata</i> (Gould, 1850)	<i>pitcairnensis</i> <i>panasesae</i>	Pitcairn Is., Polynesia Central west Pacific, Indian
<i>fucata</i> (Gould, 1850)	<i>vulgaris</i> <i>muricata</i> "Ceylon"	Ceylon, India, S.E. Asia Australia and Red Sea, Mediterranean ¹
<i>fucata martensii</i> (Dunker, 1872)	<i>muricata</i> "Akoya" "Japan Lingah"	Japan, Korea and China
<i>radiata</i> (Leach, 1814)		Arabian Gulf, Red Sea Mediterranean ²
<i>albina sugillata</i>	<i>sugillata</i> <i>irradians</i> <i>scheepmekeri</i> "Bastard pearl oyster"	Eastern and Northern Australia, S.E. Asia
<i>albina albina</i> (Lamarck, 1819)	<i>imbricata</i> <i>carchariarium</i>	Shark Bay, West Australia
<i>imbricata</i>	<i>radiata</i> <i>fimbriata</i> <i>albina</i>	Carribbean Americas Florida, Yucatan
<i>chemnitzii</i> (Philippi, 1849)		Australia, India China Sea and Japan
<i>atropurpurea</i> (Dunker, 1852)		India
<i>anomioides</i> (Reeve, 1857)		India
<i>nigra</i>	Dubious status	Red Sea
<i>concinna</i>	Dubious status	Japan
<i>simizuensis</i>	Dubious status	Japan

¹ Early Lessepsian migrant

² More recent Lessepsian migrant

Table II. Sub-species of *P. margaritifera*.

SUB-SPECIES	DISTRIBUTION
<i>typica</i> (Linnaeus)	Ryukyus, Taiwan, Australia, Micronesia and Melanesia, including Fiji.
<i>cumingi</i> (Reeve)	Cook Islands French Polynesia
<i>mazatlanica</i> (Hanley)	Baja California Panama Bay
<i>erythraensis</i> (Jameson)	Red Sea
<i>persica</i> (Jameson)	Persian Gulf
<i>zanzibarensis</i> (Jameson)	East Africa, Madagascar, Seychelle Islands
<i>galtsoffi</i> (Bartsch)	Hawaiian Archipelago

Table III. Annual pearl shell exports (in tonnes) from the South Pacific and South East Asia

COUNTRY	YEAR								
	1980	1981	1982	1983	1984	1985	1986	1987	
Cook Islands	11	35	46	34	111	106	91		114
French Polynesia	22	19	27 ¹						
Solomon Islands	7	9	26	20	46	17	38	39	
Fiji	13	35	7	11	13	10	12	23	
Palau/F.S.M.	10	-	-	3	2	3	11	-	
Papua New Guinea	8	5	1	13	6	4	5	16	
Indonesia	555	770	601	585	449	323	388		
Philippines	381	278	252	292	245	99	137		

¹ Data from Intes and Coeroli (1985); no data available beyond 1982. All other data from Philipson (1989).

Table IV. Annual pearl imports by Japan from the South Pacific and South East Asia (US\$'000)¹

COUNTRY	YEAR	
	1988	1989
French Polynesia	24,900	40,700
New Caledonia ²	1,860	491
Cook Islands	0	444
Papua New Guinea	1,442	0
Tonga	155	0
Australia	45,400	71,350
Indonesia	8,450	11,560
Philippines	5,100	3,800

¹ Source: Weekly Pearl Newspaper (Japanese), No. 1159, 2 March, 1990.

² Probably all re-exported from French Polynesia.

VI. REFERENCES

- Alagarwami, K. (1977). Larval transport and settlement of pearl-oysters (Genus: Pinctada) in the Gulf of Manaar. *Proc. Symp. Warm Water Zoopl.*, UNESCO/NIO, 678-86.
- Alagarwami, K. (1987). Cultured pearls - production and quality. In *Pearl Culture*, (Alagarwami, K. ed.) pp. 107-111. *Bull. Cent. Mar. Fish. Res. Inst.*, **39**. C.M.F.R.I., Cochin, India.
- Alagarwami, K., Dharmaraj, S., Chellam, A. and Velayudhan, S. T. (1989). Larval and juvenile rearing of black-lip pearl oyster, *P. margaritifera* (Linnaeus). *Aquaculture*, **76**(1/2), 43-56.
- Alexander, A. B. (1902). Notes on the boats, apparatus, and fishing methods employed by the natives of the South Sea islands, and results of fishing trials by the Albatross. In *Report of the Commissioner for the year ending June 30, 1901*. Part XXVII. pp. 741-780. U.S. Commission of Fish and Fisheries. Washington.
- Allen, A. W. (1906). Some notes on the life history of *Margaritifera panasesae*. *J. Linn. Soc. (Zool.)*, **29**, 410-413.
- Anon. (1956a). Closing Manihiki Lagoon is unnecessary. *The Pacific Islands Monthly*. **March, 1956**, 47.
- Anon. (1956b). Extending MOP beds in Cook Is. *The Pacific Islands Monthly*. **April, 1956**, 50.
- Anon. (1956c). The Pacific MOP industry. Some regulations need revision. *The Pacific Islands Monthly*. **August, 1956**, 126-127.
- Anon. (1959). Manihiki still closed to divers. *The Pacific Islands Monthly*. **March, 1959**, 119-120.
- Anon. (1960). Getting down to work on Manihiki. *The Pacific Islands Monthly*. **July, 1960**, 115-117.
- Anon. (1961). Manihiki pearl shell season opens soon. *The Pacific Islands Monthly*. **June, 1961**, 149.
- Beaglehole, E. and Beaglehole, P. (1938). Ethnology of Pukapuka. *Bernice P. Bishop Museum Bulletin No. 150*. Honolulu, Hawaii.
- Blanc, F. (1983). Estimation du polymorphisme enzymatique dans trois populations naturelles de nacre (*Pinctada margaritifera*) en Polynésie Française. *C.R. Seances Acad. Sci. III Sci. Vie.*, **297**, 199-202.
- Blanc, F., Durand P. and Shinh-Milhaud M., (1985). Genetic variability in populations of black pearl oyster (*Pinctada margaritifera*, Mollusc, Bivalve) from Polynesia. *Proc. Fifth Internat. Coral Reef Symp.*, Vol. **4**, 113-118.
- Bour, W., Gohin, F. and Bouchet, P. (1982). "Croissance et mortalite naturelle des trocas de Nouvelle Calédonie." *ORSTOM Report. No. 26*. Noumea, New Caledonia. 56 pp.
- Buck, P. (1932). "Ethnology of Manihiki and Rakahanga." *Bernice P. Bishop Museum Bulletin No. 99*. Honolulu, Hawaii. 238 pp.

- Cabral, P., Mizuno K. and Tauru A. (1985). Preliminary data on the spat collection of mother-of-pearl (*Pinctada margaritifera*, Bivalve, Mollusc) in French Polynesia. *Proc. Fifth Internat. Coral Reef Symp.*, Vol. **5**, 177-182.
- Chellam, A. (1978). Growth of pearl oyster *Pinctada fucata* in the pearl culture farm at Veppalodai, India. *Indian J. Fish.*, **25**(1-2), 77-83.
- Chellam, A. (1987). Biology of pearl oyster. In *Pearl Culture*. (Alagaraswami, K. ed.). pp. 13-20. *Bull. Cent. Mar. Fish. Res. Inst.*, **39**. C.M.F.R.I., Cochin, India.
- Coeroli, M. (1983). *Pinctada margaritifera*. In *Milieu lagonaire. Etat des connaissances.*, pp. 1-20. Peche Document No. **7**, E.V.A.A.M., Service de la Mer. Polynesie Francaise.
- Coeroli, M. and Mizuno K., (1985). Study of different factors having an influence on pearl production of black lip pearl oyster. *Proc. Fifth Internat. Coral Reef Symp.*, Vol. **5**, 551-557.
- Coeroli, M., de Gaillande, D. J., Landret, P. and AQUACOP. (1982). Recent innovations in cultivation of molluscs in French Polynesia. *Int. Symp. on Recent Innovations in Cult. of Pacific Molluscs*. La Jolla, December, 1982 (ms).
- Coeroli, M., de Gaillande, D., Landret, J. P. and AQUACOP (D. Coatanea). (1984). Recent innovations in cultivation of molluscs in French Polynesia. *Aquaculture*, **39**, 45-67.
- Crossland, C. (1911). The marginal processes of lamellibranch shells. *Proc. Zool. Soc. Lond.*, No. **72**, 1057-1061.
- Crossland, C. (1957). The cultivation of the mother-of-pearl oyster in the Red Sea. *Aust. J. Mar. Freshwat. Res.*, **8**, 3-49.
- Domard, J. (1962). Les bancs nacriers de la Polynesie Francaise. South Pacific Commission Fisheries Technical Meeting, Noumea, *Technical Paper No. 2*.
- Dybdahl, R. and Pass, D. A. (1985). An investigation of mortality of the pearl oyster, *Pinctada maxima*, in Western Australia. *Fisheries Department of Western Australia Report No. 71*. Fisheries Department, Perth. 78 pp.
- Dybdahl, R. and Rose, R. A. (1986). The pearl oyster fishery in Western Australia. In *Torres Strait Fisheries Seminar*, (A.K. Haines, G.C. Williams, and D. Coates, eds.). pp. 122-132. Port Moresby, February, 1985. Australian Government Publishing Service, Canberra.
- Galtsoff, P. S. (1931). The weight-length relationship of the shells of the Hawaiian pearl oyster, *Pinctada sp.* *Amer. Nat.* **65**, 423-433.
- Galtsoff, P. S. (1933). Pearl and Hermes Reef, Hawaii, hydrological and biological observations. *Bernice P. Bishop Mus. Bull. No. 107*. Honolulu, Hawaii. 49 pp.
- George, C. D. (1969). Techniques of pearl cultivation. *South Pac. Bull.* **19**, 13-9.
- George, C. D. (1978). *The Pearl*. A report to the Government of Papua New Guinea. The Food and Agriculture Organisation of the United Nations and the Asian Development Bank. Samarai, Milne Bay Province, Papua New Guinea. 169 pp.
- Gug, M. (1957). Mother-of-pearl industry in French Oceania. *S.P.C. Quarterly Bull.* **July, 1957**, 19-21
- Hancock, D. A. (1989). A review of the Shark Bay pearling industry. *Fisheries Management Paper No. 27*. Fisheries Dept. of West. Aust. 93 pp.

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Hedley, C. (1899). The Mollusca II: The Pelecypoda and Brachiopoda. *Aust. Mus. Memoir*, **3(8)**, 491-510.

Herdman, W. A. (1903). *Report to the Government of Ceylon on the pearl oyster fisheries of the Gulf of Manaar*. Part I. The Royal Society, London. 146 pp.

Hollyer, J. (1984). Pearls - jewels of the sea. *INFOFISH Mark. Dig.*, **5**, 32-34.

Hornell, J. (1914). An explanation of the irregularly cyclic character of the pearl fisheries of the Gulf of Mannar. *Madras Fish. Bull.*, **8**, 22.

Hynd, J. S. (1955). A revision of the Australian pearl-shells, genus *Pinctada* (Lamellibranchia). *Aust. J. Mar. Freshwat. Res.*, **6(1)**, 98-137.

Hynd, J. S. (1960). Report to the South Pacific Commission on an investigation of the Black-lip Mother-of-pearl Oyster, *Pinctada margaritifera* (Linnaeus) in Manihiki, Cook Islands. C.S.I.R.O. Marine Biology Laboratory. Cronulla, Sydney. 70 pp.

Intes, A. (1982). La nacre en Polynesie Francaise (*Pinctada margaritifera* Linne, Mollusca, Bivalvia). Evolution des stocks naturels et leur exploitation. *Océanogr. Notes et Documents No. 16*. (ORSTOM: Tahiti.)

Intes, A. (1984). L'huitre nacrifere et perliere en Polynesie Francaise: Mutation de l'exploitation. *Pêche Marit.*, **1272**, 161-166.

Intes, A. (*unpubl. m.s.*). Pearl farming responsible for its own death? 6 pp.

Intes, A. and Coeroli, M. (1982). Le stock naturel de nacre (*Pinctada margaritifera* L.) dans l'archipel des Gambiers. *Arch. Oceanogr. ORSTOM*, **82-2**. Centre ORSTOM, Tahiti, French Polynesia. 17 pp.

Intes, A. and Coeroli, M. (1985). Evolution and condition of natural stocks of pearl oysters (*Pinctada margaritifera* Linne) in French Polynesia. *Proc. Fifth Internat. Coral Reef Symp.*, Vol **5**, 545-550.

Intes, A., Laboute, P. and Coeroli, M. (1986). Le stock naturel de nacre *P. margaritifera* L. dans l'atoll de Scilly. *Notes et Doc. Oceanogr. ORSTOM*, **31**. Centre ORSTOM, Tahiti, French Polynesia. 39 pp.

Jacob, P. G., Zarba, M. A. and Anderlini, V. (1980). Biochemical and related features of benthic mud of Kuwaiti waters. *Indian J. Mar. Sci.*, **9(2)**, 100-105.

Jameson, H. L. (1901). On the identity and distribution of the mother-of-pearl oysters: with a revision of the subgenus *Margaritifera*. *Proc. Zool. Soc. Lond.*, **1**, 372-394

Kafuku, T. and Ikenoue, H. (1983). Pearl oyster (*Pinctada fucata*). In *Modern Methods of Aquaculture in Japan*, (T. Kafuku and H. Ikenoue, eds.). pp. 161-170. Developments in Aquaculture and Fisheries Science, **11**. Elsevier Scientific Publishing Co., Amsterdam.

Kent, W. S. (1890). On the experimental cultivation of the mother-of-pearl shell *Meleagrina margaritifera* in Queensland. *Rep. Aust. Ass. Adv. Sci.*, **2**, 541-548.

Kent, W. S. (1893). Pearl and pearl-shell fisheries. In *The Great Barrier Reef of Australia; its products and potentialities*, (W.S. Kent, ed.). pp. 204 - 224. W.H. Allen and Co., London.

Lowe, J. (1986). Report on visit to Ahe (French Polynesia) in December, 1986. m.s. 16 pp.

- Macgregor, G. (1935). Notes on the ethnology of Pukapuka. *Bernice P. Bishop Museum, Occasional Papers*, Vol. **11**. Honolulu, Hawaii.
- Malone, F. J., Hancock, D. A. and Jeffries, B. (1988). Final report of the Pearling Industry Review Committee. No **17**. Fisheries Department of Western Australia, Perth. 216 pp.
- Mansour, K. and Gabal, M. N. (1980). Food and feeding of the pearl oysters and some other lamellibranchs of the Red Sea. *Proc. Egypt. Acad. Sci.*, **33**, 209-216.
- Matsui, Y. (1957). A report on the studies made in Japan on pearl culture. In *Proc. Eighth Pacific Sci. Cong.*, Vol. **III**. pp. 225-228. University of the Philippines, Diliman, Nov., 1953. National Research Council of the Philippines.
- Matsui, Y. (1958). Aspects of the environment of pearl-culture grounds and the problems of hybridization in the genus *Pinctada*. In *Perspectives in Marine Biology*, (A.A. Buzzati-Traverso. ed.). pp. 519-531. U. Calif. Press, Berkeley and L.A.
- Millous, O. (1977). Etude des possibilites de production de naissain de nacre en laboratoire. CNEXO, Centre oceanologique du Pacifique, Taravao, Tahiti. 30 pp.
- Millous, O. (1980). Essais de production controlee de naissain d'huitres perlieres (*Pinctada margaritifera*) en laboratoire. COP/AQ - 80.017, CNEXO/COP, Tahiti, French Polynesia. 32 pp.
- Mizuno, K. (1983). Etude de la greffe de l'huitre periere a levres noires (*Pinctada margaritifera*). *Rapport No. 1*. EVAAM, Tahiti, French Polynesia. 34 pp.
- Mohammad, M-B. M. (1972). Infestation of the pearl oyster *Pinctada margaritifera* (Linné) by a new species of *Polydora* in Kuwait, Arabian Gulf. *Hydrobiologia*, **39**(4), 463-477.
- Mohammad, M-B. M. (1976). Relationship between bio-fouling and growth of the pearl oyster *Pinctada fucata* in Kuwait, Arabian Gulf. *Hydrobiologia* **51**, 129-38.
- Nasr, D. H. (1984). Feeding and growth of the pearl oyster *Pinctada margaritifera* in Dogonab Bay, Sudan, Red Sea. *Hydrobiologia*, **110**, 241-246.
- Nicholls, A. G. (1931). On the breeding and growth-rate of the Black-lip pearl oyster (*Pinctada margaritifera*). *Rep. Gt. Barrier Reef Comm.*, **2**, 26-31.
- Noakes, J. (1959). Pearl shell investigations in the Cook Islands. *South Pac. Bull.* **9**, 29-35.
- Pass, D. A., Dybdahl, R. and Mannion, M. M. (1987). Investigations into the causes of mortality of the pearl oyster, *Pinctada maxima* (Jameson), in Western Australia. *Aquaculture*, **65**, 149-169.
- Pauly, D. and Munro, J. L. (1984). Once more on the comparison of growth in fish and invertebrates. *Fishbyte* **2**, 21.
- Penn, J. W. and Dybdahl, R. (1988). A research vessel survey of pearl oyster and prawn resources north-west of Broome, Western Australia. *Fisheries Report W.A.*, No. **81**. 24 pp.
- Philipson, P. W. (1989). The marketing and processing of pearl shell in South Korea, Taiwan and Japan. In *The Marketing of Marine Products from the South Pacific*, (P. Philipson, ed.). pp. 224-238. Institute of Pacific Studies, U.S.P., Suva, Fiji.
- Powell, R. (1960). SPC sponsors pearl shell investigations in the Cook Islands. *South Pac.*

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Bull. **10**, 34-6.

Ranson, G. (1955). Rehabilitation of pearl oyster beds in French Oceania. *S.P.C. Quart. Bull.* **5**, 22-4.

Ranson, G. (1957). Observations sur l'époque de la reproduction de *Pinctada margaritifera* (L.) et de quelques autres organismes marins dans les Tuamotu. La cause du nanisme de *P. margaritifera* (L.) dans le lagon de Takapoto. In *Proc. Eighth Pacific Sci. Cong.*, Vol. **III**. pp. 1077-1080. University of the Philippines, Diliman, Nov., 1953. National Research Council of the Philippines.

Ranson, G. (1962). *Missions dans le Pacifique - récifs coralliens - huitre perlières*. Editions Paul Lechevalier, Paris. 71 pp.

Reed, W. (1962). The Sudanese shell industry and Red Sea fisheries. Report to the Government of Sudan. *FAO Report No. 1489*. 47 pp.

Reed, W. (1966). Cultivation of the black-lip pearl oyster *Pinctada margaritifera* (L.). *J. Conch.*, **26**, 26-32.

Reed, W. (1985). Brief report on prospects for pearl farm at Ahe: Ste Perle du Pacifique Sud. ms. 7 pp.

Russell, G. (1958). First steps towards a Cook Islands pearlshell farm. *The Pacific Islands Monthly*. **June, 1958**, 57-8.

Sagara, J. and Takemura, T. (1960). Studies on the age determination of the Silver-lip Pearl Oyster, *Pinctada maxima* (Jameson). *Bull. Tokai Reg. Fish. Res. Lab.*, **27**, 7-14.

Service de la Pêche. (1970). Etude sur le industrie nacrifere en Polynesie Francaise. *Bull. Tech.* No. **1**. Service de la Pêche, Tahiti, French Polynesia. 34 pp.

Shiple, A. E. and Hornell, J. (1904). Parasites of the pearl oyster. In *Report to the Government of Ceylon on the pearl oyster fisheries of the Gulf of Manaar*, (W.A. Herdman, ed.). Part **II**. pp. 77-107. Royal Society of London.

Sims, N. A. (1985). The abundance, distribution, and exploitation of *Trochus niloticus* L. in the Cook Islands. *Proc. Fifth Int. Coral Reef Symp., Tahiti*, **5**, 539-544.

Sims, N. A. (1988a). Pearl Oyster resources in the South Pacific: Research for Management and Development. *Workshop on Pacific Inshore Fisheries Resources*. Working Paper No. **4**. South Pacific Commission Noumea, New Caledonia. 25 pp.

Sims, N. A. (1988b). Trochus research in the Cook Islands, and its implications for management. *Workshop on Pacific Inshore Fisheries*. Background Paper No. **37**. South Pacific Commission. Noumea, New Caledonia. 13 pp.

Sims, N. A. (1988c). Pearls and Pearl Oysters : Poe e parau. *Cook Islands Fisheries Resource Profile No. 2*. Ministry of Marine Resources. Rarotonga, Cook Islands. 10 pp.

Sims, N. A. (1989). A survey of stocks of the black-lip pearl oyster, *P. margaritifera*, in the Cook Islands. M. Sc. (Qual.) Project Report. U.N.S.W., Kensington, Australia. 47 pp.

Sims, N. A. (1990a). Discussing and drafting a National Pearl Oyster Fisheries Management Plan. Report to the Cook Islands Government and U.S.A.I.D. (U.S.A.I.D., Suva). 47 pp.

Sims, N. A. (1990b). The black-lip pearl oyster, *P. margaritifera*, in the Cook Islands. *M.Sc.*

thesis. University of New South Wales. Kensington, Australia.

Sims, N. A. (1990c). Adapting traditional marine tenure and management practices to the modern fisheries framework in the Cook Islands. In *Traditional Marine Resource Management in the Pacific Basin: An Anthology*, (K. Ruddle and R. E. Johannes. eds.). pp. 323-358. UNESCO/Rostsea. Djakarta, Indonesia.

Sims, N. A., Preston, G. L., Yeeting, B. M. and Alfred, R. (1989). Pearl oysters in Christmas Island, Kiribati and the potential for development of a pearl culture industry. Report to the Government of Kiribati and the South Pacific Commission. Noumea, New Caledonia. 16 pp.

Skewes, T. (1990). Marine Resource Profiles: Solomon Islands. *South Pacific Forum Fisheries Agency Report 90/61*. Honiara, Solomon Islands. 52 pp.

Skinner, H. D. (1935). Note on pearl-shell pendants in the Cook Islands. *J. Polynes. Soc.* **44**, 187-9.

Takahashi, K. (1937). Notes on the polychaetous annelid, *Polydora pacifica* n.sp., which bores holes in *Pinctada margaritifera* (Linné). *Contr. Palao Trop. Biol. Station*, **7**, 155-167.

Tranter, D. J. (1957). Technique of pearl culture. *Fish. Newsl.* **16 (9)**, 11-25.

Tranter, D. J. (1958 a). Reproduction in Australian pearl oysters (Lamellibranchia). **IV**. *Pinctada margaritifera* (Linnaeus). *Aust. J. Mar. Freshwat. Res.*, **9**, 509-525.

Tranter, D. J. (1958 b). Reproduction in Australian pearl oysters. *Aust. N.Z. Ass. Adv. Sci.*, 33rd Meeting, Adelaide, Xerox ms.

Uwate, K. R., Kunatuba, P., Raobati, B. and C. Tenakanai. (1984). A review of aquaculture activities in the Pacific Islands region. Pacific Islands Development Programme, East-West Center, Honolulu. 538 pp.

Wada, K. T. (1986 a). Genetic selection for shell traits in the Japanese pearl oysters *Pinctada fucata martensii*, selected for six generations. *Aquaculture*, **57(1-4)**, 171-176.

Wada, K. T. (1986 b). Genetic variability at four polymorphic loci in Japanese pearl oysters *Pinctada fucata martensii*, selected for six generations. *Aquaculture*, **59**, 39-146.

Wada, K. T. (1987). Selective breeding and intraspecific hybridisation - molluscs. In *Selection, Hybridisation, and Genetic Engineering in Aquaculture*, (Tiews, K. ed.). pp. 313-322. World Symposium on Selection, Hybridisation and Genetic Engineering in Aquaculture of Fish and Shellfish for Consumption and Stocking. Vol 1. Schr. Bundesforschungsanst. Fisch. Hamburg.

Yamashita, S. (1986). The Torres Strait pearling industry. In *Torres Strait Fisheries Seminar*, (A.K. Haines, G.C. Williams and D. Coates. eds.). pp. 118-119. Port Moresby, February, 1985. Australian Government Publishing Service, Canberra.

Yoo, S. K., Chang, Y.J. and Lim, H.S. (1985). Growth comparison of pearl oyster, *Pinctada fucata* between the two culturing areas. *Bull. Korean Fish. Sci.*, **19(6)**, 593-598.