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PEARL-OYSTER RESOURCES IN THE SOUTH PACIFIC

Research for Management and Development

by

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ABSTRACT

Pinctada maxima (Gold-lipped, or Silver-lipped Pearl-oysters) and P. margaritifera (Black-lipped Pearl-oysters) form the basis of the major pearl-shell diving fisheries in Pacific islands. These two species also represent considerable potential for pearl-culture industries. Aspects of the biology of the two species and the history and current status of pearl-shell fisheries and pearl-culture industries are reviewed.

Pearl-shell fisheries represent classic examples of over-exploitation of a biologically vulnerable, commercially valuable sedentary resource. Pearl-culture industries are lucrative developments, but almost universally have been disrupted by heavy mortalities of cultured oysters.

The issues surrounding pearl-shell fisheries are discussed in light of these experiences. Minimum size limits have probably been underestimated, and often have been poorly applied. Regulations governing harvest seasons, using periodic closures, quotas or seasonal rotations are essential, but again, have not been successful in sustaining stocks under commercial fishing pressures. Restrictions on SCUBA, hookah rigs, and other underwater apparatus are a useful means of restricting effort in margaritifera fisheries, but are less appropriate for deeper-water fisheries for maxima.

Breeding reserves are a readily established and enforceable means of affording some protection to stocks. Despite their value, they have been of little real value by themselves, on the scale used.

A continuing supply of juvenile pearl-oysters is critical to any successful pearl-culture development programme. Artificial spat-collectors and hatchery culture developments also present possibilities for enhancement of recruitment for pearl-shell fishery stocks or establishment of broodstocks to reestablish overfished populations.

Unfortunately, maxima seems unsuited to artificial spat-collector use. Hatchery culture developments continue to encounter difficulties, but there are unconfirmed reports of recent successful commercial culture of maxima. Cautions are needed, however, with disbursement of hatchery spats, both to retain the natural genetic status of stocks and to prevent the spread of disease problems.

Control of farm mortalities can generally be achieved through improved husbandry techniques. Diseases are still of great concern, however, and have recently become evident in wild stocks of margaritifera, as well as other bivalves, in lagoons in French Polynesia.

Improvements in farm management and pearl-grafting practices continue to be of benefit to commercial culture, and supportive technical research is a continuing priority for the development of established, fledgling or future pearl-culture developments.

CONTENTS

1. THE RESOURCE

1.1 Species Present

A number of species of the pearl-oyster genus Pinctada are found throughout the South Pacific. Pinctada maxima, the "Gold-lipped" or "Silver-lipped Pearl-oyster" is the largest of the genus, with an average weight of shells from larger specimens of 5 lb (2.3 kg) per pair (Hynd, 1955). P. maxima is distributed through the central Indo-Pacific area, from Burma to the Solomon Islands, and forms the basis of the pearl-culture industry in North Western Australia and South East Asia. P. maxima has also been used in culture activities in Papua New Guinea and Solomons, and introduced stock have been cultured in Palau and Tonga (George, 1978; Uwate, et al, 1984).

Pinctada margaritifera, the "Black-lipped Pearl-Oyster" attains maximum sizes of up to 17cm D.V.M. (Dorsi-ventral measurement, or shell diameter - See Fig 1)in Torres Strait (Hynd 1955), and 30cm DVM from French Polynesia (Coeroli, et al, 1982). Specimens up to 9 kg were recorded from French Polynesia by Ranson (1952, in Coeroli, 1983). There are six varieties of margaritifera (Jameson, 1901; in Tranter 1958), found from Baja California to the Eastern Mediterranean Sea (George, 1978). Shellfisheries have flourished throughout this range at various times. Currently, Black-lipped Pearl-Oysters are cultured in French Polynesia, the Northern Cooks, and Fiji.

A smaller species, P. maculata, is also fished in some areas for the small, baroque natural pearls, but the shell is of no value, and there is little potential for culture of the species. It is distributed from Pitcairn Island to the Cocos-Keeling Islands, and attains a maximum shell diameter of only 5.5 cm (Hynd, 1955). Other pearl-oyster species found in the Western Pacific include P. fucata, P. chemnitzii, P. albina sugilata, P. mertensii and Pteria penguin.

This review concentrates primarily on Pinctada maxima and P. margaritifera, which are of greatest significance to the South Pacific as shell-fisheries, and of greatest potential for pearl-culture industries.

1.2 Habitat

P. maxima is found down to 80m depth, and although occurring occasionally on reef flats, greatest abundance is between 10m and 60m depth. (Hynd 1955). Juveniles are anchored by byssal threads, but adults lose their attachment. Adults can often then be found on more soft substrates, and can be readily cultured in trays or baskets.

P. margaritifera is limited to depths of around 40m, but it is naturally most abundant just below the low-water mark. Strong byssal thread attachments are usually maintained throughout the life of the oyster, anchoring it to a solid rock or rubble substrate. If removed, however, the oyster will continue to grow, and can thus be farmed on sand banks or culture lines.

It is in the lagoons of the Tuamotu-Gambier Archipelago of French Polynesia, and in the Northern Cook Group, that P. margaritifera reach greatest abundance. P. maxima, favouring more the shallow 'beds' or shoals offshore from larger land masses has, in the past, been most abundant off North Western Australia, Torres Strait, Papua New Guinea, and the Solomon Islands.

Pearl-oysters are filter-feeders, extracting microscopic phytoplankton from the water column. Their distribution is therefore limited to lagoons or coastal shelves with suitable levels of primary productivity, and low levels of sedimentation. They are also sensitive to water temperature and salinity levels.

1.3 Life History

(a) Reproduction: P. maxima and P. margaritifera are usually protandric hermaphrodites, although protogynic sex changes may occur and intermediate hermaphroditic stages may be found. Full maturity is generally reached in the second year. Initially, the majority are males, but a predominance of protandric sex changes usually result in an even sex ratio by the fourth or fifth year (Millous, 1977). Environmental conditions appear to exert considerable influence over sexuality (Tranter, 1958; Millous, 1977 and M. Coeroli, pers comm).

Spawning is often not limited to distinct seasons, and protracted spawnings may occur throughout the year for both species. The period of greatest spawning intensity for maxima is summer (Tranter, 1958). P. margaritifera usually exhibits two periods of maximum spawning, in summer and winter (Tranter, 1958; AQUACOP, 1982). Fertilization is followed by a planktonic larval stage of three to four weeks duration in margaritifera (Coeroli, et al. 1982); somewhat shorter (two to three weeks) in maxima. The larvae then settle out onto the most suitable available substrate. Some motility, using the byssal foot, is retained for a short while, before the animal begins to secrete byssal threads.

(b) Growth: Initial growth of the pearl-oyster is rapid. Within two years the shell diameter in margaritifera is between 10cm and 12cm (Coeroli et al, 1982; and Sims, unp data). DVMs of between 10cm and 16cm have been recorded for maxima after two years' growth. (Sagara and Takemura, 1960, R. Dybdahl, pers. comm.). Thereafter, growth consists mainly of increasing shell thickness, with L (inf.) (for DVM) of between 14cm and 17cm for margaritifera, and between 20cm and 25cm for maxima (ibid). The oyster continues to secrete nacreous layers (the pearl material) throughout its life, and so external heel depth (See Fig 1), and live weights are often considered better indicators of age in older shell than DVM. In North-Western Australia, where there is a marked annual temperature variation, growth rings evident in shell sections have been found to provide good estimates of age for maxima.(Rand Dybdahl, pers. comm.) Growth rings have not been found in shells of other pearl-oysters.

(c) Mortality: Pearl-oysters suffer greatest mortalities during the planktonic larval stage, and immediately after settlement. Predation in the plankton is typically high for such larvae, and the protracted larval development means that large numbers of spat are carried away from suitable benthic habitats by currents. Molluscivorous fishes, octopii and gastropods (eg Murex anguliferus, in Crossland, 1957) are responsible for most of the natural mortality of pearl-oysters after settlement. Intes (1984) estimated mortality in natural populations of margaritifera at between M = 0.1 to 0.2, with a life-span of up to fifteen years.

Pearl-oyster shells are attacked by a number of borers, ranging from sponges (Cliona sp), to bivalves (Lithophaga sp) and polychaetes (Polydora spp) (Coeroli, 1983; Reed, 1966; and Crossland, 1957). Takahashi (1937, in Mohammed, 1972) asserted that "one third to three fourths of cultured Pinctada margaritifera (of older oysters between five and six years old) were invaded by Polydora pacifica in the South Sea" (ibid, p463).

(d) Recruitment: The factors affecting recruitment, such as fecundity, fertilisation percentages, and larval and juvenile survival rates are not well understood. From spat-collector records in French Polynesia (Coeroli et al, 1982) and the Cooks (Sims, unp data), and fluctuations observed in natural spatfall (eg Alagarswami, undated) it is clear that recruitment varies markedly from year to year. Crossland (1957), however, obtained consistently high spatfalls over a fourteen year period on collectors in the Red Sea.

2. THE FISHERIES

2.1 Pearl-Shell Fisheries

Pearl-shell diving fisheries represent, with few exceptions, classic examples of overfishing, as demonstrated by the histories for Cook Islands', French Polynesia, and Australian fisheries. Regulations have included size restrictions, periodic closures or rotations associated with harvest seasons or quotas reserve areas, gear limitations, and license ceilings. Throughout the Pacific, as elsewhere, however, management programmes have proved woefully inadequate in conserving pearl-oyster stocks, because of their high commercial value and biological vulnerability to overfishing.

European contact with many islands was often initiated by pearl-shell traders, and by the time colonial administrative mechanisms were established, stocks had already been heavily fished (eg Penrhyn, Cook Islands. Sims unp). Although stocks were occasionally allowed to recover (through long closures, or during war periods), re-opening of fishing activities usually resulted in rapid return of stocks to marginal levels, or to economic extinction.

Pearl-shell production figures for some fisheries are given in Table 2. In Australia, in the early 70's, the Torres Strait fishery for maxima continued working, despite 50% of the stock dying (attributed to the Oceanic Grandeur incident in 1970), and "in 1977 (the) stock disappeared in total" Yamashita, (unp). In North Western Australia, natural stocks are "dwindling" (Young, 1985), due to heavy fishing for spat for culture, and incidental collection of MOP.

In French Polynesia, fishing levels since WWII had far exceeded sustainable levels on all major producing atolls but one (Takume), where the stock had been "previously virtually exhausted" (Intes, 1984 p4, and Fig 2). Only in the nearly unfished atoll of Scilly, in the Society Group, can the pearl-oyster population be considered "near virgin state" (Intes, et al, 1986, p6). The uninhabited atoll of Suwarrow, in the Cooks, which at one stage produced yields of up to 4 tons of margaritifera shell off a single coral pinnacle, has been fished to economic extinction. Penrhyn and Manihiki lagoons have also shown marked declines in production.

2.2 Pearl-Culture Developments

Pearl-culture was first developed by the Japanese, early this century. Japanese culture of P. fucata pearls expanded rapidly during the 1950's, from an annual output of 400kg in 1952 (Matsui, 1957) to a record 114.5 tons of pearls in 1961. (George, 1978). In 1982, Japanese exports of cultured pearls, of 46.2 tons, were worth US$208 million (Hollyer, 1984). Major pearl-culture industries are also found in North-Western Australia (worth an estimated A$50 million in 1986/87 (Rand Dybdahl, pers. comm.) and French Polynesia (worth 2,213 million CFP - approximately US$20 million - in 1987).

The techniques of spat collection and cultivation of pearl-oysters are widely known, and descriptions can be found in Kafuku and Ikenoue (und), and Hollyer (1984) for Japan; Crossland (1957) and Reed (1962) for the Red Sea; George, (1978) and Dybdahl and Rose (und) for Australia; and Coeroli et al (1982), and Sims (unp, and in prep) for Polynesia. Pearl-oyster culture represents considerable potential for the development of Pacific Islands. However, the histories of pearl-culture industries both beyond and within the region suggest that cautions be taken with development plans, and that sound management practices are essential.

The major pearl culture industries have all suffered from persistent, heavy mortalities. In Japan, for example, after the record year of 1961, over production resulted, in 1962, in "120 tons of deteriorated and low quality pearls", with "very high mortalities" (George, 1978, p41). Prices plummeted, driving small pearl-farmers out of business, and the "Fisheries agency restricted production by 50%" (ibid). Disease and pollution problems still plague the Japanese Industry (Hollyer, 1984).

The culture industries in Japan, North-Western Australia, and French Polynesia have all suffered from over production and overcrowding of pearl-oysters, resulting in poor quality pearls, increased pearl-graft rejection rates, and excessive pearl-oyster mortalities. These problems are exacerbated where spat-collecting provides insufficient or no seed shell for farms, and natural populations are fished for some or all of the farm stock. Pearl-farmers attempt to make up for the losses resulting from farm mortalities by increasing their standing stocks. This in turn produces further overcrowding, and poor handling on farms. Greater fishing pressures for live shell to make up for shortfalls, increases the detrimental impact on the natural population, which in turn produces even lower spatfalls on collectors. A vicious cycle can rapidly become established.

The techniques involved in pearl-grafting operations were, for many years "kept in absolute secrecy" (Wada, 1953 in George, 1969) "veiled under the protection of a patent" (Matsui ,1957, p225) by the Japanese. The specifics of the method have become more widely known in recent years, and are described in Tranter (1957), George (1969 and 1978), Mizuno (1983) and Mizuno and Coeroli (1985).

Nevertheless, Japanese technicians are still used almost exclusively throughout the industry. Pearl-nucleii retention rates, and final pearl quality are the ultimate bottom lines in a culture operation, and the extra expense of hiring more experienced Japanese technicians is usually considered well rewarded.

3. The Issues

3.1 Pearl-Oyster Stock Management

(a) Size Limits

Minimum size limits appear to have been the most widely applied regulation of pearl-shell fisheries. The ineffectiveness of pearl-shell fisheries management is probably largely due to an over-reliance on, and possibly under-estimation of minimum size limits.

Maximum economic yield per recruit has been widely accepted as the best estimate of optimum size at first capture. This has been identified either by analysis of growth and mortality estimates, compared with the relationship of shell value with age (eg Hynd, 1960), or else by rule-of-thumb. Little consideration appears to have been given to reproductive sustainability of stocks.

Minimum size limits for margaritifera have been set at 5" and 5 1/2" (12 and 13.2cm) shell diameter in the Cooks, and 13cm for most of French Polynesia. For maxima, minimum sizes of 115mm in Torres St (Yamashita, unp) and 120 mm in North Western Australia (Dybdahl and Rose,1986) have been used. Although sexually mature at these sizes, the predominance of males means that the full reproductive potential is not realised until after many years further growth. Under intensive harvesting regimes, there will be reductions in reproductive capacity and recruitment.

Increases may well be warranted in minimum legal size limits, to some level where the reproductive potential is sufficient to sustain the stock under existing levels of exploitation. Alternatively, imposition of maximum size limits, (as has been done fairly successfully with trochus fisheries) would provide protection for the larger, more fecund pearl-oysters. These possess generally less valuable, heavily wormed shells, and would be more valuable if retained as a broodstock to ensure continuing recruitment.

Size-limits in pearl-oyster fisheries face two other major areas of difficulty: 'banking' of undersized pearl-oysters; and pearl-culture requirements for younger oysters.

'Banking' or stockpiling of juvenile pearl-oysters until they attain minimum legal size has been a common practice in some pearl-shell fisheries, and is, in itself, a crude form of pearl-shell farming. However, by increasing in effect, the proportion of catch taken at the minimum size limit banking result in lower mean sizes of shells than would occur under 'normal' fishing patterns. The aggregating of pearl-oysters on the 'bank' is hardly beneficial, as the majority are immature, or males only. As banking activities are covert, it is difficult to obtain any accurate measures of the extent of, or estimate impacts of the practice.

Smaller, younger oysters are both easier to acclimatize to culture conditions, and more suitable for grafting operations, and are preferred as culture stock. In French Polynesia, the need for young culture material produces a smaller minimum size limit on Takapoto of 11cm. In Manihiki, in the Cooks, the recent advent of commercial pearl-farming saw the Island Council lift all size regulations for live oysters. In other areas, minimum size restrictions are applied equally to oysters taken for pearl-shell, or as live culture spats. The inappropriateness of increasing minimum size regulations where the culture industry is concerned, means that other management measures must be applied to better protect stocks.

(b) Harvest Seasons

Most pearl-shell fisheries have employed periodic harvest seasons, using quota limits to retain breeding stocks and allow recoveries between harvests. These attempts were previously severely limited by the lack of applicable data, where projected estimates of allowable catches were obtained largely on a subjective basis. Previous harvest yields, where known, were often the sole statistical records for fisheries, and rarely were meaningful measures of accompanying effort (as number of divers, or harvest duration) available, or applied.

Recently, SCUBA surveys of stocks have been conducted, providing indicators of the status of margaritifera populations in Polynesia. Estimates of densities, distribution, and age- or size-structure of populations have been obtained, as baselines for objective monitoring of stocks (Intes and Coeroli, 1982; Intes. et al, 1986; Sims, elsewhere this meeting). The time and expense involved in conducting such surveys is considerable, however, and they are hardly an appropriate means for determining allowable harvest levels from year to year, on each island.

Intes (1984) obtained estimates of sustainable yield using approximations of mortality and original biomass, for the atolls in the Tuamotu-Gambiers. These were only relevant as historical analyses, as French Polynesia has recently restricted quotas for shell fishing and live spat collection to minimal levels. (ibid, and M. Coeroli, pers. comm.)

In the Cook Islands, harvesting has continued since 1982 without any protection from closures,although in Penrhyn, the Island Council applies a form of rotational closures on an 'ad hoc' basis. Rotational closures have also been used in French Polynesia (US Commissioner of Fish and Fisheries, 1902; and Intes, 1984). For the past six years a rotational closure system has been used voluntarily by a private company in North Western Australia, holding an exclusive collecting license over the area concerned.(Rand Dybdahl, pers. comm.)

The biological benefits of periodic closed seasons and rotational closures are again limited by the late development of the full reproductive capacity of the population, with the delayed maturation of female oysters. Ultimately, effort must be controlled to some point where a sufficient proportion of the population escapes fishing mortality. Determination of that proportion is difficult.

(c) Gear Limits

Protection of viable broodstocks has been attempted fairly successfully in some margaritifera fisheries by the prohibition or restriction of half-suit or full-suit diving machines and, later, hookah rigs or SCUBA gear. Pearl-oysters in deeper water are therefore less heavily fished. Survey data of density distribution with depth in Manihiki and Penrhyn lagoons in the Cooks, (Sims, elsewhere this meeting), indicates that deep water stocks are afforded some protection where free-diving only is permitted.

Whether such protection is sufficient to sustain the population depends on the fishing pressure exerted. *P. margaritifera* certainly remains accessible, as its depth distribution extends only as far as the limits of skilled free-divers. There is no evidence to support local assertions that virgin stocks exist beyond 40m depth. Despite such claims being occasionally cited in literature (eg Hynd, 1960), no margaritifera have been found below 40m by the author in any of the lagoons of the Cooks (Sims, elsewhere this meeting). Although it is not possible to predict the responses of various stocks to different fishing levels, prohibition or restriction of mechanical diving apparatus is, at its simplest a useful means of limiting effort. Further, restriction of fishing activities to free-diving enhances the wider socio-economic benefits of a fishery, by maximizing employment, and ensuring a degree of egalitarian opportunity.

Gear limit considerations are less applicable to maxima, where the depth and extent of beds means that free-diving fisheries are limited in scope, and where full-time pearling boats comprise most of the fishery. Even so, some restrictions on the use of diving apparatus would assist stocks by limiting effort, and possibly preserving deep-water broodstocks in some areas.

(d) Reserves

Clearly, for easily over-exploited, sedentary stocks such as pearl-oysters which achieve full reproductive potential only after many years, permanent breeding reserves are an invaluable component of any sound management regime. The greater densities assumably enhance synchronicity of spawnings (particularly relevant to sporadic spawners like pearl-oysters), and result in higher fertilization rates. Breeding reserves should optimally be located in lagoon areas exposed to inflow at oceanic water, generally on the windward side of lagoons. Millous (1976-77) found higher reproductive activity in such areas in Takapoto and resulting larvae will generally be retained for longer periods inside the lagoon.

Despite their assumed value, and the simplicity of establishing and enforcing reserve systems, they have been used fairly ineffectively in pearl-oyster fisheries.

Concerns have occasionally been expressed about the likelihood of older shells in reserves acting equally efficiently as brood-stock for 'worms' and other borers. Epizooic commensals are rarely host-specific, however, and there is probably little detriment to overall shell value. The concept of breeding reserves is easily understood by both fishermen and traditional resource managers but traditional management systems are often displaced by more immediate, tangible economic arguments.

Reserves have been used in many lagoons in French Polynesia. High pearl-oyster densities have become established within the reserves (Martin Coeroli, pers. comm.), but have not, by themselves, provided sufficient ongoing recruitment to sustain the commercial fishing pressures on the population at large. Either a significantly larger scale of reserve needs to be used, or other management measures need to be applied with greater conviction.

A breeding reserve has been in effect since the late 1950's over a 1/4 sq mile area in Manihiki lagoon, in the Cook Islands. This reserve has, however, come to be considered more as a pearl-shell reserve, (being fished to raise money for island dance groups), than as a pearl-oyster breeding reserve.

In North Western Australia, oysters cannot be taken for MOP south of 18 degrees, 20 minutes South, affording some protection to older oysters on these main pearling grounds south of Broome. (Rand Dybdahl, pers.comm.)The benefits of such restrictions will obviously be dependent on the fishing pressures exerted on younger oysters for culture material. Annual quotas have been used in both North Western Australia (ibid), and French Polynesia (Intes, 1984) to control collection of culture oysters. A gradual tightening of quotas, or extension of reserve area boundaries could be an acceptable way to reduce reliance on wild spat collection. This has been recently applied in French Polynesia, to the point where all wild spat collection will be banned in the coming year (Martin Coeroli, pers. comm.).

(e) Stock Enhancement

The early work of Crossland (1957), followed by Hynd (1960), Ranson (1955) and Reed (1962) was directed towards spat-collection and cultivation of pearl-oysters for shell value only. These efforts were intended primarily to lessen fishing pressures on natural stocks. Spat-collectors both increase successful settlement, and reduce juvenile predation, and are therefore a useful tool in improving recruitment levels (Crossland, 1957; Reed, 1962). Consequently, artificially collected or hatchery bred spat could be used to enhance stocks where there are pearl-shell fisheries or pearl-culture industries. Where pearl culture industries are planned, or in operation, the re-establishment or enhancement of natural stocks could provide both increased spat-collector yields, and abundant wild spat as a reserve for years of poor spat-falls on collectors.

3.2 Pearl-culture Industries Management

(a) Artificial Spat Collectors

A continuing supply of juvenile pearl-oysters is as critical to any successful pearl-culture programme as continuing recruitment to natural populations is for any fishery based on wild stocks. Fisheries for oysters as culture material have suffered declines similar to those of MOP fisheries, and reviews of the management programmes under which both MOP and culture spat fisheries operate are urgently called for. Simultaneously, increasing encouragement should be given to attempts to provide artificial supplies of spat, either through setting of spat-collectors, or development of hatchery culture methods for pearl-oysters.

Artificial spat-collection methods for P. maxima have encountered some difficulties. Hynd (1960) reports success with collecting only P. fucata and P. albina sugillata in the Torres Strait. Spat-collectors were rendered less effective off North Western Australia by heavy falls of fouling organisms, and P. albina (Rand Dybdahl, pers. comm.) Results from growth trials of collected maxima spat were not encouraging, with only 47% survival, and a 2cm increase in shell diameter over a four month period (Dybdahl and Rose, 1986). The opportunities for development of both artificial spat collector, and hatchery programmes, is considerably limited under poor out-growing conditions.

In Polynesia, P. margaritifera has been collected successfully in most lagoons with natural stocks. Hardwood brush collectors have provided an average of 50 spat per bundle (AQUACOP, (1982) or maximums of over 300 per collector for optimum locations and materials (Coeroli, 1983). An initial reliance on wild spat by the French Polynesian industry has now been overcome. In 1982, 60% of farm stock was fished from the wild (Intes, (1984) but this figure has now been reduced to 20% (M Coeroli, pers. comm.). Emulation of these levels of spat- production requires identification of suitable locations and seasons (particularly where heavy fouling of collectors occurs) for optimum spat collection. In many cases, viable spat-falls on artificial collectors will be closely interrelated with the success, or otherwise, of attempts to re-establish natural brood stocks.

(b) Hatchery Culture

Earliest attempts at hatchery culture of pearl oysters by Saville Kent (George, 1978), Hynd and Tranter (Tranter, 1958), were largely unsuccessful, as the protracted planktotrophic larval stage has precise physiological and nutritional requirements. Polyspermy can produce high numbers of abnormal larvae, and temperature and salinity levels during larval life appear to be critical. Larval nutrition is problematical, with seven different species of unicellular algae cultured as food at one P. maxima hatchery. (Young, 1985)

Spawning induction experiments have proved only somewhat successful. Although spawnings have been induced in P. maxima by chemical stimulation (Wada and Tranter, in Tranter, 1958; and Young, 1985) resulting larvae have generally proved inviable. Millous (1980) induced spawning in margaritifera by chemical and thermal shock, but obtained best results from the incidental stressing of oysters during transshipment from the lagoon to the hatchery.

Successes have been achieved with margaritifera by Japanese workers in Okinawa (Tanaka, et al, 1970; and Kakuzu et al, 1971) and with maxima by Western Australian Marine Research Laboratories, (Young, 1985) but settlements have been only on an experimental scale, with less than 50 spat reaching grow-out stage (Rand Dybdahl, pers. comm). There are, however, reports that a private Japanese company in South East Asia has achieved successful hatchery culture of P. maxima since 1982-83. (Dybdahl and Rose, 1986). A private company near Thursday Island, Torres St, has also reportedly produced commercial quantities of spats (Rand Dybdahl, pers. comm.) Unfortunately, the details of this work have remained secret.

(c) Oyster Transshipments

Hatchery culture of pearl-oyster spats, if widely realised, offers considerable potential for reseeding depleted lagoons and beds, as well as supplying stock for immediate pearl-culture needs. There are also possibilities that breeding experiments could provide pearl-oysters that are faster-growing, of better coloured nacre (producing more valuable pearls), and hardier with more ability to withstand stresses of farming and grafting operations, and with greater resistance to diseases.

To permit cross-breeding trials to be effective, however, there is a need for interim restrictions on the disbursement of hatchery bred spats, and other pearl-oyster transshipments, so that genetic purities are not diluted. This is particularly so in the lagoons of Polynesia where there currently exist significant genetic heterogeneities between even the close-set lagoons of the Tuamotu-Gambiers. (Blanc, 1983)

Of more immediate concern is the control of the spread of disease causing organisms between populations. High mortalities of pearl oysters are associated with "crowding of oysters during transport and inadequate water circulation in carrier tanks" (Pass, et al, 1987. p167). In French Polynesia, "the 'disease' was probably transferred from Takapoto to other lagoons" (Reed, 1985. p2) Obviously, transshipment of oysters between naturally isolated populations should be controlled.

The scale of most culture activities prohibits effective quarantining of pearl oysters, and commercial quantities of pathogenically sterile, hatchery bred spat will not be available in the foreseeable future. The next best alternative appears to be encouragement or enforcement of measures to promote increased reliance by farmers on local pearl oyster resources, through development of artificial spat collecting programmes and enhancement of natural stocks.

(d) Disease Control

Diseases affecting pearl-oysters are probably the greatest concern facing the industry today. The impact of diseases on established pearl-culture activities in Japan, North Western Australia, and French Polynesia have been outlined in Section 2.3, above. The first signs of problems in the Japanese industry were thought to be "due to the recent increase in the number of pearl-culture grounds" (Matsui, 1957, p228). Matsui (1958) later noticed that "the continuous use of the same ground often causes a serious decline in the rate of production as well as in the quality of the pearls" (p526). He hypothesised that biochemical processes were involved, although also observed that " the removal of (faecal deposits beneath farms) often increases production." (p526)

Recent work in North Western Australia has identified one of the causative agents of diseases in P. maxima as the bacteria, Vibrio harveyi (Pass, et al, 1987). It appears that similar bacteria, possibly Vibrio alginolyticus and/or Benecka vulnifica are associated with mortalities in margaritifera in French Polynesia. (Coeroli, 1983). In both cases, onset of the 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.

Severe disease outbreaks are apparently, then, preventable simply by improving farm operational procedures. Most farms are now shifting from a fixed platform to a long-line culture method, with greater spacing of oysters, improved water circulation, and limited faecal and detrital build-up on underlying substrates.

In North Western Australia, "losses have (now) been reduced substantially " (Pass et al, 1987. p 168). "Virtually no" oyster mortalities have been recorded from those farms using the recommended new handling, holding and transshipment procedures (Rand Dybdahl, pers. comm.). Despite some improvements in the situation in French Polynesia, however, significant mortalities are still occurring on four atolls. (M. Coeroli, pers. comm.) Previously, diseases have not been evident in natural stocks, (Reed, 1985) but recently, wild stocks of margaritifera and other bivalves (eg P. maculata, Area ventricosa, Spondylus varius and Tridacna maxima) have succumbed to infection. (M. Coeroli, pers. comm.)

The incentive for identification and application of preventative practices has therefore considerably increased. Baseline pathology studies on uninfected areas could also provide useful information on the geographical distributions and processes of establishment of disease causing organisms. (eg George and Hyuga, unp).

(e) Grafting Research and Development

Japanese researchers have conducted and published the results of extensive studies into the biochemical processes involved in shell formation and calcium deposition in pearl-oysters (primarily P. mertensii; see Matsui, 1957, and 1958). Most developments in pearl nucleus grafting methods, however, are usually considered trade secrets. Only recently, in French Polynesia, have results been published of trials on actual culture of pearls. Mizuno (1983) and Mizuno and Coeroli (1985) have investigated a broad spectrum of problems and possibilities surrounding conditions for pearl production in margaritifera. This work involved application of the ultimate criterion of pearl quality, by using a co-efficient of comparative commercial value of resulting pearls to compare different treatments of cultured oysters.

Probably the most important result from these experiments was validation of the often-used assumption that a strong relationship exists between pearl-oyster shell growth rate and pearl coating rate. This permits, then, pearl-oyster growth trials using measures of shell growth, to be directly applied to commercial contexts. (eg Yoo, et al, 1986; and Sims,elsewhere this meeting.)

(f) Farm Management Practices

Together with the priority for pearl-oyster research to address disease problems and preventions, there are also longer term needs to identify the most productive husbandry systems. Recent work in North Western Australia (Dybdahl and Pass, 1985; Pass et al, 1987), French Polynesia (Mizuno, 1983; Mizuno and Coeroli, 1985, Lowe, unp; and Reed, 1985) and the Cooks (George and Hyuga unp) has addressed specific questions of methods of transporting spat, stock holding systems and densities on farms, cleaning and other maintenance procedures, and pre- and post-operation care.

Usually, estimates of sustainable carrying capacity of cultured oysters have been based mainly on the subjective opinion of experienced advisers and consultants. Dybdahl and Rose (1986) are attempting to define a carrying capacity model for maxima, based on chlorophyll 'a' concentration, filtration rate by the oysters, number of oysters and trays, and their density, and flow rate of water through the system. A wide range of other parameters may also be significant, including microbial activity in the substrate, base-line levels of Vibrio spp and other pathogens, total biomass of other filter feeders in the ecosystem, and periodic (wave or spring tide induced) patterns of water circulation, sedimentation, and flushing.

Original stock biomass appears to have little relation to potential farmed biomass for either individual farms or entire lagoon ecosystems, as environmental influences vary so widely from one location or lagoon to another. Empirical estimation of allowable densities and total farmed biomass through such models could provide a useful basis for considering other less easily quantifiable influences on pearl-oyster health, and pearl quality.

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TABLE 1 (a) : COOK ISLANDS

Pearl-shell Production (tonnes)

YEAR	EXPORT TOTAL	PRODUCTION MANIHIKI	PENRHYN
1945	14	10	0
1946	48	63	1
1947	131	89	15
1948	114	174	10
1949	288	288	20
1950	313	273	40
1951	459	380	25
1952	301	288	13
1953	309	294	15
1954	290	271	21
1955	242	351	31
1956	149	8	29
1957	222	213	27
1958	97	0	97
1959	63	0	63
1960	63	0	63
1961	?	120	?
1962	?	70	?
1963	?	0	?
1964	?	70	?
1965	?	0	?
1966	25	0	25
1967	25	0	25
1968	25	0	25
1969	145	120	25
1970	25	0	25
1971	11	0	11
1972	4	0	4
1973	9	0	9
1974	?	150	?
1975	?	0	?
1976	?	0	?
1977	?	70	13
1978	0	12	6
1979	?	?	?
1980	?	69	6
1981	32	?	?

More recent data pending.

TABLE 1 (b) : AUSTRALIA

PEARL SHELL - CATCH, EFFORT AND CPUE OF THE BROOME FLEET BY SEASON FOR THE PERIOD 1978-1987.

	NO. OF CULTURE SHELLS	NO. OF M.O.P. SHELLS	TOTAL SHELLS	HOURS DIVED	CULTURE SHELLS PER HOUR	M.O.P. SHELLS PER HOUR	TOTAL SHELLS PER HOUR
	404 952	146 692	551 644	10 583.00	38.26	13.86	52.13
	371 806	355 599	727 405	16 068.67	23.14	22.13	45.27
	364 502	260 714	625 214	18 568.80	19.63	14.04	33.67
	481 193	210 649	691 842	23 320.87	20.63	9.03	29.67
	439 092	132 931	572 023	15 710.97	27.95	8.46	36.41
	365 381	87 049	452 430	19 019.58	19.21	4.58	23.79
	242 828	47 230	290 058	11 615.97	20.90	4.07	24.97
	272 869	53 831	326 700	12 423.47	21.96	4.33	26.30
	337 004	10 929	347 933	16 454.27	20.48	.66	21.15
	359 612	0	359 612	17 134.05	20.99	0	20.99
.S	3 639 239	1 305 624	4 944 863	160 899.45	23.32	8.12	31.44

(from Rand Dybdahl, pers. comm.)

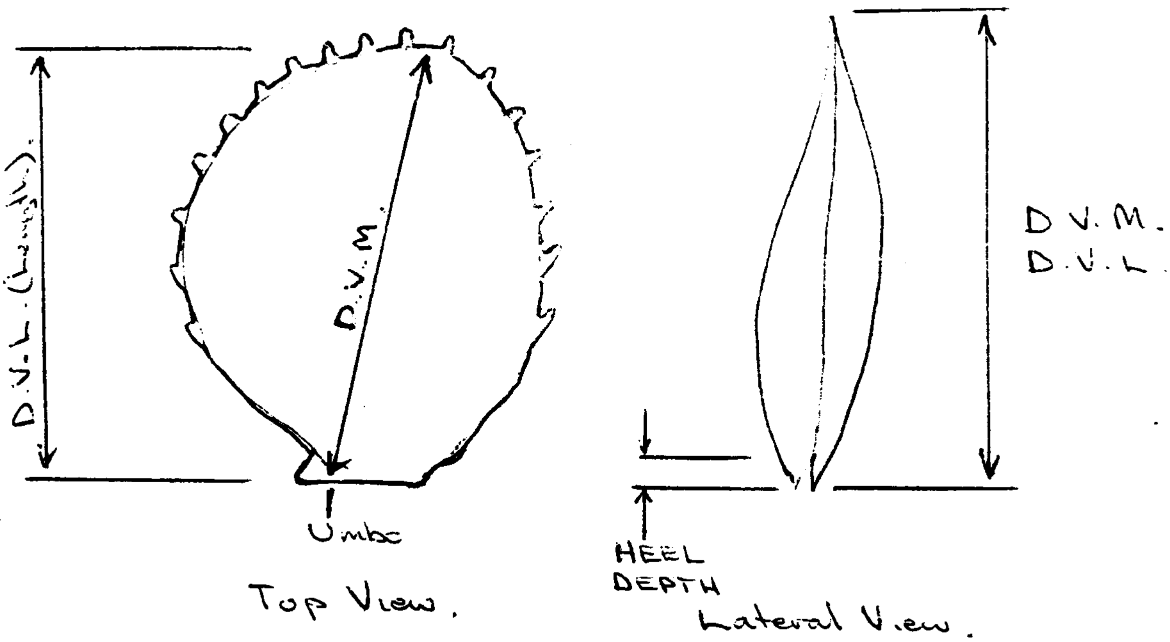
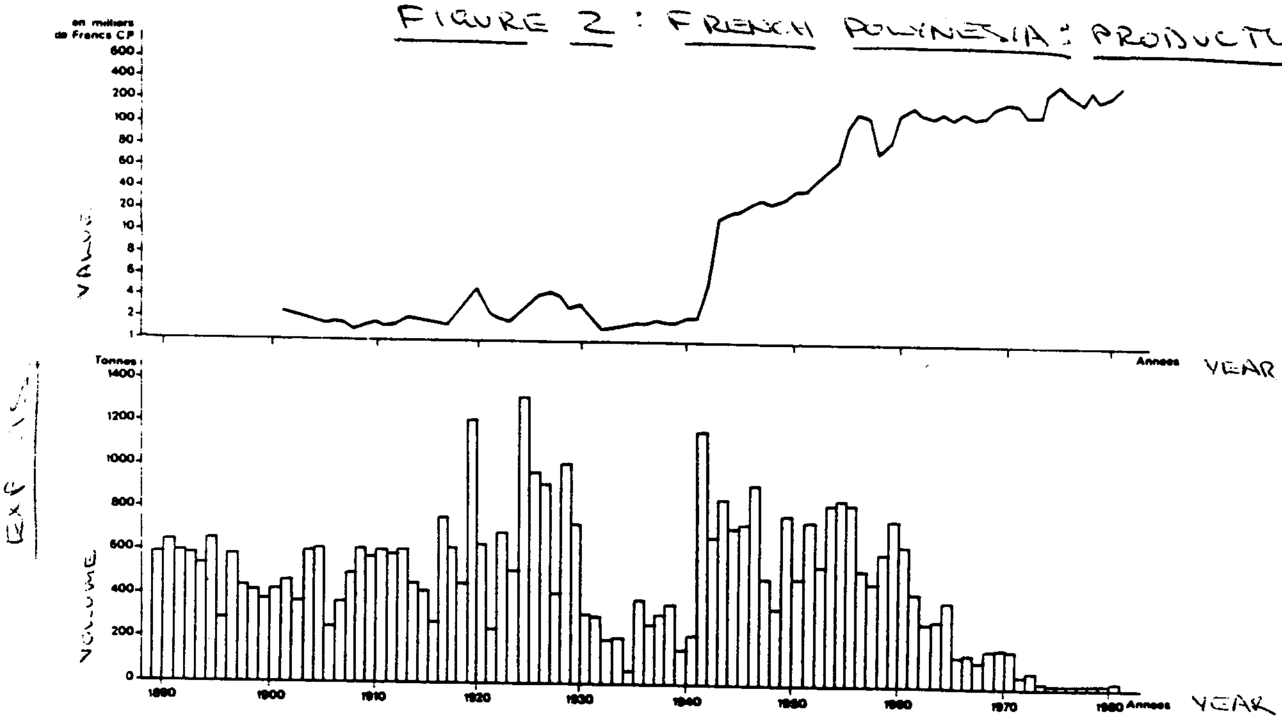


FIGURE 1: STANDARD PEARL-OYSTER MEASUREMENTS

FIGURE 2: FRENCH POLYNESIA: PRODUCTION.



(From Intes, 1954)