

COASTAL FISHERIES IN THE PACIFIC ISLANDS

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Abstract Coastal fisheries in the South Pacific are reviewed, including descriptions of fisheries, catch composition, catch rates and fisheries biology studies conducted on target stocks. The most widely targeted coastal fish stocks are reef fishes and coastal pelagic fishes. Small pelagic species are important for subsistence and small-scale commercial fisheries. Previously, small pelagic resources were important as a source of live bait for pole-and-line tuna fishing, but this method is declining and only one large bait fishery is left in the region in the Solomon Islands. The pole-and-line bait fisheries represent the only large-scale industrial fisheries to have operated in the coral reef lagoons of the Pacific. Estuarine resources are of major importance only in the large islands of Melanesia but are the staple diet of a relatively large proportion of the total South Pacific population. Deep slope fish stocks form the basis of only two commercial fisheries in the region and expansion of deep slope fishing comparable with the 1970s and 1980s is unlikely to occur again. Commercial fisheries development is currently orientated towards small- and medium-scale long-line fisheries for offshore pelagic resources, where high value tunas and billfishes are caught for export markets.

The total coastal fisheries production from the region amounts to just over 100000 t yr⁻¹, worth a nominal US\$262 000 000. About 80% of this production is from subsistence fishing. Just under half the total annual commercial catch comes from fishing on coral reefs, which includes a small tonnage of deep slope species. Invertebrates are the most valuable inshore fisheries resources and these include sea-cucumbers, trochus and pearl oyster. Lobsters and mangrove crabs form the basis of small-scale commercial fisheries, as also do penaeid shrimps, except in PNG where they are caught in large quantities through trawling. Mariculture of shrimps is becoming increasingly popular in the region and is a major industry in New Caledonia. The greatest influence on coastal fisheries in the Pacific through the next decade is likely to come from southeast and east Asia, where the demand for high value coastal fishes and invertebrates has led to large scale depletions and has motivated entrepreneurs to seek stocks in the neighbouring Pacific islands.

Introduction

The archipelagos that are commonly referred to as the “South Pacific islands” are found in an area roughly bounded by the tropics and lying between 130°E and 125°W (Fig. 1). There are three racial and cultural subgroupings of the South Pacific, namely Melanesia, Micronesia and Polynesia. The Melanesian islands are all relatively large archipelagos and include Papua New Guinea (PNG), the Solomon Islands, Vanuatu and New Caledonia. Fiji lies halfway between Melanesia in the west and the Polynesian islands of the central Pacific. Polynesia includes American Samoa, the Cook Islands, French Polynesia, Niue, Pitcairn, Tokelau, Tonga, Tuvalu, Wallis and Futuna and Western Samoa. The Micronesian islands lie mainly north of the equator and include the Federated States of Micronesia — Yap (Fig. 2, 117)³, Chuuk (Fig. 2, 16), Pohnpei (Fig. 2, 79), Kosrae (Fig. 2, 43) — Guam, the Northern Mariana Islands, Marshall Islands, Nauru, Palau, and Kiribati.

3. Numbers in parentheses refer to specific locations within countries or territories and are indicated on Figure 2.

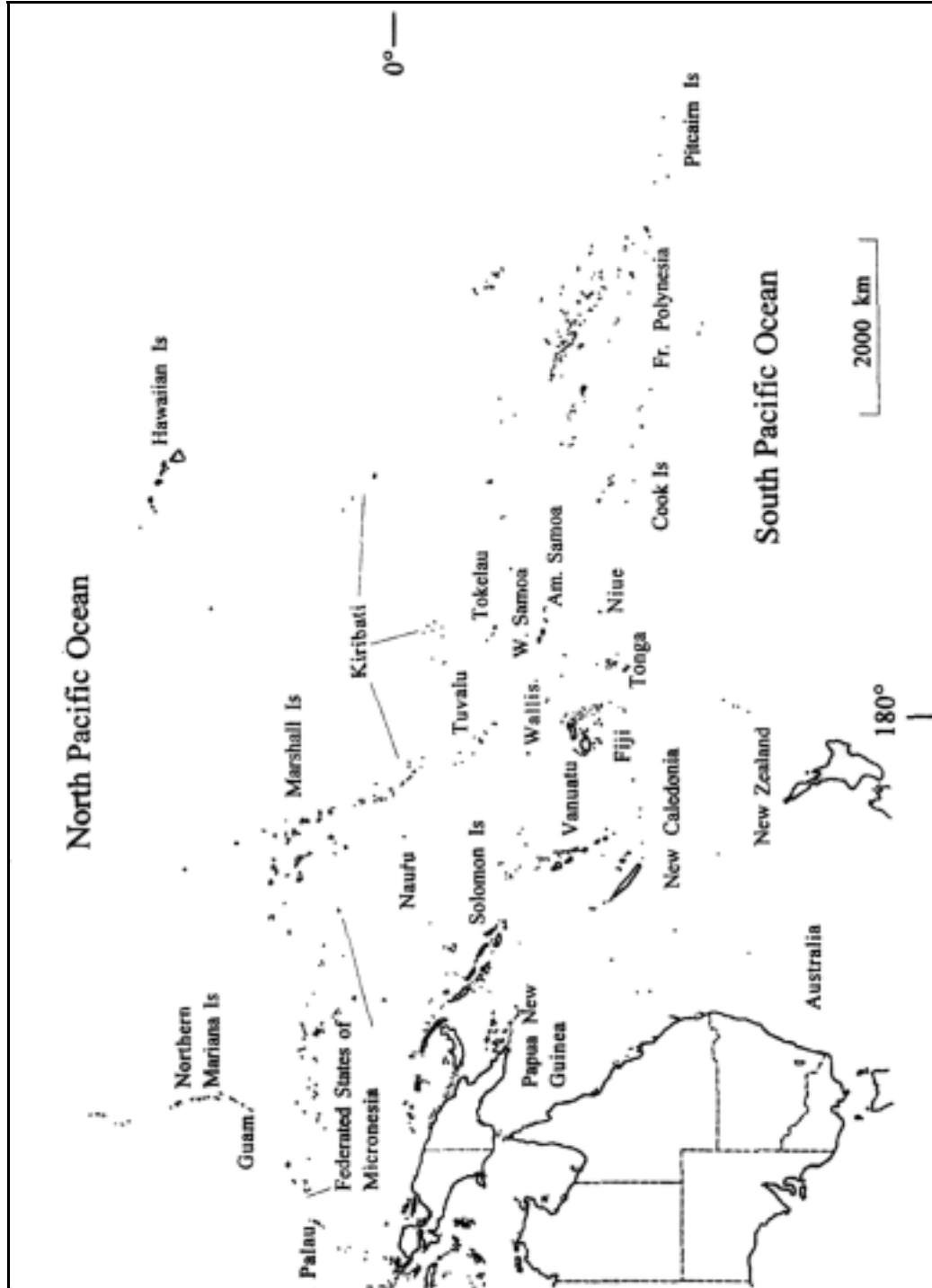


Figure 1: Map of the South Pacific showing the countries and territories of the region. Easter Island (not shown) lies 2350 km to the east of Pitcairn Island

On the periphery of this grouping are the subtropical islands belonging to: Australia — Lord Howe (Fig. 2, 123), Norfolk Island (Fig. 2, 69); New Zealand — Kermadec Islands (Fig. 2, 124); Chile — Easter Island, Sala-y-Gomez; the USA — Hawaii, Johnston Island (Fig. 2, 37), Wake Island; and Japan — Bonin (Fig. 2, 121), Kazan Islands (Fig. 2, 122). The remaining islands comprise 15 independent countries, and seven territories belonging to either France, the USA or the UK.

Some basic geographic and economic information on the South Pacific island countries and territories is given in Table 1 (p. 409). Politically, these are all members of the South Pacific Conference that was first convened in 1947 and which also includes the governments of New Zealand, Australia, the United States, Britain and France. Fourteen independent island states, with the addition of New Zealand and Australia, are also members of the South Pacific Forum that was established in 1971. Both the Conference and the Forum have secretariats housed in New Caledonia and Fiji, respectively. Both institutions support fisheries development and management in the South Pacific: the Forum through the Solomon Islands based Forum Fisheries Agency, which is concerned with managing access by distant water fishing nations to the region's tuna stocks, and the South Pacific Commission's Fisheries Programme, which performs research and development on tuna and coastal fisheries.

The combined area of the Exclusive Economic Zones (EEZs) of the South Pacific Commission island members (from the Northern Mariana Islands to the Pitcairn Islands) is 29523000 km², but the land area of 550652 km² is a small portion of this. Most of the land (84%) belongs to PNG, with the other Melanesian islands and Fiji forming a further 14% of the total. For many of the people of the South Pacific islands, particularly in land-deficient Micronesia and Polynesia, fish is a staple source of animal protein. Although some islanders venture further offshore, fisheries in the coastal zone have traditionally been the target of subsistence activity and provide a major portion of the diet. Even with increasing urbanization and the shift in preference to more imported western foods, fresh fish and invertebrates caught in coastal waters continue to be a significant item in the diet of most Pacific islanders.

European exploration in the South Pacific during the last century and the Japanese entry during the 1920s and 1930s was followed by interest in the commercial potential of invertebrate resources in the region, such as in molluscs for mother-of-pearl and pearls, and sea-cucumbers for *bêche-de-mer* production. Limited interest was shown in the finfish stocks of the region, apart from some commercial exploitation of reef and tuna stocks in the Caroline Islands (Fig. 2, 14) during the 1930s. Following the first World War, however, fishing for tunas such as skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*) and bigeye (*Thunnus obesus*), continued to expand until at present the annual landings from the waters in the South Pacific Commission statistical area amount to about 991000 t worth in the region of US\$1,460 000 000 (Anon. 1995). Following the Law of the Sea Conferences during the 1970s, the South Pacific islands claimed sovereignty over EEZs extending 200 n.mi from the land. The present commercial catches of tunas are made predominantly within the EEZs of the Pacific islands by vessels from nations on the Pacific rim such as Japan, Taiwan, USA, China, Korea and the Philippines (Anon. 1993a).

Impressive though the catches of tuna from the South Pacific are, they have limited impact on the lives of the indigenous peoples of the region. Tuna are caught by highly mechanized industrial fleets of purse seiner, long-line and pole-and-line vessels, often on the high seas. Less than 7% of this tuna is caught by Pacific island vessels and only 25% of the total landings is processed within the region, at canneries in the Solomon Islands, Fiji and American Samoa. The remaining 75% of tuna landings is processed elsewhere by countries on the Pacific rim (Anon. 1991a).

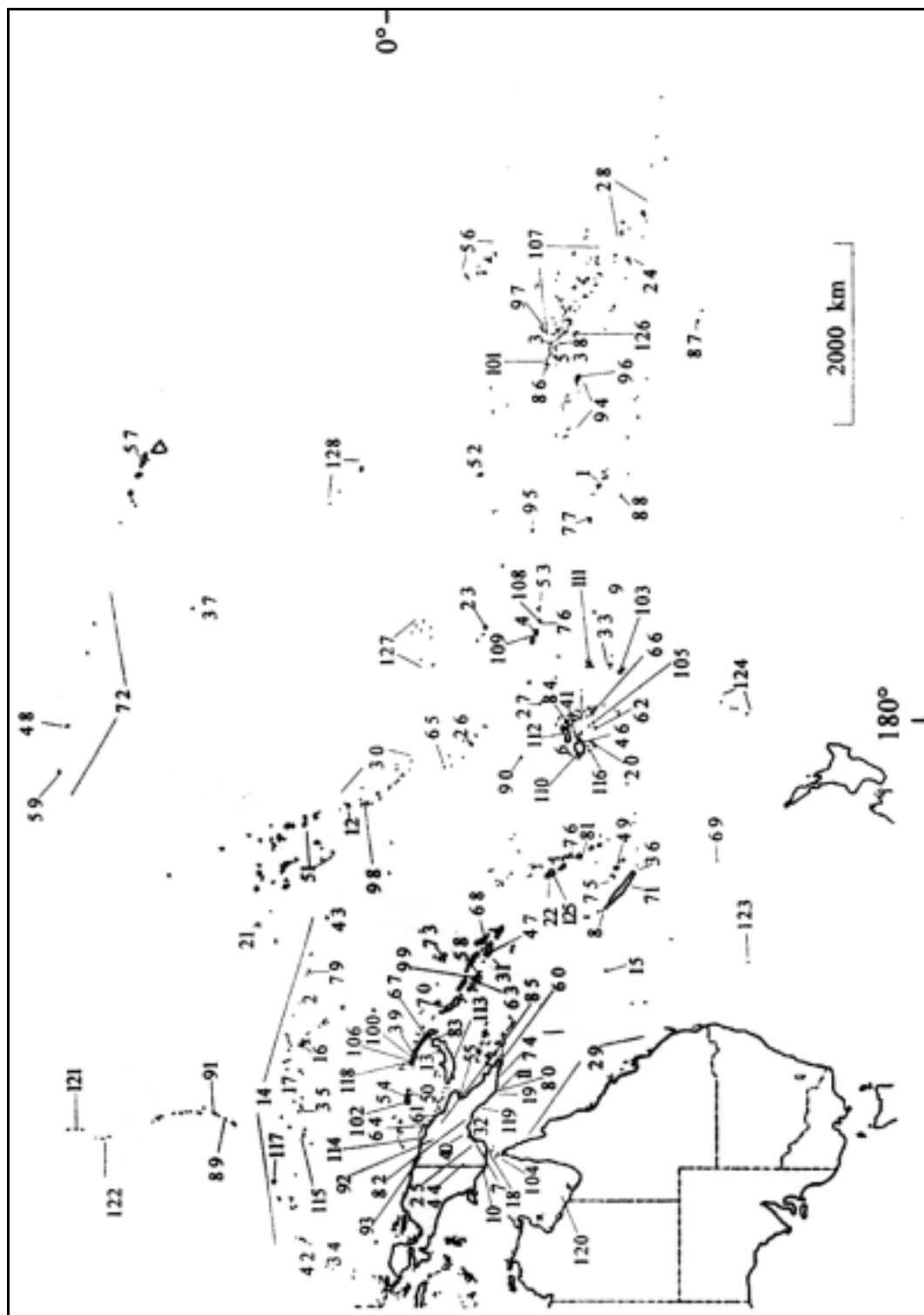


Figure 2: Locations of places and geographical features in the South Pacific mentioned in the text. The first reference in the text to a place or feature is followed by the corresponding number in parentheses.

By contrast, landings from the coastal zone are more modest, but they have a far greater social and economic impact on the residents of the Pacific islands. Moreover, there is a more immediate risk of over-exploiting the resources in the narrow coastal zones of many Pacific island countries as populations increase and technology improves the fishing power of artisanal fishers. Management of coastal fisheries is an increasingly important priority, but for this to have any hope of success, information and feedback about the status and trends in coastal fisheries must first be acquired by fisheries managers and administrators. The objectives of this paper are:

1. to describe the various coastal fisheries of the South Pacific,
2. review the various biological studies and stock assessment methods used to provide management information
3. to estimate the volume and value of these fisheries,
4. to discuss the possible future trends of these fisheries with respect to social, economic and political developments in the region.

In general we have restricted our summaries to the South Pacific islands, but refer where necessary to fisheries for the same or similar species on the periphery of the region, particularly northeast Australia and Hawaii. Northeast Australia contains the Torres Straits (Fig. 2, 104) and shares several important fisheries resources with Papua New Guinea. Hawaii, besides having strong social and cultural links with Polynesia, also provides a biological analogue for the subtropical islands in the south of the region about which relatively little is known.

The first regional fisheries meeting convened by the South Pacific Commission (Anon. 1952) highlighted the lack of quantified information on South Pacific island fisheries. However, because of the complexity and diffuse artisanal nature of coastal fisheries, together with the gradual development of national fishery administrations, developments in fisheries production from the coastal zone have not yet been comprehensively documented at the regional level. The recent reviews of Pacific islands fishery resources published by the Forum Fisheries Agency (Wright & Hill 1993) again highlighted the lack of information on the scale of harvests of fish and marine organisms from the coastal zone. There is increasing concern about environmental issues such as sea level rise from global warming and loss of biodiversity through excessive exploitation of living natural resources. Fisheries production may be affected by sea level rise and fisheries can contribute to local species depletions and extinctions through excessive harvesting. This has already happened with the giant clam *Tridacna gigas*, which has been driven to extinction in many of the islands of Micronesia, Vanuatu and probably New Caledonia (Munro 1993) and Fiji (Lewis et al. 1988a), and with certain reef fish species in parts of Micronesia (Myers 1989) and Polynesia (Bell 1980, Hooper 1985, Sims 1990). These descriptions of fisheries and estimates of fisheries production are likely to be of interest to workers in a variety of disciplines such as conservation, nutrition, economics, planning and coastal zone management.

The physical geography of the South Pacific islands

An inventory of the islands of the South Pacific, which includes notes on geology and structure of the different land masses in the region, is given by Douglas (1969). Two basic types of island can be distinguished in the South Pacific, namely high islands and atolls. Land masses raised from the ocean floor through vulcanicity and tectonic forces in time form high islands and

islands and develop fringing and coral reefs. Very young high volcanic islands such as Pagan in the Northern Mariana Islands have relatively little reef development beyond encrusting coral communities. Older high islands may have well developed fringing reefs. Such is the case with Rarotonga (Fig. 2, 88) in the Cook Islands, Tahiti (Fig. 2, 96) and Bora Bora in the Society Islands (Fig. 2, 94).

Nearly all the South Pacific islands lie within the tropics and so sea surface temperatures rarely fall much below 20°C and may rise as high as 30°C during the course of a year. The coasts of most Pacific islands are characterized by coral reefs, seagrass meadows and mangrove forests. High islands contain the greatest number of reef zones and habitats. They are also the only islands that have extensive fresh and brackish water habitats. Nutrient-rich rivers may carry large quantities of silt resulting in highly productive, but turbid muddy habitats. Mangrove forests thrive along the intertidal shorelines of estuaries and river mouths and seagrasses flourish on silty inner reef flats and shallow lagoon floors.

High islands may subside, but the barrier and fringing reefs continue to grow and develop into atolls, where a fringe of coral islands and reef surrounds a lagoon. Atolls lack rocky cliffs and platforms as well as rivers and the well developed mangrove communities found in high islands are either missing or poorly developed. They therefore lack many of the species associated with these habitats. Occasionally, volcanic forces have raised atolls well above the sea surface to produce highly porous limestone islands known as makateas. They lack rivers and have flat tops and steep sides that may plunge directly into the sea, be undercut or be fringed by rocky platforms or reef flats. Some of the countries and territories of the South Pacific consist predominantly of only one island type such as atolls (Kiribati, Marshall Islands, Tuvalu), makateas (Nauru, Niue) or high islands (Samoa, Vanuatu, Wallis and Futuna), but the remainder are usually a mixture of atolls, high islands and makateas.

Few parts of the South Pacific have such extensive freshwater discharge that coral reef development is inhibited over a wide area. The Gulf of Papua (Fig. 2, 32), the region's major estuarine area, has coral reefs at the western and eastern margins, where the influence of the massive freshwater influx from drainage of the mountainous hinterland of Papua New Guinea is reduced. Elsewhere on the smaller islands of the Pacific, the outflow of rivers has a minor influence on reef development.

The corals and coral reefs of the Pacific islands are described in Wells & Jenkins (1988) but the species of hermatypic or reef building corals in the South Pacific have been fully described only for Australia (Veron 1986), with over 330 species contained in 70 genera. The number of species of coral declines in an easterly direction across the Pacific in common with the distribution of fish and invertebrate species (see p. 404) so that there are only 30 genera present in the Society Islands of French Polynesia and 10 genera in the Marquesa Islands (Fig. 2, 56) and the Pitcairn Islands. All forms of coral reef development can be found in the South Pacific including large barrier reefs around New Caledonia and in Fiji, extensive fringing reefs, particularly around the large Melanesian islands, and patch and submerged reefs, banks and shoals throughout the region.

Mangrove forests (especially *Rhizophora* spp., *Bruguiera* spp., and *Avicennia* spp.) are prevalent in estuarine areas but sediment build up may also permit establishment of mangrove trees and bushes on the reef flat. On atolls, mangroves may be absent or present only in thin patches. A directory of Pacific island wetlands, including mangrove forests, has been compiled by Scott (1993), while the distribution, environmental aspects and ecology of Pacific islands mangroves is reviewed by Woodroffe (1987), and included in a global review of tropical marine ecosystems by Hatcher et al. (1989). Apart from the usefulness of the wood for building, charcoal and tannin, mangrove forests act to stabilize areas as where physical sedimentation

is occurring and, from a fisheries perspective, are important as nursery grounds for penaeid shrimps and some inshore fish species, and form the habitat for some commercially valuable crustaceans. Extensive mangrove forests are a feature of high islands in the western Pacific, particularly the Melanesian islands and Fiji. The natural eastern limit of mangroves in the Pacific is American Samoa, although *Rhizophora stylosa* was introduced to the Society Islands of French Polynesia in the 1970s. Mangroves are also absent from Wallis and Futuna, Tokelau and the Phoenix (Fig. 2, 127) and Line Islands (Fig. 2, 128) of Kiribati.

Seagrasses are common in all marine ecosystems and are a regular feature of most of the inshore areas in the Pacific islands. According to Hatcher et al. (1989), seagrasses stabilize sediments because leaves slow current flow, thus increasing sedimentation of particles. The roots and rhizomes form a complex matrix that binds sediments and stops erosion. Seagrass beds are the habitat of certain commercially valuable shrimps, and provide food for reef-associated species such as surgeonfishes (Acanthuridae) and rabbitfishes (Siganidae). Seagrasses are also important sources of nutrition for higher vertebrates such as dugongs and green turtles. A concise summary of the seagrass species found in the western tropical South Pacific is given by Coles & Kuo (in press), and Wells & Jenkins (1988) include information on seagrass beds in association with the coral reefs of the Pacific islands.

Climate and the marine environment of the South Pacific islands

Average annual rainfall in the South Pacific ranges from just over 1000 mm in New Caledonia to 5000 mm in Pohnpei and Kosrae States in the Federated States of Micronesia. The large high island archipelagos of Melanesia may have quite different rainfall regimes on different parts of the same island or between locations on different islands. For example, the rainfall in the Fijian capital Suva is about 3200 mm per year while that of Nadi, some 110 km to the west, is about 1900 mm per year. In PNG, Abeyasekera (1987) was able to distinguish three distinct rainfall regimes; namely, areas where rainfall is constant throughout the year, areas where rainfall peaks between May and August and areas where rainfall is highest from December to March. High islands tend to retain moisture bearing clouds and have higher annual rainfall regimes than atolls and other low islands. However, mountains may form rain-shadow areas as that receive rain only at certain times of the year as is the case with the region around the PNG capital, Port Moresby (Fig. 2, 80), which experiences strong rainfall only during November to March and has an annual total of about 1200 mm per year.

For most of the Pacific islands rainfall typically ranges from 2000 to 3500 mm yr⁻¹. Low islands such as makateas and atolls tend to have less rainfall and may suffer prolonged droughts. Furthermore, when rain does fall on coral islands and makateas where there is no major catchment area, there is little allochthonous nutrient input into surrounding coastal waters and lagoons. Lagoons and embayments around high islands in the South Pacific are therefore likely to be more productive than atoll lagoons. The productivity of high-island coastal waters, particularly where there are lagoons and sheltered waters, is possibly reflected in the greater abundance of small pelagic fishes such as anchovies, sprats, sardines, scads, mackerels and fusiliers (Anon. 1984a). In addition, the range of different environments that can be found in the immediate vicinity of the coasts of high islands also contributes to the greater range of biodiversity found in such locations.

Climatic seasonality in the South Pacific is more pronounced at higher latitudes. Even at or close to the equator there may be seasonal effects from the amount of rain carried by the

prevailing winds. Most of the region is influenced by winds that blow from the south and east (the Southeast Trades), but for about 4 – 5 months during the northern winter, the prevailing winds in the western Pacific blow from the north and west (Northwest Monsoon). Rainfall tends to be highest during the summer and autumn months both north and south of the equator. This is well illustrated by comparing the average monthly rainfall in Saipan (Fig. 2, 91) in the Northern Mariana Islands with that of Western Samoa. Both locations are at roughly the same latitude north and south of the equator with the same average mean temperature (26°C), although Samoa is wetter with an average annual rainfall of 2900 mm compared with 2200 mm in Saipan. Rainfall in Samoa reaches a maximum between November and February, while in Saipan rainfall peaks between July and October.

Information on the hydrographic characteristics of South Pacific marine environments has been summarized from various sources by Wauthy (1986). The waters that form the surface layer of the tropical west and central Pacific enter into the transpacific intertropical circulation from the eastern boundaries of two subtropical anticyclonic gyres, where the coastal upwelling of California and Peru provide enrichment of nutrient rich subsurface waters. The waters remain on the surface and the thickness well established thermocline. As these waters move from east to west they grow warmer and more impoverished as nutrients are consumed by photosynthesis and particulate materials are sedimented. Limited primary production continues on the basis of partial re-mineralization within the isolated upper surface layer of the water column.

Nutrient-depletion leads to very clear blue oceanic water in which suspended particles are depleted and living organisms are scarce. The term “oceanic desert” has been used by Lisitzin (in Wauthy 1986) to describe these nutrient poor-waters. Primary productivity in the photic zone ranges on average from 20 to 50 $\text{gCm}^{-2}\text{yr}^{-1}$ (FAO 1972). Upwelling is one mechanism by which impoverished tropical waters can be enriched with nutrients from the subsurface waters and this has been observed at the equator. Another mechanism whereby subsurface nutrient-rich waters reach the euphotic zone involves shallowing of the thermocline at 10°N and 10°S, at the edge of the equatorial counter currents. In the South Pacific, nutrient inputs from precipitation and runoff are of major significance only in the waters surrounding the large island archipelagos of Melanesia where highlands are extensive and rainfall is very heavy. Not surprisingly, the highest oceanic primary productivities in the region (90 — 180 $\text{gCm}^{-2}\text{yr}^{-1}$) are found on the shelf area of the Gulf of Papua which receives much of the drainage from PNG highlands region.

Combination of various physical factors results in the accumulation in the tropical Pacific of a thick surface layer of warm water west of 180°. This accumulation forms one of the pre-conditions necessary for the generation of cyclones or hurricanes that are a common meteorological phenomenon in the South Pacific. The second pre-condition is the existence of a cyclonic-like convergence in the lower layers of the atmosphere that can be found in the western tropical Pacific between the equatorial monsoon winds from the west and the easterly trade winds. In the northwest tropical Pacific, cyclones form most frequently between June and November, and are most frequent in August/September, with an average of 18 per year. South of the equator, cyclones occur from December to April and are less frequent than in the northwest, with an average of four per year (Wauthy 1986).

Large-scale oceanic events such as the El Niño Southern Oscillation (ENSO) also influence the coastal marine environment of the South Pacific islands. The Southern Oscillation Index is the difference in atmospheric pressure between Tahiti and Darwin, which is usually positive

due to the low pressure area over Indonesia and Australia. During an ENSO episode, the pressure gradient reverses and becomes negative for a prolonged period with a consequent shift in climatic and oceanographic conditions. The easterly trade winds weaken and westerly winds are observed over parts of the equatorial western Pacific. The area of warm water usually associated with the western tropical Pacific is displaced eastward over the central and eastern Pacific region and the ocean waters of the western Pacific cool. This phenomenon results in the appearance of an anomalous warm ocean current off the coasts of Peru and Ecuador around the Christmas season and hence was named by Peruvian fishermen “El Niño”, the familiar diminutive Spanish term for the infant Christ.

This major climatic shift produces unseasonal droughts in the western Pacific and unseasonal rains in the central and eastern Pacific. Information from commercial tuna fisheries in the South Pacific and pelagic and demersal fisheries in South America suggests that ENSO events can, depending on species, have both negative and positive effects on catch ability and apparent abundance. In the western and tropical Pacific, the abundance of surface skipjack and yellowfin tuna stocks shifts eastwards during an ENSO episode. This can be inferred from the concentration of fishing effort by tuna purse-seine vessels, which during normal years concentrate to the West of 160°E line of longitude and to the east of this line during an ENSO event (Anon. 1995). Little is known at present about how ENSO events affect coastal fish and invertebrate stocks in the South Pacific due to the lack of any suitable time series of data. It is likely, however, that such a large scale anomaly will have an influence on productivity and recruitment, especially in those species with long oceanic pelagic larval stages, and those reef species that are sensitive to anomalous water levels during spawning or recruitment.

There may be other long-term climatic cycles in the Pacific region that will influence the productivity and abundance of marine organisms. Polovina et al. (1994) describe such an event in the Hawaiian Islands that began in the mid 1970s and ended in the late 1980s. Over a 10-year period, this climatic event promoted the movement of nutrient-rich deep ocean water into the euphotic zone during the first quarter of the year. This in turn resulted in higher survival of fish, crustaceans, seals and sea birds. The decline in the event was followed by declines in the recruitment and abundance of fish, crustaceans, birds and seals. During this event an important commercial lobster fishery in the Northwest Hawaiian Islands (Fig. 2, 72) expanded rapidly in the mid 1980s then declined as recruitment to the population was markedly reduced, despite the efforts of fisheries managers to promote sustainable yields from the fishery.

Fisheries resources of the South Pacific

Marine resources in the context of this paper refer mainly to marine organisms that are caught and collected for food, but also include molluscs such as trochus, green snail and pearl oysters where harvests are mainly for the shells. As the majority of the South Pacific islands are atolls and small islands surrounded by coral reefs, the principal targets of nearshore fisheries in the region are fauna associated with coral reefs and lagoons. As stated previously, the only country with extensive estuaries is PNG, whereas the other large Melanesian islands have smaller more limited estuarine environments. Species diversity of fishes, molluscs, crustaceans and echinoderms declines in an easterly direction across the Pacific.

There are about 2 500 reef and inshore fishes in the Philippines, at the centre of the IndoPacific faunal continuum, compared with only 125 in Easter Island at the eastern margin of the region (Myers 1989). This species gradient appears to be related to the position of the South Pacific islands in relation to the Pacific Plate, the largest of the Earth's lithospheric plates. The Pacific islands lie on or along the margin of this geological structure. The biogeography of the South Pacific region and species distributions in relation to the Pacific Plate have been discussed by Springer (1982) and Myers (1989). Pacific islanders may consume a wide variety of reef fishes, including snappers (Lutjanidae), emperors (Lethrinidae), groupers (Serranidae), parrotfishes (Scaridae), mullet (Mugilidae), surgeonfishes (Acanthuridae), jacks (Carangidae), and other nearshore pelagic species such as scads (Carangidae), tunas and mackerels (Scombridae). Pacific islanders will also consume small species such as squirrelfishes (Holocentridae), hawkfishes (Cirrhitidae) and some of the smaller surgeonfish species. Observations on a typical small scale commercial reef fishery in the western and central part of the South Pacific may record between 200 and 300 species in the catch, although it is likely that only a few species will dominate landings. The fishes commonly associated with mangrove and estuarine ecosystems in Melanesia are listed by Kailola & Wilson (1978), Collette (1983), Quinn & Kojis (1986), Blaber & Milton (1990) and Thollot (1992). Species commonly caught in the large estuarine and mangrove areas include barramundi (Centropomidae), catfishes (Ariidae), threadfins (Polynemidae), ponyfishes (Liognathidae), clupeoids (Engraulidae & Clupeidae), jewfishes (Sciaenidae) and grunters (Theraponidae).

South Pacific islanders also use a great variety of molluscs for food and for their shells. Cernhorsky (1967, 1972) records over 1000 species of shell bearing molluscs from the South Pacific. In addition to these are the various cephalopods such as squids, cuttlefish and octopus that are caught in the nearshore zone. Several molluscs are of prime commercial value in the region and these include trochus (*Trochus niloticus*), green snail (*Turbo marmoratus*) and black-lip pearl oyster (*Pinctada margaritifera*). All these species are harvested primarily for mother-of-pearl used for button manufacture and furniture inlay. The black-lip pearl oyster, as the name suggests, is also valuable for the production of a form of pearl that is dark silvery-grey in colour and was originally collected from wild populations, but is increasingly being cultured artificially. A wide variety of molluscs is also consumed for food and these are discussed in detail below.

There are an estimated 300 species of shallow water holothurians in the Indo-Pacific region that account for about 27% of the echinoderm fauna in the Pacific islands (Guille et al. 1986). Holothurians form part of the subsistence diet of many Pacific islanders, although certain species are commercially valuable as a dried product known as bêche-de-mer, or trepang, that is exported, mainly to Asia. There are at least 22 species of holothurians which are caught for bêche-de-mer production in the South Pacific and these belong to the genera *Actinopyga*, *Holothuria*, *Stichopus*, *Theloneta* and *Bohadschia* (Preston 1993, Adams et al. in press).

Pacific islanders also consume a variety of crustaceans found in the nearshore zone including crabs, lobsters and shrimps. The mud crab (*Scylla serrata*) is widely distributed in the region and this is caught for commercial sale as well as for subsistence. Other reef dwelling crabs such as the three spot reef crab (*Carpilius maculatus*), the sand crab (*Portunus pelagicus*) and the red crab (*Etisus splendidus*) are also consumed for subsistence. Land crabs such as the coconut crab (*Birgus latro*) have traditionally been a component of subsistence catches and may be caught commercially, particularly where there is a developing tourist industry. Other smaller land crabs such as *Cardisoma carnifex* and hermit crabs are a seasonally important subsistence resource.

Several spiny lobster species are found in the South Pacific including *Panulirus penicillatus*, *P. longipes*, *P. versicolor* and *P. ornatus*, found mainly on tropical reefs; and *P. marginatus* and *P. pascuensis* found on subtropical reefs. These and the related slipper lobsters (Scyllaridae) are captured both for subsistence and commercial purposes. Other crustaceans that are harvested from the coastal zone include mantis shrimps (*Squilla* spp.), mud lobsters (*Thalassina anomala*) and penaeid shrimps. Over 40 species of penaeid shrimps have been identified from the waters of PNG (Rapson & McIntosh 1972) but the most abundant is the banana shrimp, *Penaeus merguensis*. Also commonly captured are tiger shrimps, *P. monodon* and *P. semisulcatus*, and the endeavour shrimps, *Metapenaeus ensis* and *M. demani*. Elsewhere, such as Fiji, *Penaeus canaliculatus* and *Metapenaeus anchistus* are locally abundant (Choy 1988), while species such as *Penaeus semisulcatus* and *Metapenaeus ensis*, which are species of minor importance in PNG, are abundant in the lagoon of Tongatapu (Fig. 2, 103), the main island of Tonga (Braley 1979).

Other invertebrates and marine organisms that are consumed regularly or as delicacies by Pacific islanders include chitons, sea-hares, marine worms and seaweeds. Populations of the marine polychaete worm, *Eunice viridis*, (palolo in Samoan and balolo in Fijian) undergo periods of mass spawning in coastal waters once a year during full moon periods. The gamete bearing segments of the worms rise to the surface where they can be collected by coastal villagers and are regarded as a great delicacy in parts of the Pacific, especially Samoa.

Fishing methods

Subsistence and artisanal fishing

There is a rich tradition of fishing techniques, beliefs and customs associated with fishing in the South Pacific islands and many of these have been described in anthropological studies made over the last 200 years (e.g. Anell 1955). In this review, however, we are concerned mainly with contemporary fishing practices and will describe those gears and fishing methods that are widely used on a regular basis in the region. Most coastal fisheries in the South Pacific are characterized by small-scale artisanal fishing methods. A considerable amount of fishing takes place from the shore or in shallow waters without the use of fishing vessels. Where fishing vessels are used, these are generally small, either non-powered canoes or canoes and dinghies powered by outboard motors and, to a lesser extent, by sail. Larger vessels of 8 – 20 m in length, powered by inboard diesel engines, are used for commercial fishing for demersal species beyond the reef slope, and for catching tuna on the open ocean.

Common gears include hooks-and-lines, traps (fixed and moveable), seine and gill nets, and spears. Hooks-and-lines can be deployed in a variety of ways, as simple droplines to catch demersal fishes, as bottom and surface long-lines to catch demersal and pelagic fishes respectively, and towed with baits and lures to troll for pelagic fishes. Traditionally, hooks were fashioned from shells, bones and wood, whereas lines were made from coconut or other plant fibre. These traditional materials have generally been superseded by monofilament lines and metal J or circle hooks. Traditional shell lures are still used in some locations such as French Polynesia (Chapman & Cusack 1988a) to troll for tuna and other large pelagic species. Hand-line or drop-line fishing in shallow coastal waters is a common subsistence and recreational fishing method in most of the Pacific. Hand-lines can be deployed on reefs, in

estuaries and on the shelf to catch demersal species. Hand-lines are also used in midwater to catch small pelagic fishes such as bigeye scads or round scads, using baits or lures. Coastal fishermen will also use hand-lines in midwater to catch tuna and other large pelagic species such as rainbow runner (*Elagatis bipinnulatus*) and wahoo (*Acanthocybium solandri*).

Commercial drop-lines for demersal species such as snappers and groupers on the deep reef slope or on banks and seamounts are mounted on reels to aid hauling from depths between 100 and 400 m. A common design of hand-reel for such operations was developed in Western Samoa by the Food and Agricultural Organisation of the United Nations and propagated throughout the region by the South Pacific Commission (Dalzell & Preston 1992). Long-line fishing has also been used to catch demersal species from the deep reef slopes, particularly in Fiji, where long-lines of between 500 and 1000 hooks were set on offshore banks and seamounts. Similar sized surface long-lines are presently employed to catch tuna, particularly large yellowfin and big eye tunas that have a high value on overseas markets in Japan and Hawaii.

Gill netting, beach seining and drive-in netting are conducted both in coralline and estuarine areas of the Pacific. Nets were traditionally manufactured by Pacific islanders from plant fibres such as coconut and pandanus, but such nets are now rarely made and used except in the most remote islands. Gill net fishing is practised on reefs and lagoons in the Pacific and in some areas, such as Kiribati, has become one of the most popular fishing methods in this archipelago. Gill net fishing is also widely practised in estuarine areas of the Pacific. In most instances nets are set from dinghies and canoes for periods of between 1 h and an overnight soak. The major drawback for fishermen with gill nets in both reefs and estuaries is damage to the nets from sharks.

Drive-in net fishing is commonly practised around many islands of the Pacific. Nets are set in an area of shallow water, on a reef plateau or in the lagoon and fish are driven by scare lines and swimmers into the net. The fish may be concentrated at one end of the net for hauling, or swimmers armed with spears may enter to kill and collect fish. A description of this type of fishing operation is given in Smith & Dalzell (1993). Surround netting involves setting a net around an area of coral or around a school of fish. The fish are then caught by swimmers who enter the net enclosure carrying spears. Beach seines may be deployed in lagoon waters to trap schooling fishes such as scads, small jacks, herrings and halfbeaks, while barrier nets can be strung across reef passages and channels to trap fish as they return from feeding on the reef plateau.

Other common net fishing techniques include cast netting and scoop netting for flying fishes. Cast nets are used in coastal shallows by fishermen to catch schooling species such as mullet and rabbitfishes. The fishermen stalk the school, which often creates a ripple pattern on the water surface, and attempt to cast a circular weighted net over the school and thus entangle the fish in the mesh. Hand-held scoop nets are commonly used in Polynesia to catch flying fishes at night. Fishermen chase the flying fishes over the water surface, spotting them by torch light and catching them in the scoop nets before the fish can launch themselves into flight (Gillett & Ianelli 1991).

Spears may be single- or multiple-pronged, traditionally made from wood and bone but nowadays made of steel. Spear fishing is conducted both above water and below. Spear fishermen may target fish from land or boat using spears and arrows, or by diving beneath the water with hand spears and spear guns. Captured fish are threaded on a line wrapped around the diver's waist, on a line trailing behind the diver or even towed in a galvanized basin buoyed by an old car inner-tube, as a precaution against shark attack. The development of masks, fins,

SCUBA gear, steel spears and spear guns has meant that the fishing power of the spear-fishermen has greatly increased. Some spear fisheries are very specialized such as that for dolphinfish (*Coryphaena hippurus*) in French Polynesia. High-powered launches will chase the dolphinfish along the surface, as this species will usually not dive to escape pursuit. As the fish tires the fisherman harpoons it with a multiple-pronged barbed spear.

Fixed or stationary traps are a common feature in coastal areas of the South Pacific. The simplest of these structures are V-shaped stone and stick enclosures with an entrance that faces the shore, as found, for example, in PNG (Hulo 1984) and Cook Islands (Baquie 1977). They may be more complex structures comprising a series of leaders or barriers that guide the fish into a series of interconnecting chambers. The chambers terminate in a single catching chamber where the fishes may be netted or speared. These more complex structures are found in French Polynesia (Grand 1985), Guam (Amesbury et al. 1986), Tonga (Halapua 1982) and Palau (Johannes 1981). Fixed barrier traps take advantage of the tidal foraging migration of different species of fish to effect capture. Fishes that have been feeding on the reef flat or in estuarine shallows will follow the receding tide into deeper water. When they encounter a fence they will swim along it and concentrate in a chamber or net where they can be caught.

The regular use of portable fish traps appears to be confirmed mainly to Micronesia and parts of French Polynesia, although bamboo and mangrove wood traps were traditionally deployed in coastal areas of the South Pacific (see for example Koch 1961 and contributions in Quinn et al. 1984). Johannes (1981) describes the deployment of portable fish traps in the shallow coastal waters of Palau, and Smith & Dalzell (1993) give a brief account of trap fishing in Woleai Atoll (Fig. 2, 115), which lies to the east of Yap. Traps in Palau are made either of traditional materials, such as sticks and vines, or welded steel bars and chicken wire and are used to catch a variety of reef fish. Traditional stick and vine traps are also used on Woleai to catch reef fishes and one type of trap is specifically designed to catch the goatfish (*Mulloidides flavolineatus*) when seasonally abundant in the lagoon. Cubiform wire mesh traps are deployed in the lagoon of Rangiroa Atoll (Fig. 2, 88), Tuamotu Archipelago in French Polynesia, to catch surgeonfishes, especially *Acanthurus xanthopterus* and *A. bleekeri*.

A variety of other fishing and collecting activities are conducted along Pacific shorelines and reefs in addition to fishing with spears, lines, traps and nets. Kite fishing is still employed in some parts of the region to catch needle fish (Belonidae) (Johannes 1981, Hulo 1984). A spider web lure is towed behind a canoe beneath a *Pandanus-leaf* kite. Needle fish or longtoms, which prey mainly on small pelagic fish, will attack the web lure as it skips over the sea surface and become snared as their teeth tangle in the spider web. Molluscs and echinoderms can be picked off the reef at low tide, and octopus may be drawn out of holes in the reef with a metal hook. In most locations molluscs, crustaceans, sea-cucumbers and seaurchins, collected mainly by women and children, may form a significant fraction of the total reef harvest (Wass 1982, Mathews & Oiterong 1991, Rawlinson et al. 1994).

Larger predatory fishes may also be caught in nooses at the water surface. Migrant phosphate mine workers from Tuvalu and Kiribati have been observed to noose wahoo (*Acanthocybium solandri*) that aggregate around mooring buoys on Nauru (Cusack 1987). A bamboo pole is rigged with a short line and a teaser bait, usually a flying fish, attached to one end. A second pole has a running noose attached to one end. The bait is splashed on the water surface until a wahoo responds and begins to make passes at it. The fisherman then attempts to position the noose between the wahoo and the bait so that the fish will pass through and can be snared. Perhaps the most spectacular example of this type of fishing is the catching of reef sharks by fishermen from Kontu village on New Ireland (Fig. 2, 67), PNG (Kohnke 1974). Reef sharks

are attracted or called by the use of a coconut shell rattle shaken in the water, which draws the shark to the canoe. The shark is coaxed through a cane noose with a reef fish (preferably rabbitfish). The noose is attached to a wooden propeller that spins as the shark dives, tightening the cane around the gills and suffocating it.

Industrial scale Fisheries

Most of the islands of the South Pacific have steeply shelving slopes and are surrounded by coral, unsuitable for conducting trawl fishing. Trawls can be deployed on the soft bottoms of estuarine areas of the bigger islands, however, for catching shrimps and demersal fishes. Only one South Pacific country, PNG, has established commercial trawl fisheries. The most important of these is the trawler fleet in the Gulf of Papua that numbers between 10 and 20 vessels and targets stocks of penaeid shrimps. The trawlers displace about 150 gross tonnes (gr.t.) and are twin rigged with two 12-fathom (footrope) nets. This fleet fishes 24 h per day throughout the year in the northern and eastern Gulf of Papua and has been operational since 1969. In the early 1980s, a smaller shrimp fishery, limited in most years to two vessels, commenced in Orangerie Bay (Fig. 2, 74) on the southeast Papuan coast.

The lagoons and sheltered embayments of the Pacific islands often contain small pelagic fishes that can be used as live bait for pole-and-line tuna fishing. The small pelagic resource is usually a complex of clupeoid species including anchovies (Engraulidae) and sprats, sardines and herrings (Clupeidae) as well as small scads (Carangidae), mackerel (Scombridae), silversides (Atherinidae) and fusiliers (Caesionidae). The small gracile anchovies belonging to the genera *Encrasicholina* and *Stolephorus*, and the sprats of the genus *Spratelloides*, are the principal targets of tuna live-bait fisheries in the South Pacific.

Fleets of pole-and-line tuna vessels (mainly from Okinawa) have operated from Palau, PNG, Kiribati, Fiji, New Caledonia and the Solomon Islands. A typical vessel is about 20 m in length and displaces about 60 gr.t. Catches of live bait are made from the pole-and-line boats using a stick-held dip net or bouke-ami. Catches are made at night after concentrating the bait fishes around powerful submersible lights. The captured bait is concentrated in one end of the net and loaded into buckets for transfer to tanks set in the deck of the tuna vessel. The bouke-ami is then stowed while the tuna vessel sails for the open sea to pursue tuna schools. The deployment and operation of the bouke-ami is described in detail by Muiyad (1980). Pole-and-line tuna fishing has largely been superseded by purse-seining and is now confined chiefly to the Solomon Islands and Fiji fleets with small fisheries in Tuvalu and Kiribati (Anon. 1995).

Finfish fisheries

Reef fisheries

Description

Fishing on coral reefs occurs in all the countries and territories of the South Pacific and most of the techniques employed are comparable between the different locations. We have therefore not described at length the reef fisheries in each country; instead we have summarized the relevant literature in Table 1 and selected examples that might be described as typical of a country

or sub-region within the South Pacific. Without exception, all reef fisheries in the South Pacific are small-scale fisheries using simple non-mechanized gears. The major differences between Pacific island reef fisheries are the range of gears used, the emphasis on particular gears and most importantly, the fishing pressure applied to reef fish stocks. Fish does not appear to be as important in subsistence diets in the large island archipelagos of Melanesia as in the smaller resource-limited countries of Micronesia and Polynesia (Coyne et al. 1984). The annual *per capita* production for the Pacific islands can be approximated from the figures in Table 27 (p. 499) and the population figures in Table 1. This ranges from 7 — 40 kg or a mean of 23 kg for the Melanesian islands, while for the Polynesian and Micronesian islands the ranges are 6 — 121 and 4 — 170 kg, with means of 61 and 63 kg respectively. Fishing effort on all coastal fisheries stocks, including reef fishes, is substantially greater in the Micronesian and Polynesian islands, in comparison with the Melanesian islands.

In all but the remotest islands, reef and other coastal fisheries have both a subsistence and a commercial component. The size of the commercial fisheries sector is dependent on the degree of urbanization of the island population, the amount of available land for agriculture and the development of the cash economy. Subsistence reef fishing methods tend to be very simple and in most of the examples given in Table 2, fishes caught by hand-lines and spears make up most of the subsistence catch. Larger volumes of fish can be generated through the use of community fishing methods such as group spearing and drive-in net fishing and these methods may be employed when greater amounts of fish are required for occasions such as village feasts. Commercial reef fisheries also include hand-lines and spears but in the examples in Table 2 there is a greater emphasis on the use of nets such as gill nets, drive-in nets and fish corrals.

Table 1: Geographical and economic statistics for the countries and territories of the South Pacific.

Country	Land area (km ²)	Population (1994)	Pop. density	Annual growth rate (%)	Total GDP (US\$ 000)	Per capita GDP
American Samoa	200	54 600	273	3.7	203 125.3	5194.8
Cook Islands	237	19 100	81	1.1	70 095.5	4052.1
Federated States of Micronesia (FSM)	701	105 900	151	3.0	246 011.2	2652
Fiji	18 272	777 700	43	2.0	1,620 707.4	2118.5
French Polynesia	3521	218 000	62	2.5	3,202 764.2	15 305.2
Guam	541	146 700	271	2.3	1,180 427.8	9637.7
Kiribati	810	78 300	97	2.3	33 875.4	468
Marshall Islands	181	54 069	299	4.0	74 735.8	1556
Nauru	21	10 600	505	2.9	160 875	17 486
Niue	259	2 100	8	-2.4	6891.6	3077.8
Northern Mariana Is	471	56 600	120	9.5	571 297	10 094
New Caledonia	19 103	182 200	10	2.0	2,125 919.6	12 753
Palau	488	16 500	34	2.2	49 367.1	3247.4
Papua New Guinea	462 243	3,951 500	9	2.3	5,670 260.7	1468
Pitcairn	5	60	12			
Solomon Islands	27 556	367 400	13	3.4	262 526.2	738.7
Tokelau	10	1500	150	-1.3	624	372.8
Tonga	747	98300	132	0.5	138 035	1415.7
Tuvalu	26	9500	365	1.7	64 187.2	7053.5
Vanuatu	12 190	164 100	13	2.8	208 878.5	1308.8
Wallis & Futuna	255	14 400	56	1.3		
Western Samoa	2935	163 500	56	0.5	165 885.7	1017.9

Table 2: Summary of literature sources describing reef fisheries in the Pacific islands.

Country	Location	Reference
Australia	Torres Straits	Johannes & MacFarlane (eds) 1991
American Samoa	Tutuila	Craig et al. 1993, Saucerman 1994
Cook Islands	Rarotonga	Baquin 1977
	Palmerston	Anon. 1988a
Federated States of Micronesia		Smith 1992a
	Woleai Atoll	Smith & Dalzell 1993
	Kosrae	Wilson & Hamilton 1992
	Yap	Uwate 1987
Fiji	Rotuma	Anon. 1983a
	Rabi (Fig. 2, 84)	Anon. 1983b
	Dravuni (Fig. 2, 20)	Emery & Winterbottom 1991,
	South & East Fiji	Jennings & Polunin 1995a,
	Viti Levu	Rawlinson et al. 1994
French polynesia	Tuamotu Archipelago	Grand 1983, 1985, Stein 1988
	Kaukura	Grand 1983
	Rangiroa	Grand et al. 1983
	Tikehau	Morize 1985, Caillart 1988a
Guam		Amesbury et al. 1986, Katnick 1982,
		Knudson 1987, Myers 1993
Hawaii		Smith 1994
Kiribati	Gilbert Islands	Mees et al. 1988
	Tarawa	Yeeting & Wright 1989
Marshall Islands		Smith 1992b
Nauru		Dalzell & Debaio 1994
New Caledonia		Loubens 1978a, Leblic & Teulieres
		1987, Anon. 1988b, 1994a
Niue		Dalzell et al. 1992
Northern Mariana Islands		Hamm et al. 1994
Palau		Johannes 1981 1991, Nichols 1991,
		Mathews & Oiterong 1991, Kitalong
		& Dalzell 1994
Papua New Guinea	Kavieng	Wright & Richards 1985, Dalzell &
		Wright 1990
	Port Moresby	Lock 1986a, b, c, d
	Western Manus	Chapau & Lokani 1986
Pitcairn Islands	Pitcairn Island	Sharples 1994
Solomon Islands	Marovo Lagoon	Hviding 1988
	Roviana, Tulagi and Vona Vona	Leqata et al. 1990, Blaber et al 1990
	Gizo	Sasabule 1991
	Roviana	Gina-Whewell 1994
	Ontong Java	Bayliss-Smith 1974
Tokelau	Fakaofo (Fig. 2, 23)	Hooper 1985
Tonga	Tongatapu	Zann 1981, Halapua 1982, Munro
		1990
Tuvalu	Funafuti	Zann 1980, Patiale & Dalzell 1990
	Nanumea	Chambers 1984
Vanuatu		David & Cillauren 1989
Wallis & Futuna	Wallis	Taumaia & Cusack 1988
	Futuna (Fig. 2, 27)	Galzin 1985
Western Samoa	Upolu	Helm 1992, Zann et al. 1991

In PNG, the largest of the Melanesian archipelagos, fishing activity, including subsistence fishing, is very limited around most of the coast and this is true of fishing on coral reefs (Dalzell & Wright 1986). Wright & Richard's (1985) study of the Tigak Islands (Fig. 2, 100) reef fishery in northern PNG is a good descriptive account of subsistence and commercial reef fishing applicable to most coral reef areas of PNG and probably most of rural Melanesia. Almost all the subsistence catch came from hand-line fishing and spear fishing from canoes and dinghies.

Wright & Richards note that catches are made to satisfy only immediate food requirements and nets are rarely employed as their use requires more organization and yields a large surplus catch. There is no full-time commercial reef fishery in the Tigak Islands. When cash is required, villagers will occasionally catch relatively large volumes of fish for sale in the main urban centre of Kavieng (Fig. 2, 39), mostly through gill and surround netting. The main influences on the volume of commercial landings by individual villages were distance from markets in Kavieng and the price of the main agricultural commodity, copra (Dalzell & Wright 1990).

The main motivation for commercial fishing in the Melanesian islands is lack of any agricultural land. Daugo Island (Fig. 2, 19) is a small barren coral island on the Papuan Barrier Reef with poor top soil, few trees and bushes and no fresh water, which the islanders have to bring from the mainland. As the Daugo Islanders have no subsistence or cash crops they have turned to full-time professional fishing and are among the main suppliers of fresh reef fish to Port Moresby, the capital city of PNG. Lock (1986a, b, c, d) described the Daugo Island reef fishery where two-thirds of the catches come from surround nets, drive-in nets and gill nets deployed from outboard-powered dinghies. The balance of the catch comes from hand-lining, spear fishing and trolling. Unlike the villagers of the Tigak Islands who fish only occasionally, the fishermen of Daugo Island are active daily, fishing from dawn until mid-afternoon, when they travel to the produce markets in Port Moresby to sell their catches.

Descriptions of reef fishing for subsistence purposes in the Solomon Islands (Bayliss-Smith 1974, Hviding 1988, Leqata et al. 1990) and Vanuatu (David & Cillauren 1989) are comparable with those in PNG. Subsistence catches are taken mainly with hand-lines from canoes. Sales of copra and vegetable produce are among the main sources of income in most locations, rather than commercial fishing. As with PNG, the most successful commercial reef fishermen are landless migrants from other provinces who have no alternative incomes from agriculture (Sasabule 1991). Both New Caledonia and Fiji have large urban populations and well established commercial reef fisheries, both of which are dominated by landings of emperors, particularly *Lethrinus nebulosus* (Dalzell et al. 1992, Anon. 1994a). Commercial reef fish catches in both countries are taken mainly with hand-lines and gill nets (Loubens 1978a, Anon. 1988b, Rawlinson et al. 1994). New Caledonia and Fiji, in particular, have well developed tourist industries with over 80000 and 280000 visitors per annum, respectively, that provide an extra market for commercial reef fish catches.

Subsistence reef and lagoon catches in the rural areas in both New Caledonia and Fiji and are taken by a combination of spear fishing, hand-lining and net fishing (Leblic & Teulières 1987, Emery & Winterbottom 1991, Rawlinson et al. 1994, Jennings & Polunin 1995a, b). In Fiji, around 30% of rural Fijians go fishing at least once a week (37% of the males, 48% of the females, and 5% of the children, on the main island of Viti Levu), but this involves nearly 100% of village households (Rawlinson et al. 1994). The main reef fish targeted are species in the family Lethrinidae, but serranids, hemiramphids, gerreids and scombrids are also prominent, and carangids are important around the larger islands. Fiji has approximately 2 000 registered artisanal fishing boats (Anon. 1994b). New Caledonia has a large fleet of recreational craft, over 11 000 registered vessels mostly berthed in the capital city, Noumea (Fig 2, 71) (Nguyen-Khoa 1993). According to Loubens (1978a), about 60% of the total catch from the southwest lagoon of New Caledonia is taken by recreational fishermen, using mainly hand-lines and spear fishing. Furthermore Kulbicki & Grandperrin (1988) showed that there was a positive correlation between catch per unit effort (CPUE) of lagoon species and distance from Noumea in a 50-km radius after which catch rates level off. The 50-km radius is

approximately the outer limit of the range of most recreational fishermen (Loubens 1978a).

As fish, in general, comprise a greater component of the diets of Polynesians and Micronesians, this demand creates more intensive subsistence and commercial fisheries than in Melanesia. In Tonga and Western Samoa, nearly 70% of the respective populations are concentrated on one island in each archipelago, namely Tongatapu and Upolu (Fig 2, 109). Zann et al. (1991) state that over three-quarters of the villages on Upolu are engaged in fishing with an average of between two and four fishing trips per week and that half the households in rural areas are reliant on reef fisheries as the main subsistence source of protein. Almost all fishing occurs in shallow inshore waters less than 10 m deep, with spear fishing being the most regularly employed fishing method, followed by net fishing and handlining. Two thirds of the catch is consumed with the balance being sold in markets in Apia (Fig 2, 4), or increasingly sent by air to American Samoa, where there is a very high demand for fresh reef fish (Craig et al. 1993).

Tongan reef fisheries have been described by Halapua (1982) and more recently by Tu'avao et al. (1994). Commercial reef fish catches are made by spear fishing, hand-line fishing, gill and drive-in netting and from fish corrals. The commercial reef fisheries in Tonga are structured around small-boat operators who employ a number of fishermen and take the major share of the catch revenue. Spear fishing and net fishing are conducted on the reefs around Tongatapu; however, hand-line fishermen have been forced to travel to offshore reefs and banks due to depletion of stocks around the main island. Fish corrals set on the reef plateau around Tongatapu were mainly constructed for catching mullet, and were so successful that stocks declined markedly, leading to a ban (not fully implemented, however) on this type of gear. The decline in catches has led to a decline in the number of fish corrals around Tongatapu. Landlessness is also a factor in the commercial reef fishery in Tongatapu. Most of the spear fishermen in the commercial fishery are migrants from the Ha'apai Islands (Fig 2, 33) who, possessing no land, turn to a simple and cheap fishing method to provide incomes.

Fishes are one of the very few resources that offer any commercial potential in the Polynesian and Micronesian atolls, and reef and lagoon fishes are the easiest and most convenient for fishermen to target. Commercial reef fisheries in French Polynesia supply the main island of Tahiti where half of the population of this territory now live. About 40 % of the fish sold through the market in Tahiti are reef fishes from the atolls of the Tuamotu Archipelago (Fig 2, 107). Descriptions of the reef fisheries in these atolls have been given by Grand (1983, 1985), Grand et al. (1983), Morize (1985) and Caillart (1988a). About 90% of the commercial reef fish landings in these islands are from fish corrals deployed on the atolls of Kaukura (Fig 2, 38), Aratua (Fig 2, 5), Tikehau (Fig 2, 100), Rangiroa and Apataki (Fig 2, 3) (Stein 1988). Other fishing techniques such as gill nets, hand-lines, portable fish traps and spear fishing are used to supplement commercial catches, when production from the corrals is reduced. Similar movement of commercial reef fish catches from an outlying atoll to the main urban centre is also found in the neighbouring Cook Islands. Relatively large volumes of parrotfishes, mullet and trevallies, caught with gill nets and drive-in nets at Palmerston Atoll (Fig 2, 78), are regularly sent to markets in Rarotonga (Richards 1993).

Reef fishing in the remoter atolls of Micronesia and Polynesia are entirely for subsistence, apart from the small amounts of fish that might occasionally be traded with passing ships. Smith & Dalzell (1993) described reef fishing methods used on Woleai Atoll, one of the outlying atolls in the Caroline Islands, where many aspects of traditional life are maintained. Reef fishing methods include hand-lines, spear fishing, portable fish traps and drive in net fishing. While

this is similar to other islands in the Pacific, gears like leaf sweeps used for drive-in-fishing and fish traps are still manufactured from traditional materials. Furthermore, techniques such as fish trapping require considerable skill and there are several different trap types deployed in different seasons to target various reef fish species. Increasing urbanization in atolls, as elsewhere, is leading to changes in reef fisheries with the development of commercial fisheries and the adoption of more modern efficient fishing techniques. At Tarawa (Fig. 2, 98), the principal atoll of Kiribati and home to 40% of the population of the Gilbert Islands (Fig. 2, 30), the numbers of monofilament hand-lines and gill nets increased exponentially over a 10-year period to become the most important fishing methods for reef and lagoon fishes (Yeeting & Wright 1989).

Many of the American associated islands of Micronesia (Palau, Guam, Northern Mariana Islands, Federated States of Micronesia) are becoming increasingly urbanized as populations grow and accelerate demand for fresh fish and in particular fresh reef fish. Tourism, mainly from Japan, is a major industry in islands such as Guam, Palau and Saipan, and is also creating an additional demand for reef fish. A large range of traditional techniques to catch reef fish have been documented on Guam (Amesbury et al. 1986) but, as elsewhere, they are largely replaced with more modern gears. Commercial reef fishing on Guam comprises mainly hand-line fishing and spear fishing, with minor contributions from various net fishing methods (Myers 1993). Commercial hand-line fishing targets reef fish stocks in waters < 150 m, mainly emperors (Lethrinidae), jacks (Carangidae) and snappers (Lutjanidae). Spear fishing consists of two components based on whether SCUBA equipment is used. Higher proportions of certain species such as wrasses (Labridae), groupers (Serranidae), parrotfishes (Scaridae) and goatfishes (Mullidae) are caught by spear fishermen using SCUBA equipment. Commercial spear fishermen on Guam have driven certain reef species, such as the bump-headed parrotfish (*Bolbometopon muricatum*) and the Napoleon wrasse (*Cheilinus undulatus*), to very low population levels and similar practices are thought to be depleting populations of the same species on Palau (Myers 1989, Hensley & Sherwood 1993).

Traditional and contemporary fishing methods for catching reef fish in Palau, include hand-lining, spear fishing, gill netting, fish trapping and set nets (Johannes 1981). Women and children on Palau obtain a subsistence catch of fish primarily by hand-lining in reef pools during the day or spearing fishes from the surface at night (Mathews & Oiterong 1991). No information is available on the relative contribution to commercial and subsistence catches by the various gears, although Johannes (1981) states that set nets and spear fishing are the two most important and productive reef fishing methods employed on Palau. Set nets, known locally as kesokes, work on the same principle as fish corrals in that they trap fish as they migrate into deeper water with the falling tide, and concentrate the catch in the apex of a stationary V-shaped barrier net (Johannes 1981). Besides markets in the capital, Koror (Fig. 2, 41), reef fishes are also exported to Guam and Saipan, both as official exports and in the form of passenger luggage on planes. An increasing number of fish buyers are coming to Palau from Guam and the Northern Mariana Islands to buy fish for sale at home and transporting it in ice boxes as luggage (Preston 1990a, Adams 1993a), which means that this is not registered in the official exports from Palau.

Reef fisheries in countries with very limited reef and lagoon areas such as Niue, the Northern Mariana Islands and Pitcairn Island may still form an important component of total fisheries landings. In the Northern Mariana Islands, surrounded mainly by narrow fringing reefs and with limited lagoon area, reef fishes account for half of commercial fish landings. The principle fishing methods include gill nets, fish fences or corrals, hand-lining and spear fishing (Watt 1990). Nearly all subsistence catches are shallow water reef fishes taken by similar gears. Niue

is a makatea or raised atoll with a narrow coral-encrusted rock shelf. Half of the total fish catch on Niue comes from fishing on the narrow reef around the island, and about two-thirds of this catch is taken by hand-line fishing (Dalzell et al. 1993). Commercial fishermen on Niue concentrate on deep slope and pelagic fish and all reef fish catches are part of the subsistence production. The small population on Pitcairn Island fish regularly for subsistence and, perhaps surprisingly for such a remote location, for commercial purposes (P. Sharples, South Pacific Commission, pers. comm.). Because of historical interest in Pitcairn, however, several vessels stop by the island each month for the Pitcairners to market fish and carvings. Fishing is conducted on the fringing reefs and reef slope around Pitcairn Island, either from dinghies or from the rocky shore. Almost all fishing is conducted with hand-lines targeting the drummer, *Kyphosus bigibbus*, and the grouper, *Epinephelus fasciatus*, for subsistence, while the red grouper, *Variola louti*, and the larger eteline snappers on the deep slope are the targets of commercial fishing.

By contrast, fisheries production on Nauru and Futuna, both islands with narrow fringing reefs and no lagoon area, is mainly from pelagic rather than reef fisheries. Nauru, like Niue, is a makatea but it is unusual in that despite its small size it is a very wealthy country, as a result of substantial revenues generated from mining the phosphate bearing rock that forms most of the interior of the island. Nauruans fish mainly for recreational purposes from powered skiffs, trolling for large pelagic species rather than fishing for reef fishes (Dalzell & Debaio 1994). The several thousand Kiribati and Tuvaluan mine workers on Nauru supplement their incomes by commercial fishing, mainly for large pelagic fishes. A little commercial hand-line fishing for reef fishes is conducted, however, on the reef slope in waters between 50 to 100 m, often using a T-shaped or cruciform wire assembly, known as a Christmas Tree, with between 18 and 32 hooks. Small amounts of reef fish are also caught commercially by spear fishing using SCUBA. In all, reef fishes comprise about 10% of the total fish landings on Nauru. Reef fishes are also caught on Futuna for subsistence, using handlines, spears, and gill nets (Galzin 1985). As on Nauru reef, however fishes make only a minor contribution ($\approx 6.0\%$) to the total fisheries production on the island, most of which comes from exploitation of large pelagic fishes.

The foregoing summarizes the salient features of reef fisheries in the South Pacific islands. We will also briefly mention the characteristics of reef fisheries on the Australian Great Barrier Reef (GBR) (Fig. 2, 29) and around the Hawaiian archipelago. Commercial reef fishing on the GBR is highly specialized and mainly targets the coral trout, *Plectropomus leopardus*, and the emperor, *Lethrinus chrysostomus*, together with other high value snappers, groupers and emperors. Catches in both the commercial and recreational fisheries are made with handlines. Other reef fishes that are highly valued by Pacific islanders such as surgeonfishes, parrotfishes, rabbitfishes and wrasses are generally not targeted by commercial and recreational fishermen. The total annual commercial reef fish catch from the GBR amounts to about 3000 t (Brown et al. 1994). Reef fisheries in Hawaii exhibit more similarities to those in the Pacific islands, although subsistence catches are not as important and recreational catches form the largest proportion of the non-commercial catch. Like New Caledonia, Hawaii has a large fleet of recreational craft, estimated to be 12690 vessels and nearly 190 000 anglers (Smith 1993). Reef fishes form a relatively small part of the total commercial inshore catch of about 700 t yr⁻¹ ($\approx 10\%$) but market preferences increase the value of the reef fishes catch (Smith 1993). Reef fish are caught predominantly with hand-lines and gill nets by commercial fishermen, while angling with rod-and-reel assemblies, and spear fishing with and without SCUBA equipment generate most of the recreational reef fish catch.

The composition of reef fish catches is extremely varied, both in time and location. Table 3 presents information on the composition of reef fish landings from various locations in the South Pacific classified to the family level. The dominant feature of fish landings in many parts of the Pacific is the emperors (Lethrinidae), while other important components include surgeonfishes (Acanthuridae), snappers (Lutjanidae), parrotfishes (Scaridae), and coastal tunas and mackerels (Scombridae). Although these families contain a large range of species, often one or a few species will dominate in each family. In New Caledonia and Fiji, for example, landings of emperors consist mainly of *Lethrinus nebulosus* (Dalzell et al. 1992, Anon. 1994b), while in Tikehau Atoll (French Polynesia) emperor landings consist mainly of *Lethrinus miniatus* (Caillart 1988a). Similarly, surgeonfish landings in New Caledonia are dominated by *Naso unicornis* (Anon. 1992a), while *Acanthurus dussumieri* and *Naso* spp. (mainly *N. unicornis* and *N. brevirostris*) constitute most of the surgeonfish landings in the reef fishery on the South Papuan coast (Lock 1986a). Although commercial reef fish landings in Palau contain over 200 species, half of the catch comprises only seven species (*N. unicornis*, *Bolbometopon muricatum*, *Lutjanus gibbus*, *Lethrinus ramak*, *Hipposcarus longiceps*, *Siganus canaliculatus*, *S. lineatus*).

Pelagic species such as the small mackerels, *Rastrelliger* spp., and the large predatory Spanish mackerel (*Scomberomorus commerson*) are common components of reef fish landings although not reef fish *sensu stricto*. Fishermen trolling along the reef edge often catch large pelagic predators such as Spanish mackerels, dogtooth tunas (*Gymnosarda unicolor*), rainbow runners and queenfish (*Scomberoides* spp.), which may be included in the reef fish catch. Furthermore, landings of carangids may be dominated by the small bigeye scads, *Selar crumenophthalmus*, and the less common *S. boops*. These small schooling pelagic fishes are universally prized as a food fish throughout the Pacific and in some years, when particularly abundant, will dominate landings of jacks and of reef fishes in general (Helm 1992, Saucerman 1994). A feature of bigeye scad landings in reef fisheries is their inconsistency, where they can dominate landings in one year and be virtually absent from the fishery the next (Helm 1992, Hensley & Sherwood 1993, Saucerman 1994).

Catch composition will also depend on the type of fishing gear employed in the fishery. Hand-lines catch predominantly predatory species such as snappers, groupers and emperors, but small hooks baited with items such as seaweed, coconut flesh and congealed squid ink can be used to catch herbivores such as surgeonfishes, rabbitfishes and rudderfishes (Amesbury et al. 1986). Spear and net fishing tend to take a broader range of species. This is well illustrated by Table 4, which shows the catch composition for three different methods of net fishing plus hand-lining and spear fishing on shallow reef stocks of the South Papuan Barrier Reef near Port Moresby. Two-thirds of the hand-line catch are emperors with most of the balance of the catch made up from snappers, jacks and groupers. Emperors are also a dominant feature of the net catches, but there is a wider range of species taken including herbivores such as surgeonfishes, parrotfishes and rabbitfishes. Spear fishermen rely on getting close to their quarry and emperors tend to shy away from divers underwater. Other species, such as surgeonfishes, groupers and scombrids such as Spanish mackerel, that become curious of divers, are vulnerable to spear fishermen.

There are few long time series of catch species composition data for reef fisheries in the South Pacific from which to judge the long-term effects of fishing on reef fish communities. Kitalong & Dalzell (1994) examined a 14-yr time series of commercial reef fish landings data from Palau and concluded that there had been little change in the composition of landings over time at the level of the family. Declines were noted, however, of certain species, such as

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Table 3: Percent composition of reef fish catches from various locations in the South Pacific region.

Family	Fiji	PNG (North)	PNG (South)	Solomon Is	Kiribati	Palau	Guam	N. Mariana Islands ¹	Kosrae (FSM)	Am. Samoa	W. Samoa	Tongatonga	Tikehau (Fr. Polynesia)	Nauru	New Caledonia
Lethrinidae	17.66	10	29	6.2	7.8	14	17.70	1.35	5.36	1.44	19.5	38.36	6		31.02
Chanidae	0.32	2													
Balistidae	0.33	2					0.57			0.97			2	4.74	
Albulidae	0.01	1			16.5								2		
Hemiramphidae	1.66	1													
Serranidae	12.62	9	3	6.6	3.1	9	7.58	1.01	5.21	12.84	4.55		4	3.62	18
Scombridae	18.74	3	10	15.3	24.3							1.39			12.57
Carangidae	7.41	14	8	10.2	3.2	4	16.59	1.26	7.88		8.05	1.59	18	3.26	
Mullidae	1.48		5	5.1	2.9	1	1.81	0.38	3.56	2.22	8.05	4.56	10	0.77	
Lutjanidae	11.01	13	5	192	11.1	12	3.63	0.26	7.36	7.02	1.75	1.33	6	39.54	3.50
Acanthuridae	406	5	7	6.4		14	9.12	1.11	22.73	27.76	19.5	16	20.78	3.65	
Scaridae	3.84	8	5	11.5		18	8.48	5.55	6.91	6.33	14	2.69	10	1.17	
Belonidae	0.17		5	3.9			0.33			0.02				0.61	
Mugilidae	10.24	21	4		3.3	1	0.36	0.04	6.57	7.47	10.45	17.00	6	1.12	10.85
Siganidae	1.08	1	6	3.9		10	5.62	1.80	7.31	0.01	1.05	1.43	2		3.91
Sphyraenidae	7.45				3.2		7.90	0.10				1.07	2	0.24	
Gerridae	0.21	2			5.3					0.01				0.07	
Haemulidae	1.33	3	4	5.4						0.01					
Labridae							4.31	0.03		2.77	0.8			0.16	
Holocentridae									5.05	12.47	2.25	4.47		17.26	
Theraponidae	0.39									0.03					
Others		8	6	6.3	19.3	17	15.99	87.10	22.06	18.62	10.05	26.12	16	6.62	16.51

1. Most reef fish landed in the Northern Mariana Islands are reported only as mixed reef fish.

Table 4: Percent catch composition by different artisanal fishing methods on reef fish stocks on the South Papuan Barrier Reef.

Family	Fishing method				
	Spear	Hand line	Gill net	Drive-in net	Surround net
Carcharhinidae			1	2	
Mylobatidae				1	
Chanidae			2	1	
Hemiramphidae					3
Belonidae			0		1
Serranidae	21	10	3		1
Carangidae	5	7	11	13	4
Lutjanidae	3	12	13		6
Gerridae			0	3	
Haemulidae	14		10	5	1
Lethrinidae	1	65	42	31	37
Sparidae					0
Mullidae				3	12
Mugilidae				11	
Platacidae	4				
Kyphosidae	8		2		1
Sphyraenidae	2			1	
Labridae	2				2
Scaridae	3		1	7	10
Acanthuridae	17		2	2	17
Siganidae			0	8	5
Scombridae	17		11	5	
Balistidae		3	0	1	
Others	3	3	2	6	0
Total	100	100	100	100	100

Crenimugil crenilabis, that were thought to be linked to excessive fishing pressure. Stein (1988) summarized information from a 25-yr time series of landings of reef fishes from the Tuamotu Archipelago but, unfortunately, did not comment on whether there have been major shifts in the catch composition over this time. Catch data between 1982 and 1991 from Guam were analyzed by Hensley & Sherwood (1993) who showed that there were large declines of certain species in the reef fish catch such as goatfish (*Mulloides flavolineatus*), parrotfish (*Bolbometopon muricatum*), wrasse (*Cheilinus undulatus*), and large snappers and groupers.

Catch rates

Catch rates from deployment of artisanal gears such as hand-lines, spears and nets are at best modest (Tables 4 – 7). Catches from hand-line fishing in shallow water ranged from 0.03 to 12.12 kgline⁻¹h⁻¹ and from 0.44 to 3.5 kgline⁻¹h⁻¹ for overall mean catch rates. In most instances, the hand-line gear consists of monofilament line equipped with between 1 and 3 hooks, usually with some form of sinker, although in Nauru, wire rigs bearing between 18 and 32 hooks (see p. 414) are preferred to maximize catches. The principal targets of shallow water hand-line fishing are groupers, snappers, emperors and jacks. The highest catch rates in Table 5, reported by Dalzell & Preston (1992), are from fishing mainly on snapper and grouper stocks beyond the reef margin in waters between 80 and 400 m in depth (see p. 432). Catch rates from underwater spear fishing ranged from 0.08 to 9.6 kgman⁻¹h⁻¹, with average ranging from 0.4 to 8.5

Table 5: Summary of catch rate (CPUE, catch per unit effort) and catch composition data for hand-line fishing on shallow coral reef and deep-slope fish stocks in the South Pacific

Location	Target stock	CPUE (kgline ⁻¹ h ⁻¹)		Principal components	Source
		range	mean		
Papua New Guinea (Port Moresby)	Shallow reef species	0.68 – 40	2.46	Lutjanidae, Carangidae, Serranidae, Lethrinidae	Lock 1986a, c
Papua New Guinea (Tigak Is)	Shallow reef species	na	1.2	Lutjanidae, Carangidae, Serranidae, Lethrinidae	Wright & Richards 1985
American Samoa	Shallow reef species	0.25 – 1.51	0.54	na	Saucerman 1994
Guam	Shallow reef species	0.03 – 2.04	0.55	Carangidae, Lethrinidae, Acanthuridae, Siganidae	Katnik 1982
Palau	Shallow reef species	2.2 – 7.32	3.49	Lutjanidae, Lethrinidae, Serranidae	Anon. 1992e 1993b
Fiji (Ba Fig. 2, 6)	Shallow reef species	0.14 – 12.12	2.27	Lutjanidae, Lethrinidae, Carangidae, Serranidae	J. Anderson, MRAG, London, pers. comm.
FSM (Kosrae)	Shallow reef species	na	1.78	na	Smith 1992a
Tonga (Tongatapu)	Shallow reef species	na	0.44	Lethrinidae, Holocentridae, Lutjanidae	Munro 1990
Tuvalu (Funafuti)	Shallow reef species	0.33 – 5.93	2.35	Lutjanidae, Lethrinidae, Serranidae, Carangidae	Patiale & Dalzell 1990
Wallis	Shallow reef species	na	1.3	Lutjanidae, Lethrinidae, Serranidae, Carangidae	Taumaia & Cusack 1988
FSM (Pohnpei)	Shallow reef and deep slope species	0.69 – 5.12	3.01	Lutjanidae, Carangidae, Serranidae, Lethrinidae	Dalzell unpub data
FSM (Yap)	Shallow reef and deep slope species	0.97 – 3.1	1.67	na	Uwate 1987
FSM (Chuuk Outer Banks)	Shallow reef and deep slope species	1.31 – 4.57	2.30	Lutjanidae, Carangidae, Lethrinidae, Scombridae	Diplock & Dalzell 1991
Nauru	Shallow reef and deep slope species	0.75 – 72	3.0	Lutjanidae, Serranidae, Carangidae, Holocentridae	Dalzell & Debaio 1994
Tropical Pacific atolls	Deep slope species	0.4 – 19.0	7.7	Lutjanidae, Serranidae, Carangidae, Lethrinidae	Dalzell & Preston 1992
Tropical Pacific high islands	Deep slope species	2.2 – 13.2	6.0	Lutjanidae, Serranidae, Carangidae, Lethrinidae	Dalzell & Preston 1992
Tonga	Deep slope species	3.64 – 5.31	45	Lutjanidae, Serranidae, Lethrinidae	Mees 1994
Papua New Guinea (Kavieng)	Deep slope species	0.6 – 11.24	3.1	Lutjanidae, Serranidae, Lethrinidae	Richards & Sundberg 1984
Papua New Guinea	Deep slope species	na	3.7	Lutjanidae, Serranidae, Carangidae, Lethrinidae	Chapau 1988
FSM (Pohnpei)	Deep slope species	3.9 – 5.5	4.7	Lutjanidae, Carangidae, Serranidae, Lethrinidae	McCoy 1990
Tuvalu	Deep slope species	1.72 – 9.62	6.1	Lutjanidae, Serranidae, Carangidae	Anon. 1993c
Vanuatu	Deep slope species	0 – 5.00	1.44	Lutjanidae, Serranidae, Lethrinidae	Schaan et al. 1987
Niue	Deep slope species	2.1 – 8.5	5.5	Lutjanidae, Serranidae, Carangidae	Dalzell et al. 1992

na = not available

Table 6: Summary of catch rates (CPUE, catch per unit effort) and catch composition of spear-fishing on South Pacific reefs.

Location	Target stock	CPUE (kgman ⁻¹ h ⁻¹)		Principal catch components	Source
		range	mean		
Papua New Guinea (Port Moresby)	Reef & lagoon species & large pelagics	1.2 – 3.6	2.4	Serranidae, Acanthuridae, Scombridae, Haemulidae	Lock 1986a
Papua New Guinea (Kavieng)	Reef & lagoon species	na	2.4	Scaridae, Serranidae, Lutjanidae, Haemulidae	Wright & Richards 1985
Palau	Reef & lagoon species	7.4 – 9.6	8.5	Scaridae, Serranidae, Acanthuridae, Lethrinidae	Anon. 1992e, 1993b
Nauru	Reef and reef slope species	0.2 – 4.3	2.0	Lutjanidae, Holocentridae, Serranidae, Acanthuridae	Dalzell & Debaio 1994
Guam	Reef & lagoon species	0.08 – 1.14	0.41	Scaridae, Kyphosidae, Siganidae, Acanthuridae	Katnik 1982
Kosrae	Reef. & lagoon species	18 – 57	3.28	na	Smith 1992a
Woleai	Reef & lagoon species	0.55 – 204	1.27	Acanthuridae, Scaridae	Smith & Dalzell 1993
(Micronesia)	species			Balistidae, Labridae	
Tonga	Reef & lagoon species	1.2 – 1.7	14	Acanthuridae, Scaridae, Holocentridae, Serranidae	Halapua 1982
Fiji (Dravuni)	Reef & lagoon species	0.81 – 1.6	1.20	Serranidae, Acanthuridae, Lutjanidae, Carangidae	Emery & Winterbottom 1991
Fiji (Ba)	Reef & lagoon species	0.12 – 5.7	1.51	Lethrinidae, Lutjanidae, Serranidae, Scombridae	J. Anderson, MRAG, London (pers. comm..)

na = not available

kgman⁻¹h⁻¹. The principal targets for spear fishing are groupers, surgeonfishes, parrotfishes and snappers (Table 6).

Tables 7 and 8 give details of catches by gill nets, drive-in nets and beach seining in the Pacific islands. Unlike spear fishing and hand-lining where CPUE is invariably reported as kgman⁻¹h⁻¹ or kgline⁻¹h⁻¹, a range of different units to express CPUE have been used. Comparisons are further complicated by the variation in net length and mesh sizes employed. Catch per set is the commonest reported CPUE for gill nets and this ranged from 4.2 to 31.8 kgset⁻¹ for the examples given here. The principal targets for gill net fishing appear to be jacks, mullets, emperors, goatfishes and snappers. The same problems in the expression of effort and CPUE were found with the examples of drive-in net fishing in Table 8. Catch rates for drive-in-net fishing varied between 0.25 and 3.9 kgman⁻¹h⁻¹, or 13.1 and 42.7 kgset⁻¹. The beach seine catches in Table 8 were all directed towards catching small pelagic fishes in coral reef lagoons, and all but one of these were taken from the published records of the South Pacific Commission's Skipjack Survey and Assessment Programme. The very high average catch rate for beach seining in Rabaul (Fig. 2, 83), PNG was a result of regular fishing on a large school of bigeye scads (*Selar* spp.). Elsewhere, in the Pacific, beach seine catches, predominantly of small pelagic fishes, tended to be lower, with catches comprising sardines, herrings, goatfishes and jacks.

Records of catch rates from traditionally manufactured portable fish traps set on reefs in the South Pacific could not be found in the literature. Available information on performance of fish traps comes from experimental deployment of Caribbean-style traps on Pacific reefs to catch species in the shallow reef community or on the deep reef slope to catch mainly large groupers and snappers. Dalzell (1996) quotes average catch rates of between 0.85 and 4.6 kgtrap⁻¹ for traps set on shallow reefs and 3.2 to 8.9 kgtrap⁻¹ for traps set on deep reef slopes. Caillart & Morize (1985) quote average catch rates from fish corrals at Tikehau Atoll during the peak of

Table 7: Summary of catch rate (CPUE, catch per unit effort) and catch composition data for gill net fishing on reef and small pelagic fish stocks in the South Pacific region

Location	Net length (m)	Mesh size (cm)	Target stock	CPUE		Principal catch components	Source
				range	mean		
American Samoa			Reef & lagoon species	3.3 – 6.8 kgh ⁻¹	5.0 kgh ⁻¹	na	Saucerman 1994
Kiribati	na	5.7 – 12.7	Reef & lagoon species	5.0 – 96.0 kgtrip ⁻¹	43.4 kgtrip ⁻¹	Albulidae, Carangidae, Mugilidae, Mullidae	Anon. 1991c
Solomon Islands	na	5 – 15	Reef & lagoon species	0.26 – 0.90 kgl00mnet ⁻¹ h ⁻¹	0.46 kgl00mnet ⁻¹ h ⁻¹	Sharks, Chanidae, Carangidae, Mugilidae	Blaber et al. 1990
Cook Islands	90 – 230	4.5 – 5.0	Small pelagics & reef fish	0.14 – 18.04 kg10mnet ⁻¹	2.2 kg10mnet ⁻¹	Carangidae, Priacanthidae, Mullidae, Caesionidae	Chapman & Cusack 1988d
Fiji (Rabi Island)	150	1.9 – 7.6	Reef & lagoon species	15 – 26 kgset ⁻¹	189 kgset ⁻¹	Lethrinidae, Lutjanidae, Mugilidae, Holocentridae	Anon. 1983a
Fiji (Rotuma Fig. 2, 90)	229	7.6	Reef & lagoon species	10.0 – 600 kgset ⁻¹	31.8 kgset ⁻¹	Mugilidae, Carangidae, Lutjanidae, Lethrinidae	Anon. 1983b
Papua New Guinea (Port Moresby)	na	5.0 – 12.7	Reef & lagoon species	na	2.0 kgman ⁻¹ h ⁻¹	Lethrinidae, Lutjanidae, Carangidae, Scombridae	Lock 1986a
Papua New Guinea (Rabaul)	35 – 100	3.8	Small pelagics	0.7 – 6.7 kgset ⁻¹	3.0 kgset ⁻¹	Carangidae, Clupeidae	Dalzell 1993a
Papua New Guinea (Manus)	100	7.6 – 15.0	Reef & small pelagics	0.0 – 17.2 kgset ⁻¹	757 kgset ⁻¹	Sharks, Scombridae, Chanidae, Clupeidae	Chapau & Lockani 1986
Kosrae (FSM)	na	na	Reef & lagoon species	4.2 – 9.1 kgh ⁻¹	6.3 kgh ⁻¹	na	Smith 1992a
Tonga	100 – 1200	5.0	Reef & lagoon species	5.6 – 7.2 kgset ⁻¹	6.0 kgset ⁻¹	Acanthuridae, Labridae, Siganidae, Lethrinidae	Halapua 1982
Guam	na	na	Reef & lagoon species	0.67 – 12.24 kgset ⁻¹	4.24 kgset ⁻¹	Acanthuridae, Mullidae, Scaridae, Labridae	Karnik 1982

na = not available

Table 8: Summary of catch rate (CPUE, catch per unit effort) and catch composition data for drive-in-net and beach seine fishing on reef and small pelagic stocks in the South Pacific region.

Location	Net length (m)	Mesh size (cm)	CPUE Target stock	Principal catch range	mean	components	Source
Drive in net							
Woleia (Micronesia)	35	4.5	Reef & lagoon species	8.1– 129.4 kgset ⁻¹	42.7 kgset ⁻¹	Acanthuridae, Scaridae, Siganidae, Lethrinidae	Smith & Dalzell 1993
Palau	na	na	Reef and small pelagic species	2.3 – 11.1 kgman ⁻¹ h ⁻¹	5.1 kgman ⁻¹ h ⁻¹	Carangidae, Lethrinidae, Acanthuridae, Siganidae	Anon. 1993b
Papua New Guinea (Port Moresby)	na	5.0 – 12.7	Reef & lagoon species	1.41 – 4.95 kgman ⁻¹ h ⁻¹	252 kgman ⁻¹ h ⁻¹	Lethrinidae, Carangidae, Mugilidae, Siganidae	Lock 1986a
Papua New Guinea (Tigak Is)	100	6.3 – 7.5	Reef & lagoon species	na	3.9 kgman ⁻¹ h ⁻¹	Mugilidae, Chanidae, Carangidae, Scaridae	Wright & Richards 1985
Papua New Guinea (Manus)	100	7.6	Reef & lagoon species	0.45 – 0.74 kgman ⁻¹ hr ⁻¹	0.69 kgman ⁻¹ h ⁻¹	Scaridae, Mugilidae, Carangidae, Acanthuridae	Chapau & Lokani 1986
Cook Islands (Palmerstoll Atoll)	14 – 480	2.3	Reef & lagoon species	0 – 41 kgset ⁻¹	13.1 kgset ⁻¹	Scaridae	Anon 1988a
Nauru	na	na	Reef & lagoon species	1.1 – 8.0 kghr ⁻¹	3.9 kghr ⁻¹	Kyphosidae, Mugilidae, Acanthuridae, Lutjanidae	Dalzell & Debaio 1994
Guam	140 – 280	na	Reef & lagoon species	0.09 – 0.46 kgman ⁻¹ h ⁻¹	0.25 kgman ⁻¹ h ⁻¹	Siganidae, Acanthuridae, Labridae, Lethrinidae	Katlik 1982, Amesbury et al 1986
Beach seine							
Papua New Guinea (Rabaul)	200	2.5	Small pelagic species	na	350 kgset ⁻¹	Carangidae, Clupeidae	Dalzell 1993a
Papua New Guinea (Kavieng)	100	2.5	Small pelagic species	1.0 – 44.6 kgset ⁻¹	17.3 kgset ⁻¹	Carangidae	Dalzell unpub. data
Butaritari (Kiribati) (beach seine)	80	0.5	Small pelagic species	8 – 345 kgset ⁻¹	130.6 kgset ⁻¹	Clupeidae, Atherinidae, Apogonidae	Kleiber & Kearney 1983
French polynesia (Marquesas Is)	80	0.5	Small pelagic species	5 – 33 kgset ⁻¹	18.6 kgset ⁻¹	Clupeidae, Mullidae, Carangidae	Gillett & Kearney 1983
Tokelau (Fakaofu Atoll)	80	0.5	Small pelagic species	7.5 – 25.5 kgset ⁻¹	13.5 kgset ⁻¹	Mugilidae, Clupeidae	SSAP 1983a
Tonga (Vava'u)	80	0.5	Small pelagic species	13 – 18 kgset ⁻¹	15.0 kgset ⁻¹	Atherinidae, Clupeidae, Mullidae	SSAP 1983b
Marshall Islands (Majuro & Jalult Atolls (51))	80	0.5	Small pelagic species	16 – 38 kgset ⁻¹	21.5 kgset ⁻¹	Clupeidae, Atherinidae, Lethrinidae	SSAP 1984

Na = available

the fishing season (November — February) of 380 — 580 kgday⁻¹. Grand (1983) does not give daily catch rates for fish corrals at Kaukura Atoll but reports that the average fish production ranged from 1 to 2.3 tcorral⁻¹month⁻¹, with a mean of 1.5 tcorral⁻¹month⁻¹.

As stated earlier a variety of other methods are used to catch fishes on coral reefs, although documentation on these is scarce. Average catch rates for cast netting on reefs in Nauru (Dalzell & Debao 1994), Guam (Katnick 1982) and Kosrae (Smith 1992a) were 0.7 kgman⁻¹h⁻¹, 2.8 kgman⁻¹h⁻¹ and 5.6 kgman⁻¹h⁻¹ respectively, and comprised rudderfishes (Kyphosidae), rabbitfishes, surgeonfishes, jacks and goatfishes. Collection of invertebrates and molluscs is a common pastime on reefs for women and children, and may add significantly to the overall harvest from the reef (see p. 427). Mathews & Oiterong (1991) made a detailed study of women's reef fishing activities and found that they target over 25 species of echinoderms, molluscs and crustaceans for collection, as well as catching fish with hand-lines and nets. Catch or harvest rates of all species for gleaners in Kosrae ranged from 2.2 to 4.1 kgh⁻¹, with a mean of 3.6 kgh⁻¹.

Fisheries biology and stock assessment

The biology of reef fishes has received considerable interest in the past 50 yr, due in part to the development of SCUBA equipment and the ability of biologists to conduct observations *in situ*. Sale (1980) provided the first major review of reef fish biology and ecology, and more recently various contributions in Sale (1991) have provided the most comprehensive review of various aspects of reef fish biology. Aspects of the biology of South Pacific reef fishes are also covered by Wright (1993) and Pyle (1993) who, together with Sale, include information on the biology of reef fishes in the Atlantic and Indian Oceans. Many of the studies on reef fish biology in the South Pacific have been conducted on the Australian GBR, Hawaii, French Polynesia and Guam. The focus of much of the research on Pacific reef fishes in the last five decades has been on small strongly site-associated species, such as damselfishes, with which it is relatively easy to conduct underwater observations and experiments. However, Munro & Williams (1985) pointed out in their review of reef fisheries management that there is a general dearth of stock assessment studies of commonly exploited reef fish populations, either in the South Pacific or elsewhere, and that there are very few estimates of life history parameters and population studies such as age, growth, mortality, and recruitment that are essential for stock assessment.

We shall not undertake a detailed biological review in this section, nor in the subsequent sections on other coastal fisheries resources. We are mainly concerned here with documenting those studies that have been conducted in the South Pacific on the most commonly exploited fish and invertebrate stocks, and which have generated information on life histories relevant for management. From Table 3 (p. 416), the principal reef fish families include the emperors, surgeonfishes, snappers, jacks, parrotfishes, groupers, mullet, goatfishes, rabbitfishes and squirrelfishes. As stated earlier, coastal scombrids may form an important component of reef fish catches, but the biology of these species in the Pacific is reviewed further below (p. 444). We will also review the methods used to estimate reef fish standing stocks and to compute maximum sustainable yields (MSYs) from reef fish stocks in the region and compare yields among the different locations in the Pacific.

The emperors or lethrinids are probably the most widely studied of the Pacific reef fishes that form major components of reef and lagoon fishery landings. Lethrinids have proved very amenable to ageing using well established techniques for reading annuli in otoliths and scales,

as well as through more recent techniques for ageing using otolith microstructure (daily increments) and length based methods. Loubens (1978b, 1980) estimated age and growth of emperors and a range of other reef fish species from otolith annuli including the economically important species *Lethrinus nebulosus* and *L. miniatus* (= *L. chrysostomus*). Age and growth of *L. nebulosus* from the Australian GBR have also been determined through reading of otolith annuli (McPherson et al. 1985). Scales (Walker 1975) and otoliths (Brown et al. 1994) have both been used to age *L. miniatus* from the GBR and subsequent age-frequency distributions were used to generate catch curves for mortality estimation. Otolith microstructure or daily growth increments were also used to estimate the age and growth of *L. olivaceus* (= *L. miniatus*) in French Polynesia (Caillart et al. 1986), *L. semicinctus* in northern PNG (Mobiha 1993), and *L. rubrioperculatus* in American Samoa (Ralston & Williams 1988a). Age, growth and mortality of exploited stocks of emperors, mainly *L. nebulosus*, *L. mahsena* and *L. harak*, have been studied in Fiji (Dalzell et al. 1992) using a combination of length based methods and age estimates from otoliths. *L. harak* was also included in a study of commonly exploited reef stocks in Palau (Kitalong & Dalzell 1994), where growth and mortality estimates were generated from length-frequency data.

Life spans of the larger *Lethrinus* species such as *L. nebulosus* and *L. olivaceus* would appear to be in excess of 20 yr, while small species such as *L. nematacanthus* and *L. semicinctus* have life spans of between 7 and 10 yr. Loubens (1978b, 1980) also estimated age and growth from otolith annuli for the smaller lethrinids or breams in New Caledonia belonging to the genus *Gymnocranius*, including *G. japonicus*, *G. lethrinoides* and *G. rivularis*. Age and growth of another bream, *Nemipterus peroni* (= *furcosus*) (Nemipteridae), was also included in Loubens (1980) study and Chapau (1993) has used otolith annuli and tagging to estimate age, growth mortality rates and abundance of the same species in populations in northern PNG. Both groups of breams have average life spans of about 5 — 10 yr.

Surgeonfish biology and life histories have been studied in a number of locations in the South Pacific, most notably *Acanthurus triostegus* in Hawaii (Randall 1961), *Naso brevirostris* in Tikehau Atoll (French Polynesia) (Caillart 1988b) and *Acanthurus nigricauda* and *A. xanthopterus* in northern PNG (Dalzell 1989). Age and growth of these species have been described from a combination of observations on captive specimens (*A. triostegus*), otolith microstructure (*A. nigricauda*, *Naso brevirostris*), length frequency data (*Acanthurus xanthopterus*, *Naso brevirostris*) and tagging (*Acanthurus triostegus*, *A. xanthopterus*). Daily growth increment formation was validated in the otoliths of several juvenile surgeonfishes including *Ctenochaetus binotatus*, *C. striatus*, *Zebrasoma scopas* and *Z. veliferum* from the GBR (Lou & Moltschanowskyj 1992). Otolith microstructure has also been used to provide preliminary age and growth estimates for *Acanthurus lineatus* and *Ctenochaetus striatus* from American Samoa (Ralston & Williams 1988a). *C. striatus* has been studied in some detail in French Polynesia as it is frequently implicated in cases of ciguatera poisoning (Bagnis 1970). Attempts to estimate growth for this species from tagging data were unsuccessful (Walters 1968, Bagnis 1970) but growth, mortality and recruitment were determined for *C. striatus* from Moorea using length-frequency data (Arias-Gonzalez et al. 1993). Similar analyses were also conducted with length-frequency data for *Naso unicornis* from Palau (Kitalong & Dalzell 1994).

Surgeonfishes appear to have relatively long life spans. Randall (1961) reported adult surgeonfishes such as *Naso unicornis* and *Acanthurus xanthopterus* living for between 15 and 20 yr in captivity. Age and growth studies of *A. nigrofusus* populations on the GBR suggest that this species, one of the smallest acanthurids, has an average maximum life span of over 20 yr (Hart & Russ in press), together with another common species, *Ctenochaetus striatus*

(N. V. C. Polunin & E. D. Brothers unpub. data). Furthermore, 40 presumptive annuli have been observed in the otoliths of *Acanthurus lineatus* from the same location (A. Fowler, Bedford Institute of Oceanography, pers. comm.; Polunin & Brothers unpubl. data). It should be noted that surgeonfishes on the GBR are subject to virtually no fishing pressure and populations only experience mortality through natural causes.

Some aspects of the biology of the rabbitfishes or siganids have been studied both in wild populations and from studies in captive populations in Guam (Tsuda et al. 1976). The species covered in the various contributions in Tsuda et al. (1976) include *Siganus spinus*, *S. rostratus* and *S. argenteus*. The biology of wild populations of *S. lineatus* and *S. canaliculatus* was observed from wild populations in Palau (Drew 1973), while in Fiji the biology of *S. vermiculatus* was described from a combination of observations on wild and captive populations (Gundermann et al. 1983). Only the growth of juveniles was observed in each of these various studies, either in captive populations (Tsuda et al. 1976, Gundermann et al. 1983) or from tagging of juveniles (Drew 1973). The biology of *S. canaliculatus* in Palau has also been described by Hasse et al. (1977), while the population biology of this and other rabbitfish species (*S. argenteus* and *S. lineatus*) in Palau were described by Kitalong & Dalzell (1994) from length frequency data.

The biology of shallow water snappers has received less attention than the more commercially valuable deep slope species. Loubens (1978b, 1980) succeeded in ageing in New Caledonia *Lutjanus amabilis*, *L. bohar*, *L. fulviflamma*, *L. kasmira*, *L. quinquelineatus* and *L. vitta* by reading otolith annuli. In the same location, Baillon & Kulbicki (1988) have aged the sweetlip, *Diagramma pictum*, from otolith and scale annuli and from otolith microstructure. Although not strictly a snapper, this species belongs to the family Haemulidae, which is closely related to the Lutjanidae. Wright et al. (1986) described the biology of the red bass, *Lutjanus bohar*, in northern PNG and estimated age, growth and mortality parameters from length-frequency data. Length-frequency data were also used by Kitalong & Dalzell (1994) to generate the same parameters for *L. gibbus* in Palau.

Ralston & Williams (1988a) included the small blue-lined snapper, *L. kasmira*, in studies of depth distributions, growth and mortality of deep slope fishes in the Northern Mariana Islands. Age estimates in this study were made from otolith microstructure, whereas mortality rates were computed from length data. The age and growth of *L. kasmira* in American Samoa have also been estimated from otolith microstructure, while Morales-Nin & Ralston (1990) estimated the age and growth of the same species in Hawaii, where it is an introduced exotic, from both otolith annuli and daily increments. Another small snapper, *L. fulvus*, from French Polynesia (Caillart et al. 1986) was aged using otolith microstructure. Age and growth of three large snappers from the Australian GBR, *L. sebae*, *L. malabaricus* and *L. erythropterus*, were determined from otolith annuli (McPherson & Squire 1992). Although these three species are not strictly speaking shallow water snappers, they can be found in a greater range of depths than the eteline snappers, including shallow reef areas. Longevities of between 10 and 20 yr appear to be typical for *Lutjanus* spp. and Loubens (1980) reports life spans in excess of 20 yr for even small species such as *L. fulviflamma* and *L. quinquelineatus*.

Parrotfishes, although a common component of reef catches, have received little attention from fisheries biologists in reef areas. The formation of annular marks in the otoliths of *Scarus schlegelii* from the GBR has been validated by Lou (1992), while daily increments in the otoliths of a range of juvenile parrotfishes, including *S. rivulatus*, *S. globiceps*, *S. psittacus*, *S. sordidus*, *S. niger*, *S. frenatus* and *S. oviceps* (all from the GBR) have been observed by Lou & Moltschaniwskyj (1992) and Lou (1993). Coutures (1994) used annular marks on scales to age the largest of the parrotfishes, *Bolbometopon muricatum*, in New Caledonia, and estimated

mortality rates from length-frequency data. Kitalong & Dalzell (1994) also used length-frequency data to generate growth and mortality parameters for the same species in Palau. Lou's (1992) estimates of age and growth of *Scarus schlegeli*, one of the species in the middle of the size range of the Scaridae, suggest longevity of between 6 and 9 yr, while Coutures' data for *Bolbometopon muricatum* indicates a life span of about 25 yr. Polunin & Brothers (unpubl. data) using a combination of scanning electron and light microscopy on putative annual and finer banding in otoliths, inferred longevity of over 20 yr for *Scarus globiceps*, *S. sordidus* and *S. frenatus*. The related wrasses or Labridae, appear to have received even less attention than the parrotfishes. Kitalong & Dalzell (1994) estimated growth and mortality parameters from length-frequency data for the large Napoleon wrasse, *Cheilinus undulatus*, in Palau. Preliminary studies on this species from the GBR suggest that ageing through reading otolith annuli is practicable and that this species has an expected life span of about 25 yr (G. McPherson, Northern Fisheries Centre, Cairns, pers. comm.).

Groupers are among the most important of the reef fish landings but little is known about the biology of species captured in the Pacific islands. The age, growth and mortality of the coral trout *Plectropomus leopardus* on the central GBR has been studied by Ferreira & Russ (1992), while a detailed comparative study of the population biology of *P. leopardus* from different locations on the GBR is given by Brown et al. (1994). Earlier estimates of the age and growth of *P. leopardus* were made from length-frequency data (Goeden 1978) but this species like others on the GBR has otoliths with clear annual markings. Loubens (1978b, 1980) aged *P. leopardus* from otolith annuli and included some age-at-length estimates for *Epinephelus areolatus*, *E. fasciatus*, *E. hoedti*, *E. maculatus*, *E. merra* and *E. tauvina*. Little else has been documented on the biology of other groupers in the South Pacific. Morize & Caillart (1989) have made some preliminary investigations of ageing juvenile and adult *Epinephelus polyphekiadon* (= *microdon*) from French Polynesia from otolith microstructure. Their results suggest that the periodicity of primary growth increments is once every two days rather than daily and that the rate of increment formation is correlated with growth but not with fish length. Longevity of groupers in the South Pacific based on the studies reviewed here appear to be typically in excess of 10 yr.

The biology of other commonly exploited reef fishes in the South Pacific is more fragmentary with most examples confined to studies in Hawaii, the GBR and French Polynesia. Like the groupers, jacks (Carangidae) are also a major component of reef fish catches but the biology of these species does not appear to have been the focus of much attention from fisheries biologists in the region. The biology of the large jacks, *Caranx melampygus* and *C. ignobilis*, in Hawaii has been studied by Sudekum (1984), who was able to age *C. melampygus* by primary growth increments in the otoliths. Also in Hawaii, a study was conducted on the movements, distribution and growth rates of the goatfish *Mulloidichthys flavolineatus* by Holland et al. (1993) using tagging data. Other studies on reef fishes in Hawaii that have generated life history data related to fisheries management include age and growth from otolith microstructure of the millet seed butterflyfish, *Chaetodon miliaris* (Ralston 1976) and of the brick soldierfish *Myripristis amaena*, which Dee & Radtke (1989) suggested had a typical life span of 14 yr. Growth and mortality of another soldierfish *Sargocentron microstoma* in French Polynesia have been estimated from length-frequency data by Arias-Gonzalez et al. (1993).

Relatively few estimates of biomass or standing stocks have been made for reef fish populations in the Pacific islands and these are summarized in Table 9. The majority of estimates are from the Australian GBR and the French territory of New Caledonia. The tech-

Table 9: Estimates of biomass or standing stocks of reef fish on South Pacific coral reefs.

Location	Reef type	Biomass (tkm ⁻²)		Method	Source
		Range	mean		
Woleai atoll (FSM)	Atoll lagoon back reef	5 – 25	12	Depletion fishing	Smith & Dalzell 1993
Australian GBR	Inshore reef		92	Explosives	Williams & Hatcher 1983
Australian GBR	Mid-shelf reef		237	Explosives	Williams & Hatcher 1983
Australian GBR	Outer shelf		156	Explosives	Williams & Hatcher 1983
Australian GBR	Coral island fringing reef	17.5 – 195	97.5	UVC	Goldman & Talbot 1976
Papua New Guinea (New Ireland)	Fringing reef		43.5	Explosives	A. Wright FFA pers. comm.
Chesterfield Islands (Fig.2, 15)	Coral islands and atolls	1.7 – 230	105	UVC and rotenone	Kulbicki et al. 1990
New Caledonia	Fringing reef		110	UVC	Kulbicki 1988
New Caledonia	Mid shelf reefs	78 – 96	90	UVC	Kulbicki 1988
New Caledonia	Barrier reef		92	UVC	Kulbicki 1988
New Caledonia	Ouvea Atoll	25 – 400	56.2	UVC	Kulbicki et al 1994
Enewetak	Atoll reef		42.5	UVC	Odum & Odum 1955
Hawaii	Fringing reefs	0.8 – 237	38.8	UVC	Brock 1954
French Polynesia	Fringing reefs		140	UVC	Galzin 1987
Western Samoa	Fringing reef slopes and lagoon	11.7 – 74.7	38.7	UVC	Samoilys & Carlos 1991 ^a
Fiji	Barrier reefs	22.2 – 289	25.1	UVC	Samoilys & Carlos 1992 ^b

a, b. Biomass estimates of Serranidae, Acathuridae, Scaridae, Lethrinidae & Lutjanidae only

UVC = underwater visual census, see text

niques used to estimate standing stocks include underwater visual census (UVC), controlled use of explosives, poisoning and short-term intensive fishing experiments. UVC techniques comprise underwater counts of reef fishes, either along a transect line of a given width or in a given radius from the observer, and estimation of lengths of all individuals for subsequent conversion of numbers to weight through length-weight equations. As a technique for estimating abundance and biomass of target species, UVC has several limitations, as evident from the rarity of emperors in extensive counts around reefs of six different fishing grounds in Fiji (Jennings & Polunin 1995c), whereas these species constitute a major part of the reef catch. Explosive sampling is based on setting charges where fishes will be killed or stunned within a known radius and then can be collected by divers following detonation. However, species such as eels, gobies and blennies in which the swimbladder is poorly developed or absent are not as susceptible to this method of sampling. The use of poisons involves surrounding patch reefs or parts of a reef with nets then introducing an ichthyocide such as rotenone on to the reef to kill all fish within the demarcated area. The objective of such intensive fishing over a short period of time is to reduce the standing stock and hence the CPUE where factors such as growth mortality and recruitment are negligible. The reduction in CPUE can be correlated with cumulative catch

(Leslie's method) or fishing effort (DeLury's method) to determine initial biomass or standing stock within the area being subjected to intensive fishing (Ricker 1975).

From the examples in Table 9, the average standing stock biomass on Pacific reefs ranges from 12 to 237 tkm⁻². It is difficult to make any serious comparisons of these figures, given the range of methods used and the restricted number of locations. The lowest mean figure from Woleai Atoll was obtained from a series of intensive fishing experiments. Smith & Dalzell (1993) have suggested that their biomass estimates refer only to that fraction of the total biomass that was susceptible to the fishing methods employed, namely spear fishing and drive-in net fishing. Furthermore, the inner reefs of Woleai Atoll are fished regularly by the inhabitants of this island, who rely on fish as a main source of protein and so the low biomass estimates may also reflect the removals by fishing. Smith & Dalzell noted that there was an apparent correlation between biomass on the four reefs in their study and the time interval between the experiments and the last large-scale community fishing events on these reefs. The other examples in Table 9 are from reefs that are unexploited or were only lightly fished during the period of observations. The highest figures overall are from the Australian GBR. Here the use of explosives, although not effective against certain species, permitted sampling throughout the water column and revealed the large contribution from planktivores, especially fusiliers (Caesionidae), to the reef fish biomass. Based on the limited data in Table 9 it appears that unexploited or lightly exploited coastal reefs may typically have standing stocks of reef fishes in the range 50 to 100 tkm⁻².

As the areas of reef, lagoon and coastal shelf in many locations in the South Pacific and elsewhere are readily obtainable from nautical charts, aerial photographs and satellite images, it is often possible to express the catch from reefs in terms of production per unit area. This then gives an index of exploitation that can be compared with other locations and from which it may be possible to obtain an indication of the sustainable yield. There are a number of examples from the South Pacific and elsewhere in the tropics where the amount of fish and/or invertebrates taken from a given area of reef have been estimated. However, authors have used a variety of techniques to estimate the fish and invertebrates harvested from a given area, and they have given different definitions of the area of reef being fished. Some workers have restricted the definition of reef to include only actively growing hermatypic reef to depths ranging between 8 and 60 m (see Russ 1991). Some authors have estimated yields based on reef area and on area of shallow lagoon, which included tidal mangrove areas, seagrass beds and sand flats. Others have included the reef and the adjacent shelf area to a depth of 200 m in their estimation of reef yields. These boundary conditions clearly affect the results substantially. Using a depth limit of 40 m for reef areas and 60 m for other habitats, Jennings & Polunin (1995a) estimated yield ranges of 0.3 — 10.2 tkm⁻²yr⁻¹ (reef fish/reef area) and 0.2 — 3.4 tkm⁻²yr⁻¹ (reef fish/total area) in six Fijian fishing-grounds (qoliqoli).

The selection of species to be included in harvests creates particular problems when comparing reef yields between different locations. Catches by reef fishermen may contain substantial catches of scombrid fishes such as tunas and mackerels (Table 3, p. 416) or snappers, groupers and other deep slope species caught away from the reef, thus inflating reef yields. Reef yields may also include the shellfish and other invertebrates collected from the inshore reefs at low tide. This gleaning activity can in some locations account for a significant fraction of the total harvest from a reef area, as in Western Samoa where invertebrates account for 36% of the total reef landings (Wass 1982, Munro 1984), and in Fiji where they account for 72% by weight of artisanal catches and almost half of subsistence landings (Rawlinson et al. 1994). Despite these inconsistencies it is still possible to draw some conclusions from the estimates of yield from Pacific reefs summarized in Table 10. The observed yields are primarily a function of fishing effort that is itself a function of population density. In the smaller Pacific island countries where marine produce has always been a primary source of protein, population pressure may lead to relatively high levels of exploitation on nearshore stocks. Small islands such as Nauru and Niue, with limited reef and shelf area and extensive fishing activity, have estimated yields of

4.8 tkm⁻² (Dalzell & Debao 1994) and 9.3 tkm⁻² (Dalzell et al. 1993) respectively from the reef and shelf areas combined. The highest estimated annual fisheries yields were for fringing reefs in American Samoa, with a range of 8.6 to 44.0 tkm⁻² and a mean of 27 tkm⁻².

Table 10: Estimated yields from coral reef fisheries in the South Pacific.

Location	Area fished Habitat type	Maximum depth fished		Yield (tkm ⁻² yr ⁻¹)	Source
		(km ²)	(m)		
Papua New Guinea Kavieng	Fringing reefs and patch reefs	207.7	30	0.42	Wright & Richards 1985
Papua New Guinea Port Moresby	Barrier and fringing reefs	116	40	5.0	Lock 1986b
Papua New Guinea Manus	Fringing and patch reef	61.1	20	2.8	Chapau & Lokani 1986
Papua New Guinea (total)	All coral reefs	39 940	30 – 60	0.21	Dalzell & Wright 1986
American Samoa	Fringing reef	3.0	40	8.6 – 44.0	Wass 1982
Western Samoa	Fringing reef	300.0	40	11.4	Zann et al. 1991
Tarawa (Kiribati)	Atoll reef and lagoon	459.0	30	7.2	Mees et al. 1988
Ontong Java (Solomon Islands)	Atoll reef and lagoon	122	na	0.6	Bayliss-Smith 1975
Nauru	Fringing reef and reef slope	7.5	100	4.5	Dalzell & Debao 1994
Niue	Fringing reef and reef slope	6.2	60	9.3	Dalzell et al. 1993
Vanuatu	Fringing reef and reef slope	1063	100	1.9	David & Cillauren 1989
Futuna	Fringing reef	150	na	0.01	Based on data in Galzin 1985
Palau	Fringing and barrier reefs	450	20	1.7 – 30	Kitalong & Dalzell 1994
Fiji (Koro (41) & Lakeba (45))	Fringing reefs	8.4	na	5.0	Bayliss-Smith 1975
Fiji (Yanuca (116), Dravuni, Moala (62), Totoya (105), Nauluvatu (66))	Fringing reefs	na	na	0.3 – 10.2	Jennings & Polunin 1995a
Ifaluk Atoll (35)	Atoll reefs and lagoon	5	na	5.1	Stevenson & Marshall 1974, based on observations by Alkire 1965

Locations in Melanesia, where agricultural land is generally more abundant and population densities much lower, tend to have much lower yields from nearshore fisheries. In PNG the annual total reef fisheries yield for the whole country was estimated to be 0.21 tkm⁻² (Dalzell & Wright 1986). Based on data presented by David & Cillauren (1989), the total yield of reef fishes and invertebrates in Vanuatu amounted to only 0.16 tkm⁻². Higher annual yields have been recorded at individual locations in PNG such as Manus (Fig. 2, 54) (≈ 3.0 tkm⁻²) (Chapau & Lokani 1986) and at the capital city Port Moresby (≈ 5.0 tkm⁻²) (Lock 1986c), but these are still relatively modest when compared with islands in Polynesia and Micronesia. The limited data suggest that finfish yields in the range 5 to 20 tkm⁻²yr⁻¹ are probably sustainable in the long term. If coastal reefs typically have standing stocks in the range 50 to 100 tkm², then annual sustainable harvests are likely to represent between 5 and 40% of the standing stock (fishable teleost biomass), although we acknowledge that this amounts to little more than speculation given the limits of the present data on standing stocks and yields.

A log book study of six Fijian fishing grounds (qoliqoli) established that at least up to $10.2 \text{ t km}^{-2} \text{ yr}^{-1}$ (reef fish/reef area up to 40 m depth), yield was linearly related to a rescaled index of effort (Jennings & Polunin 1995b), indicating that such harvests are sustainable and indeed they appear to have been maintained for some years in the most fished area (Jennings & Polunin 1995a). Although catch composition varied between grounds, there was no evidence that less-favoured species were increasing at the more intensely fished sites (Jennings & Polunin 1995a).

The most comprehensive study of fisheries resources and potential MSY in the region has been conducted by the French scientific organization ORSTOM in Ouvea Island (Fig. 2, 75) (Kulbicki et al. 1994), one of the Loyalty Islands archipelago that lie to the east of New Caledonia. From a series of underwater observations and experimental fishing surveys, Kulbicki et al. (1994) estimated that the total standing stock of reef and lagoon fish was 46500 t of which 12500 t was found on the reefs. Kulbicki et al. (1994) estimated that the MSY for the fishable stock might be as high as 4300 t yr^{-1} or about 10% of the total standing stock, but recommended that a more conservative yield of 1000 t yr^{-1} would be a better management objective. This would amount to a relative yield of about $1.1 \text{ t km}^{-2} \text{ yr}^{-1}$ from the lagoon and reef area combined. The present volume of landed catch from Ouvea is only 50 t yr^{-1} or one-twentieth of the predicted MSY.

Other attempts to estimate MSY for reef fisheries have used modifications of simple surplus production models, either the simple parabolic form initially developed by Schaefer (1954) or the exponential modification of Schaefer's model proposed by Fox (1970). Both forms of the model are based on the assumption that growth in fish populations conforms to a logistic or S-shaped curve, with maximum production from a given stock at some intermediate population density (Ricker 1975). The sustainable yield is the level of fishing effort that takes only the annual surplus production from the population without depleting the biomass. In the Schaefer model the relationship between catch and fishing effort conforms to a symmetrical parabola with MSY when the population is reduced through fishing to half of the unexploited biomass. The exponential Fox model is an asymmetrical dome shaped curve where MSY occurs when the population is reduced to about 40% of the unexploited biomass.

Conventional versions of the Schaefer and Fox surplus production models require time series of catch and effort data to generate MSY and optimum fishing effort. While long time series of reef fish catch data (15 — 25 yr) are available for countries such as Palau, French Polynesia and Fiji, there are no accompanying data on fishing effort due to the multiplicity of gears involved in the fishery. A shorter, incomplete set of catch and fishing effort data for Tarawa Atoll (Kiribati) was analyzed by Yeeting & Wright (1989). A direct measure of fishing effort was not available but an index of effort could be expressed as number of canoes or skiffs, and numbers of gears such as hand-lines and gill nets. Catch was broadly separated into reef catch, lagoon catch and ocean catch. Ocean catches were predominantly tunas caught by trolling and, not surprisingly, mean annual catch rates showed no relationship to annual fishing effort. Mean annual catch rates from the atoll's lagoon and reef stocks showed an inverse linear relationship with effort in gear numbers and in terms of vessel numbers, and catch and effort data could be fitted with Schaefer curves. The conclusions from this analysis were that the MSY of reef and lagoon fish stocks in Tarawa Lagoon was about 2800 t yr^{-1} or a yield from the total fished area (141.8 km^2 reef and 330.4 km^2 lagoon) of $6 \text{ t km}^{-2} \text{ yr}^{-1}$.

Lock (1986bc) fitted a Fox surplus production model using spatial variation in fishing, effort and catch on a number of different reefs in the Port Moresby-Daugo Island reef fishery over a 1-yr period, to compensate for the lack of a time series of catch and fishing effort data. This method was adopted from Munro (1983) who developed this technique to estimate the MSY for the nearshore canoe fishery in Jamaica. Lock's estimate of MSY for the Port Moresby-Daugo Island Fishery was 524 t yr^{-1} or a yield of 7.6 $\text{tkm}^{-2}\text{yr}^{-1}$. Munro (1984) also used this approach with data from Wass (1982) to fit a surplus production model to yield data for finfish and invertebrates from reefs around Tutuila Island in American Samoa. Although total harvests from Tutuila (Fig. 2, 108) are not known, Munro concluded that the data indicated an annual finfish MSY of 20 tkm^{-2}yr and an invertebrate yield of 15 $\text{tkm}^{-2}\text{yr}^{-1}$.

Another approach to investigating fisheries yield from coral reefs has been to construct a trophodynamic model of a reef system. Polovina (1984a) developed an ecosystem box model, ECOPATH, to estimate the biomass budget of an ecosystem given inputs that specify the ecosystem components, together with their mortality, diet and energetics value. This approach was used to model a coral reef ecosystem at French Frigate Shoals in the Northwest Hawaiian Islands (Polovina 1984b, Atkinson & Grigg 1984, Grigg et al. 1984), and suggested that fisheries yield might be maximized by harvesting low in the food chain, particularly if top carnivores can be cropped to release predator pressure on selected prey. One use of trophodynamic modelling of reef communities has been the indication that fishes around reefs contain substantial proportions of the total amount of inorganic nutrient elements such as nitrogen stored within biomass (Polunin 1996). The implication is that in some cases intense fishing may lead to nutrient-depletion because of the removal of a major reservoir within the reef system, recovery of which may be slow. The extent to which reef fish productivity may depend on nutrient inputs, however, is unknown. The opportunity to examine changes in biomass and turnover of reef fish stocks in nutrient-poor and upwelling-enriched regions offered by the Pacific has apparently not been explored. The potential role of planktonic inputs in the production of groupers, snappers and other important reef predators is being explored, however, by using carbon, nitrogen and sulphur stable isotopes (N. V. C. Polunin unpubl. data).

Socioeconomic developments

Shallow water reef fisheries, like most coastal fisheries in the Pacific, remain the preserve of small-scale artisanal fishermen. Even in the commercial sectors of most countries, the gears employed are largely non-mechanized, and in the Pacific, most reef fish catches are generated from hand-lines, spears, gill nets or drive-in nets. The only exception has been the proliferation of fish corrals in the Tuamotu Archipelago of French Polynesia, where these gears are used to catch large volumes of reef fishes to satisfy the demand for fish on Tahiti, the principal island in the territory. Elsewhere, fishermen have sought to improve catches through the greater use of modern fishing gears such as monofilament lines and nets, diving equipment and more reliance on outboard motors to range over wider areas. Governments have sought to encourage greater fisheries production from reef and other coastal fisheries by providing better facilities for fishermen to dispose of catches and in some instances provision of easy credit or "soft" loans to buy vessels and equipment.

In the past, most catches from nearshore reef fisheries were consumed at or close to the landing site but, as indicated earlier, there was a greater dispersal of landings from their point of origin to other domestic and international markets as national economies developed and urbanisation increased. Besides the examples given earlier for French Polynesia, Cook Islands and Western

Samoa, reef fishes are now exported from Kiribati to Hawaii and Nauru, from Solomon Islands to Japan, and from Fiji to Tonga and New Zealand. A trend in the western part of the region is the development of live reef fish fisheries for the restaurant trade in Southeast Asia. Reef fishes, such as coral trout, other groupers and Napoleon wrasse, are caught around the coast of PNG and shipped live by air and sea to markets in Hong Kong, mainly for the restaurant trade, although there is also a demand for live stonefish (*Synanceia verrucosa* and *S. horrida*) for traditional Asian medicines as well as for food (Richards 1993). A similar type of operation was conducted from Palau to Hong Kong before concern over levels of fishing pressure forced the closure of the fishery (Johannes 1991). Interest has also been shown in developing live reef fish exports from Tuvalu (I. Keay, Tuvalu Fisheries Division, pers. comm.) and from the Australian GBR (A. H. Richards, Forum Fisheries Agency, pers. comm.) and Richards (1993) has suggested that as reef fish resources are increasingly depleted in the South China Sea region, companies based in Taiwan, Hong Kong and Singapore will venture increasingly into the South Pacific in search of groupers and Napoleon wrasse.

There is also growing interest in the Pacific islands in developing export fisheries for the international aquarium fish trade. Aquarium fish fisheries are operating in Fiji, the Cook Islands, Vanuatu, Palau, Kiribati, Tonga and the Marshall Islands. The common target species of aquarium fish fisheries are the smaller reef species not normally targeted heavily for food. Pyle (1993) lists 10 families (Pomacanthidae, Chaetodontidae, Acanthuridae, Labridae, Serranidae, Pomacentridae, Balistidae, Cirrhitidae, Gobiidae and Blenniidae) as the most important to the aquarium trade. Over 240 species of reef fish are listed in the export figures reported from Palau (Anon 1993b), with the most common being the damselfishes (Pomacentridae), *Chrysiptera cyanea*, *Chromis albipectoralis* and *Dascyllus aruanus*, which are of little unit value, price range US\$0.2 – 0.3 per fish. However, this is much higher than the price received for reef fishes sold for food and comparatively rare specimens such as *Ctenochaetus tomiensis* may be worth as much as US\$25 per fish.

Improvements in fishing power of gear and growth of human populations have in many locations been paralleled by declines in stocks, catch rates and, in some cases, landed volume of reef fishes. Certain species may be extremely vulnerable to particular fishing gears. As stated earlier, the combination of spear fishing and SCUBA gear is believed to be responsible for the extinction of *Bolbometopon muricatum* and *Cheilinus undulatus* at Guam and the large-scale population decline of these species on Palau. Other cases of finfish stock depletion have been reported in the Pacific. These include declines in reef and lagoon fish stocks in Palau (Johannes 1981, 1991), reef fishes and lagoon fishes in Kiribati (Yeeting & Wright 1989), bonefishes, milkfishes and parrotfishes in the Cook Islands (Anon. 1988a, J. Dashwood, SPC Fisheries Programme, pers. comm.), various grouper stocks in French Polynesia (Bell 1980), Tokelau (Hooper 1985) and the Cook Islands (Sims 1990), and reef and small pelagic fishes in Western Samoa (Helm 1992).

In many locations in the Pacific, exploitation of reef resources is regulated by communities, particularly via traditional concepts of marine tenure (see contributions in Ruddle & Johannes 1985 and South et al. 1994). In some locations, customary ownership of fishery resources has almost disappeared, resulting in open access to nearshore reef resources. Fisheries management and development must account for traditional ownership where it exists, and this may be formalized in legislation as in Fiji (Adams 1993c, Adams 1996). Contemporary approaches to managing reef fisheries in some locations in the region may include very detailed fisheries regulations and ordinances that specify closed seasons, areas closed to fishing, size limits for certain species and mesh size limits for fishing gear. Such approaches are likely to be more

enforceable in the commercial sector than at the community or village level.

Apparently, the only objective attempt to assess the robustness of traditional management in the face of resource pressure has been that of A. Cooke and N. V. C. Polunin (unpubl; see also Cooke (1994) and Cooke & Moce (1995). An index of “management aptitude” was derived from the responses of eight Fijian qoliqoli managers to a set of specific questions including queries as to their use of information for management, approach to goodwill payments, work with the Fisheries Division and management and enforcement measures taken. Of four qoliqoli subject to high commercial fishing pressure, two showed high aptitude and two low aptitude. Among the qoliqoli studied, those with highest aptitude showed, in particular, evidence for liaison and collaboration with the Fisheries Division. The inference was that those exhibiting low aptitude might benefit from some form of co-management with the Fisheries Division.

Coastal reef finfish catches will continue to be the main source of subsistence protein for most Pacific island countries for the foreseeable future, but there is likely to be an increasing volume of high value species being transported to domestic urban and tourist centres and exported to overseas markets. Problems are likely to occur in countries where yields from coral reef fisheries cannot keep pace with population growth and where there are no major developments in targeting offshore fish stocks or aquaculture. Those islands most at risk from this “Malthusian overfishing” (as defined by Pauly 1990) of reef fish will be those with a high human population in comparison with the available reef and lagoon area. There is not yet any comprehensive quantification of coastal fisheries habitat as for the Pacific islands, so this ranking cannot yet be made, but islands such as Saipan, Upolu, Rarotonga and Tarawa, for example, would definitely appear to be in a high-risk category.

Deep-slope fisheries

Description

Beyond shallow reef slopes, in depths where hermatypic corals do not flourish, lie the deep reef slopes. These are usually areas of sand and coral boulders, but with other sediments also present depending on island type and proximity to rivers and alluvial deposition. The deep reef slope typically starts at about 80 m and extends to about 400 m depending on the steepness of the island shelf. The fish community of the deep reef slope is simpler than the neighbouring shallow reef and comprises mainly large carnivorous species of snappers (Lutjanidae), groupers (Serranidae), emperors (Lethrinidae) and jacks (Carangidae). Catches of snappers from the deep reef slope are dominated by members of the genera *Pristipomoides* and *Etelis* (referred to here collectively as eteline snappers) that are high quality fish with a high demand from overseas markets in Japan and Hawaii. These deep-slope fish stocks have, until recently, been lightly exploited or unexploited throughout most of the South Pacific region. Exceptions are the limited subsistence fisheries for deep-slope snappers and oil fish (*Ruvettus pretiosus*) at some Polynesian atolls (Wankowski 1979) and in Hawaii where deep-slope fish stocks have been continuously exploited for over 50 yr (Ralston & Polovina 1982, Polovina 1987, Shomura 1987).

During the early 1970s, the South Pacific Commission commenced surveying the deep reef slope stocks of the Pacific islands and demonstrating techniques useful for exploiting these stocks (Dalzell & Preston 1992). Initial surveys in Polynesia and Melanesia revealed the existence of fishable stocks but the techniques used were not appropriate for the Pacific

islands. From 1979 onwards the Commission propagated the use of more appropriate fishing technology, based around small diesel-powered dories and manual fishing reels first developed in Western Samoa (Gulbrandsen 1977). The efforts of the Commission and its extension programme led to the establishment of deep-slope fisheries in many locations in the South Pacific, including Tonga, Fiji, Vanuatu, American Samoa, Western Samoa, Solomon Islands, PNG, Federated States of Micronesia and French Polynesia.

Not all of these fisheries have persisted and the reasons why they have failed in various locations are a mixture of both stock depletion and socioeconomic factors. The most successful deep-slope fishery is probably the fishery in Tonga, which began on the nearshore slopes of the archipelago but graduated to the numerous seamounts in the Tongan EEZ from which most of the Tongan deep-slope catch now originates. The deep-slope fishing fleet is composed of wooden dories between 6 and 11 m in length, powered by 20 hp Yanmar diesel engines. The boats were constructed locally with credit supplied from two United Nations agencies. All boats use between four and five wooden hand-reels, most commonly baited with the commercial long-line bait of saury (*Cololabis saira*).

Descriptions of the Tongan fishery are given by Langi & Langi (1987) and Latu & Tulua (1991). The dories make voyages lasting 5 days, of which 2 days are traveling time and three days are spent fishing on seamounts. On average between three and four reels are deployed during a fishing trip for a period of about 7 h per day. Each vessel completes about 30 fishing trips per year. Most of the dories are based in Tongatapu, with a small number of boats landing fish into Vava'u. The fishermen sell their catch to fish buyers, some of whom also own fishing vessels. About two-thirds of the catch is sold locally, while the prime species *Etelis coruscans* and *Pristopomoides filamentosus* are air freighted to markets in Hawaii. Initially, about 40 dories were operating in the fishery, but the fleet has now shrunk to between 15 and 20 vessels: some boats have been used for other purposes such as bêche-de-mer collection or simply were no longer seaworthy. Annual landings from the Tongan deepslope fishery amount to between 210 and 514 t yr⁻¹ with current production at around 250 t yr⁻¹.

The deep-slope fishery in Fiji has not been as well documented as the Tongan fishery but was nearly as large during the mid 1980s in terms of production volume. Furthermore, the Fiji fishery was innovative in the use of larger more sophisticated fishing vessels, using commercial fish-finding sonars and deploying bottom long-lines and hydraulically operated reels rather than the simple wooden hand-reel. The Fijian fishery was also the first in the South Pacific to explore the possibility of exporting fish to more lucrative overseas markets. Lewis et al. (1988b) provide the best description of the Fiji deep-slope fishery prior to its demise after 1987. The Fiji deep-slope fleet comprised one 20 m Hawaiian long-liner, four larger local vessels (three drop-line and one long-line) and a number of 9 m dories, similar to those used in Tonga. The larger vessels deploying hydraulic reels used lines with five or more hooks per line. Bait used throughout the fishery was skipjack rejected by the local cannery. The larger vessels used a palu, or chum bag, to aggregate fish and increase catch rates. At the peak of the Fiji fishery about 200 t of deep-slope fishes were landed annually, with about 75% of this sold overseas. Disruption in airline scheduling following political events in 1987 was a serious setback to the fishery, where profit margins were not large. However, the vessels involved in the fishery began to shift from demersal fishing to pelagic long-lining to catch large high-value tunas such as yellowfin (*Thunnus albacares*) and bigeye (*T. obesus*). These species can be caught more reliably than deep-slope fishes, realize a much better return on overseas markets and stocks are not nearly as limited as stocks on the deep slope. The expansion of the deep-slope fishery in Fiji was based largely on catches from unexploited stocks, where catch rates could fall by one order of magnitude in a short period of time, particularly when fishing on seamounts.

The Vanuatu deep-slope fishery was based on the Village Fisheries Development Plan (VFDP) that was conceived as a strategy to increase the supply of fresh fish from village based fisheries in the country. As part of the overall plan, locally built wooden dinghies and catamarans were equipped with the Samoan hand-reel and various incentives were offered to village groups to become involved in the fishery, such as duty-free gasoline. In recognition of the fact that Vanuatu villagers were not used to fishing outside the shallow reef zone, a training centre was established in Luganville (Fig. 2, 125), to impart the skills required to become an artisanal fishermen targeting deep slope fishes. The fishery expanded from just six boats in 1982 to 180 by 1988, although not all boats were engaged in full-time fishing. Descriptions of the deep-slope fishery in Vanuatu are given by Schaan et al. (1987) and Carlot & Nguyen (1989). The volume of landings in the Vanuatu fishery between 1982 and 1988 ranged from 10 to 86 tyr^{-1} with a mean of 50 tyr^{-1} , while a survey of commercial fisheries in Vanuatu during 1992 suggested an annual production from the deep-slope fishery of about 80 t (Anon. 1992b). Dalzell (1992a) noted that in response to declines in catch of deep-slope fishes, Vanuatu fishermen were now targeting shallow reef species. Although the VFDP was planned to increase fish supply for the village population, much of the deepslope catch is now sold to the restaurant and hotel trade in Port Vila (Fig. 2, 81) and Luganville.

PNG has by far the largest resource of deep-slope species in the South Pacific but only one commercial fishery, on the north coast of the mainland, was ever successfully established there. The fishery landed between 5 and 20 tyr^{-1} between 1983 and 1985, before going into decline after government support for the fishery was reduced (Chapau & Dalzell 1991). A combination of factors contributed to the decline of the American Samoan fishery, which was comparable in scale to the fishery in northern PNG, but where landings were exported to Hawaii to realize greater profits. Among the factors responsible for the decline in the fishery were a fall in catch rates of deep-slope stocks, volatility of the prices on the Hawaiian market, delays in payment for export catches and competition from purse-seine by-catch on the domestic market (Itano 1991).

Elsewhere in the South Pacific, small amounts of deep-slope fishes are caught for local markets. Landings of deep-slope fishes in French Polynesia are mainly from recreational fishermen and landings range from 0.5 to 10 t annually (Wrobel 1988). Between 40 and 80 t of deep-slope fishes are landed annually in New Caledonia for domestic consumption (Anon 1994a). Recently, a commercial survey of seamounts and banks in the Tuvalu EEZ has led to catches of deep-slope fishes, some of which have been marketed in Hawaii (Anon 1993c). Small amounts of deep-slope fishes have been caught and air-freighted to Japan and Hawaii from the Federated States of Micronesia, but production has not been consistent (P. Dalzell unpub. data).

Catch composition

By contrast to shallow reef fish fisheries, which have been largely ignored by fisheries scientists in the South Pacific, deep-slope species have been the focus of a considerable amount of research and monitoring. Dalzell & Preston (1992) present the most coherent data set on composition of deep-slope fishery catches throughout the Pacific. These data (Table 11) are based on surveys conducted by the South Pacific Commission on what are essentially unexploited stocks. Nearly all the Pacific islands are included in this data set, notable excep-

tions being Guam, Nauru and Pitcairn. The snappers, or Lutjanidae, are divided into two groups, following the taxonomy proposed by Johnson (1980); the subfamilies Etelinae and Apsilinae, or deep-slope snappers, and the subfamilies Lutjaninae and Paradichthyinae, or shallow water snappers.

The Lutjaninae are more a feature of shallow lagoon habitats but species such as *Lutjanus bohar* and *L. argentimaculatus* migrate down the deep reef slope as they increase in size (Wright et al. 1986). Indeed, of the total number of fishes caught in the Commission surveys, *L. bohar* was the commonest species (4.6%), followed by *Caranx lugubris*, *Pristipomoides filamentosus*, *Etelis carbunculus* and *Pristipomoides flavipinnis* that together formed over 20% of the total catch. A further eight snapper species (*Pristipomoides zonatus*, *P. multidentis*, *P. auricilla*, *Etelis radiosus*, *E. cornescens*, *Lutjanus gibbus* and *Aphareus rutilans*), formed a further 20% of the total.

Factors such as position or longitude, average depth fished, seasonality, island type and size and fishing intensity will have an effect on the composition of catches. Dalzell & Preston (1992) compared species composition between catches at high islands and catches around atolls. They showed that catches from high islands contain a significantly greater amount of the commercially valuable eteline snappers than at atoll sites. Furthermore, catches at atoll sites contained greater numbers of sharks, which have little or no commercial value. Regional differences also exist between the species composition of deep-slope catches from the Pacific islands. We have summarized data on catches from the South Pacific Commission's surveys

Table 11: Percent composition of deep-slope catches from different locations in the South Pacific.

Country/ Territory	Lutjaninae		Serranidae		Carangidae/ Scombridae	Gempy- lidae	Sphyrae- nidae	Other teleosts	Sharks
	Etelinae	Lethrinidae							
American Samoa	42.4	18.1	14.9	2.1	12.4	0.7	8.9	0.8	0.0
Belau	36.0	11.8	4.1	12.4	15.2	7.0	1.7	3.5	5.2
Cook Islands	50.7	2.0	1.2	9.4	9.9	4.7	0.1	6.7	15.2
Federated States of Micronesia	21.7	18.6	4.4	7.4	18.5	2.4	1.0	4.9	21.2
Fiji	24.6	11.9	5.4	8.1	15.1	2.7	5.2	1.5	25.6
French Polynesia	28.7	2.5	0.2	30.2	19.7	14.1	0.1	1.6	3.0
Kiribati	13.5	32.8	3.4	21.6	5.5	5.4	0.4	0.7	17.1
Marshall Islands	8.5	14.3	6.5	10.1	8.1	1.1	0.3	2.3	48.9
New Caledonia	24.4	9.6	19.4	11.4	56	0.0	2.8	0.2	25.3
Niue	10.1	27.2	11.2	13.5	9.2	3.9	1.2	15.3	3.3
Northern Marianas	60.3	0.0	0.1	0.5	34.4	0.0	0.0	0.0	0.0
Papua New Guinea	49.2	16.1	3.8	7.2	7.0	0.5	0.9	0.4	153
Solomon Islands	61.0	14.3	0.4	10.8	1.9	0.0	7.8	3.8	0.0
Tokelau	21.8	2.9	6.1	6.9	27.9	5.5	1.5	2.3	25.4
Tonga	49.0	3.9	20.2	13.8	5.5	0.8	1.1	0.5	5.0
Tuvalu	17.1	10.2	0.9	10.1	12.6	32.8	0.7	0.5	15.2
Vanuatu	45.5	10.6	2.1	19.1	3.9	4.6	0.2	1.3	12.9
Wallis & Futuna	56.8	4.6	5.8	12.2	11.6	0.0	0.1	0.3	8.8
Western Samoa	45.9	7.1	1.2	5.6	5.0	25.0	0.0	3.8	65

Table 12: Composition by species of three families taken by deep-slope hand-line fishing in the South Pacific region.

Family and species	Percentage composition by sub-region		
	Melanesia	Micronesia	Polynesia
LUTJANIDAE			
ETELINAE/ APSILINAE			
<i>Aphareusfurca</i>	0.05	0.82	0.90
<i>A. rutilans</i>	7.98	6.27	8.34
<i>Aprion virescens</i>	1.49	4.41	6.49
<i>Etelis carbunculus</i>	6.76	20.56	9.47
<i>E. coruscans</i>	4.71	15.02	5.53
<i>E. radius</i>	2.79	0.20	0.89
<i>Pristipomoides kuskarii</i>	3.13	2.91	0.00
<i>P. amoenus</i>	1.20	0.52	0.21
<i>P. auricilla</i>	1.59	5.82	27.63
<i>P. filamentosus</i>	23.41	10.83	10.84
<i>P. flavipinnis</i>	18.61	9.32	4.80
<i>P. multident</i>	22.99	1.11	0.98
<i>P. zonatus</i>	2.80	17.29	18.19
Others	2.50	4.92	5.73
LUTJANINAE			
<i>Lutjanus argentimaculatus</i>	8.76	18.08	2.65
<i>L. bohar</i>	22.59	43.38	33.18
<i>L. gibbus</i>	11.85	29.66	15.20
<i>L. kasmira</i>	2.16	1.85	32.06
<i>L. malabaricus</i>	18.86	0.25	0.22
<i>L. monostigma</i>	8.64	0.95	0.49
<i>L. rufolineatus</i>	2.04	4.38	1.57
Others	25.10	1.44	14.62
LETHRINIDAE			
<i>Gymnocranius japonicus</i>	5.23	0.30	0.82
<i>Lethrinus chrysostomus</i>	11.80	0.89	53.18
<i>L. kallopterus</i>	0.81	5.33	4.00
<i>L. miniatus</i>	15.90	32.99	17.01
<i>L. reticulatus</i>	0.15	3.11	0.00
<i>L. variegatus</i>	1.76	11.09	5.94
<i>Wattsia mossambica</i>	52.09	27.51	7.99
Others	12.27	18.79	11.07
SERRANIDAE			
<i>Cephalopholis aurantia</i>	0.25	1.25	2.32
<i>Epinephelus areolatus</i>	4.39	8.26	4.01
<i>E. chlorostigma</i>	7.05	2.35	0.23
<i>E. cometae</i>	8.13	0.16	0.41
<i>E. fasciatus</i>	0.00	0.55	1.82
<i>E. jlavocaeruleus</i>	1.53	1.76	0.27
<i>E. magniscutis</i>	0.49	0.63	0.00
<i>E. miliaris</i>	3.79	18.23	9.43
<i>E. morrhua</i>	27.35	14.44	12.48
<i>E. retouti</i>	1.13	0.47	10.02
<i>E. septemfasciatus</i>	4.73	0.08	5.15
<i>Saloptia powelli</i>	0.89	0.16	5.60
<i>Variola louti</i>	7.24	8.10	11.75
Others	33.02	43.58	3649

presented by Dalzell & Preston to highlight differences between four common components of deep slope catches, namely eteline snappers, lutjanine snappers, emperors and groupers, with respect to the three archipelagic groupings of Melanesia, Micronesia and Polynesia (Table 12). This effectively splits the Pacific into the small high islands and atolls north of the equator (Micronesia), the large high islands in the west of the Pacific and south of the equator (Melanesia) and the small high islands and atolls of the central Pacific that lie to the south of the equator (Polynesia).

In the small high islands and atolls of Micronesia, north of the equator, deep-slope catches of eteline snappers are dominated by *Pristipomoides auricilla* and *P. zonatus*. In similar habitats in the central and southern Pacific *P. zonatus* is also a major component in deep-slope catches along with *Etelis carbunculus* and *Pristipomoides filamentosus*. Catches on the slopes of the large Melanesian islands are dominated by *P. multidentis* and to a lesser extent by *P. filamentosus*. As with the etelines, there are subregional differences in the lutjanine snapper composition from deep-slope hand-lining. In the Polynesian islands the small blue-line snapper, *Lutjanus kasmira*, and the red bass, *L. bohar*, each form about one third of the lutjanine snapper catch, with the other major contribution being from *L. gibbus*. In similar habitats in Micronesia, *L. bohar* is the dominant lutjanine snapper, along with *L. gibbus* and *L. argentimaculatus*. On the larger slope areas of the Melanesian islands, *L. bohar*, *L. argentimaculatus* and *L. gibbus* are still dominant features of the snapper catch but dominance is shared with *L. malabaricus*.

Over half of the catch of emperors from the deep slopes around the large Melanesian islands comprises the deep-slope bream, *Wattsia mossambica*. Other dominant emperors included large and readily identifiable *Lethrinus olivaceus* (= *miniatus*) and *L. miniatus* (= *chrysostomus*). *L. olivaceus* and *Wattsia mossambica* were also dominant features of the emperor catch from Micronesian islands along with *Lethrinus kallopterus* and *L. variegatus*. The dominant feature in the catch from Polynesian islands was *L. miniatus* followed by *L. olivaceus*. *Wattsia mossambica* formed only a small portion of the lethrinid catches around Polynesian islands.

The proliferation of species in the family Serranidae and the difficulties in identifying species, particularly in the field, are reflected in the relatively large percentages in the other species category (Table 12). However, grouper catches from the Pacific islands tend to be formed mainly from the following species: *Epinephelus morrhua*, *E. miliaris*, *E. retouti* and *Variola louti*. In Melanesia, *Epinephelus morrhua* was clearly the dominant grouper species in deep-slope catches, while in Micronesia dominance was shared between *E. miliaris* and *E. morrhua*, and in Polynesia, among *E. morrhua*, *E. miliaris* and *E. retouti*. The coral cod *Variola louti* was common to grouper catches in all three locations, while *Epinephelus cometae* and *E. chlorostigma* were dominant features of catches in Melanesian waters, and *E. areolatus* of catches from Micronesia. Another feature of deep-slope catches from Melanesian and Polynesian islands, particularly from unexploited fishing grounds is the giant grouper *E. septemfasciatus*. This species is among the first to be fished out in deep-slope fisheries where effort is particularly heavy.

Brouard & Grandperrin (1985) classified catches of deep-slope catches in Vanuatu according to depth. Shallow species were defined as those in waters < 120 m and included many species commonly found on coral reefs such as squirrelfishes, small groupers, emperors and snappers. Species in waters of intermediate depths (120 — 240 m) consisted mainly of eteline snappers of the genera *Pristipomoides* and *Paracaesio*, and the larger emperors, lutjanine snappers and groupers. Deep water species (> 240 m) included the three *Etelis* species, large groupers such as *Epinephelus septemfasciatus*, hexanchid sharks and oil fish (*Ruvettus pretiosus*). Sundberg

& Richards (1984) arranged the 10 most common species in deep-slope (80 — 300 m) catches from northern PNG from common to less common as follows: *Lutjanus bohar*, *Lethrinus miniatus*, *Lutjanus erythropterus*, *Aphareus rutilans*, *Lutjanus malabaricus*, *L. argentimaculatus*, *Wattsia mossambica*, *Pristipomoides multidens*, *Etelis coruscans* and *E. carbunculus*.

Catch rates

The most comprehensive summary of catch rates from fishing on Pacific island deep-slope stocks is given in Dalzell & Preston (1992). It should be noted, however, that these catch rates are for mainly unexploited stocks and do not apply to commercial fishing. Catch rates ranged from 0.5 — 19.0 $\text{kgline}^{-1}\text{h}^{-1}$ with a mean of 7.0 $\text{kgline}^{-1}\text{h}^{-1}$. These gross catch rates include sharks, which are sometimes discarded and not recorded in catches. Catch rates for teleost fish only ranged from 0.3 — 14.5 $\text{kgline}^{-1}\text{h}^{-1}$, with a mean of 6.6 $\text{kgline}^{-1}\text{h}^{-1}$. Average catch rates around high islands and atolls were 5.5 and 6.8 $\text{kgline}^{-1}\text{h}^{-1}$ respectively but there were no significant differences between these means.

Average catch rates in commercial fisheries and survey fisheries in the South Pacific are also included in Table 5 (p. 418). Catch rates in the Tonga deep slope fishery ranged from 2.76 — 13.3 $\text{kgline}^{-1}\text{h}^{-1}$ with an overall mean of 6.4 $\text{kgline}^{-1}\text{h}^{-1}$ for the years 1986 — 92 (Mees 1994). Sustained fishing on deep-slope stocks over a period of 1 yr in northern PNG by Richards & Sundberg (1984) produced catch rates ranging from 0.6 to 11.24 $\text{kgline}^{-1}\text{h}^{-1}$, with a mean of 3.1 $\text{kgline}^{-1}\text{h}^{-1}$. Similarly, Chapau (1988) reported an average catch rate of 3.7 $\text{kgline}^{-1}\text{h}^{-1}$ in the small commercial deep-slope fishery based near Wewak (Fig. 2, 114) in northern PNG between 1983 and 1985. A similar small-scale operation fishing around Pohnpei (Federated States of Micronesia) and the nearby atolls of Ant and Pakin (Fig. 2, 2) between 1983 and 1986 produced catch rates that ranged from 3.9 to 5.5 $\text{kgline}^{-1}\text{h}^{-1}$ with a mean of 4.7 $\text{kgline}^{-1}\text{h}^{-1}$ (McCoy 1990). A small-scale pilot commercial fishery operating around Pohnpei in 1989 experienced catch rates of 0.7 — 5.1 $\text{kgline}^{-1}\text{h}^{-1}$ with a mean of 3.0 $\text{kgline}^{-1}\text{h}^{-1}$ (P. Dalzell unpub. data). Survey fishing of banks and seamounts around Tuvalu during 1992 and 1993 experienced catch rates ranging between 1.72 and 9.62 $\text{kgline}^{-1}\text{h}^{-1}$ with an overall mean of 6.1 $\text{kgline}^{-1}\text{h}^{-1}$ (Anon. 1993c). Catch rates experienced by village fishermen fishing on deep-slope stocks in Vanuatu in the mid 1980s ranged from 0 to 5.00 $\text{kgline}^{-1}\text{h}^{-1}$ with a mean of 1.44 $\text{kgline}^{-1}\text{h}^{-1}$. Average monthly catch rates for hand-line fishing on the Chuuk Outer Banks (Fig. 2, 17) ranged from 1.3 — 4.57 $\text{kgline}^{-1}\text{h}^{-1}$ with a mean of 2.30 $\text{kgline}^{-1}\text{h}^{-1}$. Catches comprised both deep-slope and shallow water reef fishes. Sustained commercial fishing on the deep-slope stocks of Niue between 1988 and 1990 generated average monthly catch rates ranging between 2.1 and 8.5 $\text{kgline}^{-1}\text{h}^{-1}$, with an overall mean of 5.5 $\text{kgline}^{-1}\text{h}^{-1}$.

Less information is available on catch rates from long-line fishing on deep-slope stocks and most of the fishing refers to surveys of virgin stocks. The limited information available has been summarised in Table 13. Average catch rates ranged from a low of 6.8 kg100hooks^{-1} on the Chuuk Outer Banks to a high of 124 kg100hooks^{-1} on the shelf area off the south coast of Espiritu Santo (Fig. 2, 22) in Vanuatu. The catch data from Fiji are from a commercial fishing operation that fished on the outer banks and sea mounts in Fiji's EEZ and are probably more indicative of the returns from this method of fishing on deep-slope fish. Also included in Table 13 is a summary of long-line fishing in the lagoon of New Caledonia in waters between 5 and 40 m in depth. Although in shallow waters the composition of the New Caledonia target stocks

Table 13: Summary of catch rate and catch composition data for long-line fishing on coral reef and associated stocks in the South Pacific region.

Location	Target stock	CPUE (kg100hooks ⁻¹)		Principal catch components	Source
		range	mean		
New Caledonia	Shallow reef species	3.0 – 12.2	8.2	Lethrinidae, Serranidae, Labridae, Lutjanidae	Kulbicki & Grandperrin 1988
Chuuk Outer Banks	Deep slope species	1.6 – 12.3	6.8	Lutjanidae, Carangidae, Lethrinidae,	Diplock & Dalzell 1991
Tonga	Deep slope species	na	11	Lutjanidae, Serranidae, Carangidae, Sharks	Mead 1987
Fiji	Deep slope species	12.5 – 29.2	19.1	Lutjanidae, Serranidae	Walton pers. comm.
Vanuatu (Paama (Fig 2, 76) & Espiritu Santo)	Deep slope species	10 – 92.5	33.7	Lutjanidae, Serranidae, Sharks	Fusimalohi & Preston 1983
Vanuatu (Espiritu Santo)	Deep slope species	15 – 389	124.6	Lutjanidae, Serranidae, Lethrinidae, Carangidae	SPC unpub. data

at the family level was closer to that from deep-slope fishing than from reef areas, their inclusion in Table 13 allows for some comparisons to be made with deep-slope catch rates.

Seasonal trends in catch rates of deep-slope fishes have been reported from Vanuatu (Brouard & Grandperrin 1985) and from Tonga (Latu & Tulua 1991). In Vanuatu catch rates for *E. carbunculus* and *E. coruscans* reached a maximum between February and June, with minima towards the year's end. Maximum catch rates of *Pristipomoides flavipinnis* and *P. multidens* were observed between April and July. By contrast the CPUE for *Lutjanus malabaricus* was at a maximum during December and lowest in June and July. There was little evidence of seasonality in CPUE from the total catch from the deep-slope fishery in Tonga; however, individual species had very clear seasonal maxima in Tonga. The CPUE of both *Pristipomoides filamentosus* and *P. flavipinnis* were lowest in September and highest in December-January. *Etelis coruscans* was observed to have two peaks in CPUE, during May and during November, while only a single peak in CPUE was observed for *E. carbunculus* during November. Two seasonal peaks in CPUE were also observed from catches of *Lethrinus chrysostomus*, during February and July. The seasonal pattern for *Epinephelus morrhua* resembled that of the *Pristipomoides* spp., but with a peak in April and a low point in August. The seasonal pattern for *Epinephelus septemfasciatus* showed a strong peak in CPUE during May.

Variation in catch rate with depth and time of day has been investigated in Vanuatu (Brouard & Grandperrin 1985) and PNG (Richards & Sundberg 1984). Brouard & Grandperrin (1985) concluded that there was little difference between day and night catch rates, but that when the data were broken down by 40 m depth intervals, catch rates were greatest in shallow water at night. Richards & Sundberg (1984) reported on a study that was specifically designed to test the differences in CPUE among depths and times of day. They found that peaks in CPUE occurred progressively later in the day from the deepest to the shallowest depths over 24 h. Dalzell & Preston (1992) summarized the information from surveys of deep-slope stocks to investigate the interaction of depth and time of day on deep-slope catches. CPUE increased with increasing depth between 50 and 150 m, was constant between 150 and 250 m, and declined with increasing depth between 250 and 450 m. Hourly catch rates showed no particular pattern in

shallow waters, but resolved into peaks at 12.00 and between 22.00 and 02.00h at depths beyond 200 m. The average pattern of catch rates over a 24 h period, for all depths, produced peaks at 12.00, 15.00, 20.00 and 03.00h. Ralston et al. (1986) found that the abundance of fish at Johnson Atoll peaked at 170 m depth with a smaller minor peak at 250 m. Overall, the pattern of abundance was similar to the depth pattern of catch rates observed from survey fishing data by Dalzell & Preston (1992). Ralston et al. (1986) found that on average, catch rates were twice as high in the morning than in the afternoon but that catch rate began to improve with the onset of the evening crepuscular period.

The foregoing data do not include information on individual species captured and the resultant patterns in CPUE with depth and time of day are the result of various species interactions. Haight et al. (1993) reported the results of experimental fishing on the outer banks of the Hawaiian Islands for eteline snappers using hand-lines and long-lines. This study showed that overall CPUE in numbers of fish fluctuated throughout the diel cycle and peaked during the crepuscular periods (04.00 to 06.00h and 18.00 to 20.00h). Catch rates of individual species also fluctuated markedly, with *Pristipomoides* spp. and *Etelis cornescans* being caught mainly in the morning, in contrast to *E. carbunculus*, which was captured mainly during the evening and night. Other species, such as *Aprion virescens*, were captured throughout the day but generally not at night.

Fisheries biology and stock assessment

Unlike shallow water reef fishes, there has been a considerable amount of stock assessment research and biological studies made on Pacific deep-slope fish stocks. A series of review papers on deep-slope fish biology and stock assessment was edited by Polovina & Ralston (1987). Age, growth and related biological studies commenced on deep slope species in the Pacific during the 1980s, principally on the eteline species with the intent of monitoring the effects of fishing and conducting stock assessments. Ralston (1981) presented an account of the population biology of *Pristipomoides filamentosus* in the Hawaiian Islands that included a new approach to ageing long-lived fishes from daily growth increments. The same method, which has also been described in detail by Ralston & Miyamoto (1981), does not require a complete reading of the growth record in the otolith microstructure but only requires several counts of increment densities at successive distances from the otolith core so that these can be integrated to give a complete estimate of the age of the fish.

This methodology has been used to age several deep-slope species from the Northern Mariana Islands (Ralston & Williams 1988b), PNG (Richards 1987) and Vanuatu (Brouard & Grandperrin 1985). A comparative study of the age and growth of *Etelis carbunculus* from Hawaii, Northern Mariana Islands, Vanuatu and French Polynesia was made by Smith & Kostlan (1991) using Ralston's technique. They were able to show that there were major differences in age at length for the four widely separated stocks of the same species. Other estimates of growth of deep-slope species have been made by analysis of length frequency data from Vanuatu (Carlot 1990) and Tonga (Sua 1990, Mees 1994). Most of the studies listed above have computed mortality rates for deep-slope species from length frequencies, catch curves or a combination thereof. Deep-slope species typically have life spans of between 20 — 30 yr, with concomitantly low natural mortality rates. Ralston (1987) has reviewed the mortality rates of deep-slope snappers and groupers and has suggested that agents responsible for natural deaths in these species include predation, parasitism, cold water shock and red tide poisoning. Ralston

(1987) has also reviewed information from fisheries for tropical deep-slope snapper and grouper species and concluded that these species have a relatively limited productive capacity and are vulnerable to overfishing.

Two basic approaches have been used to estimate the MSY from deep-slope fish stocks in the South Pacific: multi-species surplus production models where the catch of all or a group of the commonest species are combined and plotted against effort; and biomass estimation and yield calculations based on biological characteristics. A third method for assessing deep-slope stocks is to conduct direct observations on fish populations *in situ* while conducting survey fishing. Such a series of observations has been made by Ralston et al. (1986) at Johnson Atoll, where survey fishing was complemented by a series of deep-slope fish abundance estimates made from a small submersible. More recently, Ellis & DeMartini (1994) have correlated estimates of abundance of juvenile *Pristipomoides filamentosus* and other Hawaiian deep-slope fish made by a remote video camera with demersal long-line catch rates targeted at the same stocks. However, such methodology, requiring expensive specialized technologies and skills, is unlikely to be commonly used in the Pacific.

Ralston & Polovina (1982) fitted a multi-species version of the Schaefer stock production model to catch and fishing effort data from a deep-slope hand-line fishery on the banks between the islands of Maui, Lanai, Kahoolawe and Molokai (Fig. 2, 57) in Hawaii. They found that the annual predicted MSY was 106 t or 272 kgn.mi⁻¹ of 100 fathom isobath. Ralston & Polovina (1982) explained that expressing yield per linear measure was probably more appropriate for steep-sided islands than the use of an areal or planar measure. Other authors have adopted this convention and expressed yields as kgn.mi⁻¹ of 100 fathom or 200 m isobath. Elsewhere, King (1992a) fitted simple Fox and Schaefer production curves to data for catches of the five principal species (*P. filamentosus*, *Etelis carbunculus*, *E. coruscans*, *Epinephelus septemfasciatus* and *E. morrhua*) in the Tongan deep slope fishery. King (1992a) found that the MSY predicted by the two models was 255 and 284 tyr⁻¹ respectively. A similar analysis for all demersal species suggested MSYs of 400 and 560 t respectively, but the fit to the data was rather poor. The length of the 200 m isobath in Tonga is estimated to be 294 n.mi (Lam & Tulua 1991) thus the yields estimated from King's (1992) analysis range from 0.87 to 0.97 tn.mi⁻¹ for the principal five species to between 1.36 and 1.90 tn.mi⁻¹ for the total demersal catch.

The other approach to estimating MSY from deep-slope stocks in the South Pacific is to use depletion models to estimate the unexploited biomass and then, using the biological characteristics of the stock, estimate what fraction of the virgin biomass can be harvested. The simplest approach has been to conduct short-term intensive fishing experiments to generate cumulative catch and CPUE data for use with a Leslie stock depletion model (see p. 420). For situations where fishing has commenced and longer time series of catch and effort data are available, then Allen's (1966) method, which incorporates natural mortality rates and recruitment, is more appropriate.

Polovina (1986) used the simple short-term Leslie depletion method to estimate the biomass and catchability coefficients of deep-slope fishes in the 175 to 275 m depth range, from a 13-day intensive fishing experiment at a small pinnacle reef in the Northern Mariana Islands. Based on these results and with further fishing at most of the islands and seamounts in the Northern Mariana Islands, Polovina & Ralston (1986) were able to estimate the total biomass of deep-slope fishes in this archipelago and the MSYs for the seven principal species in the catch, namely, one jack, *Caranx lugubris*, and six snappers, *Pristipomoides zonatus*, *P. auricilla*, *P. filamentosus*, *P. flavipinnis*, *Etelis carbunculus*, and *E. coruscans*. They suggested that the MSY for the deep-slope stocks of Northern Mariana Islands was about one-third of the original

unexploited biomass, which ranged between 0.260 and 1.207 n.mi⁻¹ of 200 m isobath with a mean of 0.675 tn.mi⁻¹ 200 m isobath, giving an MSY of 0.22 tn.mi⁻¹ of 200 m isobath or an absolute value of 109 t.

The more complex approach to estimating biomass and yield using Allen's method has been employed by Langi et al. (1988) for deep slope fisheries on seamounts around the Tongan archipelago. They stated that the average surplus production or MSY from three seamounts was 0.74 tn.mi⁻¹ of 200 m isobath, or an absolute value of 217 t for the 294 n.mi of 200 m isobath in Tongan waters. The Allen and Leslie depletion methods were both used to estimate biomass and MSY for several other locations in the South Pacific and are presented in a series of papers contained in Polovina & Shomura (1990). These locations include banks and seamounts in Fiji, island slopes in Vanuatu and island slopes and seamounts in PNG, as well as a re-analysis of the data from Tonga using an extended data set. A summary of these estimates was presented in Polovina & Shomura (1990), which suggested that the unexploited recruited biomass ranged from 0.2 to 7.0 tn.mi⁻¹ of 200 m isobath, and that MSY lay in the range of one-tenth to one-third of the unexploited virgin biomass.

Mees (1994) re-analyzed catch and length frequency data from the Tonga deep-slope fishery and fitted a dynamic production model to catch and effort data from the Tongan fishery to obtain a total MSY of 588 t. Using a modification of Allen's model, Mees (1994) estimated a yield of 0.50 — 0.77 tn.mi⁻¹ of 200 m isobath for a guild of six main species in the fishery (*Pristipomoides filamentosus*, *P. javipinnis*, *Etelis carbunculus*, *E. coruscans*, *Epinephelus septemfasciatus* and *E. morrhuaf*, and of 0.33 — 0.63 tn.mi⁻¹ of 200 m isobath for *Pristipomoides filamentosus* only. Mees (1994) noted that individual species' catch rates showed an increase over time for *Etelis coruscans* and a decrease for *Pristipomoides filamentosus*. This was due less to depletion, however, than an increasing trend to fish deeper to target for *E. coruscans* which was more valuable on export markets. Mees (1994) did conclude, however, that there might be some fishing-induced effects between *E. coruscans*, and *Epinephelus septemfasciatus*, with catch rates of the former species increasing as populations of the latter are reduced. Mees (1994) reasoned that *E. septemfasciatus* is the largest fish exploited in the fishery and large specimens will not be replaced rapidly. As they are fished out, the remaining smaller specimens provide less competition to *Etelis coruscans* for the baited hooks and hence the catch rate of this species increases. Indeed, Mees notes that fishermen in Tonga report actively fishing for this species in order to remove it in order to increase catches of *E. coruscans*.

A similar observation was made by Polovina (1986) during short-term intensive fishing experiments in the Northern Mariana Islands. Polovina noted that as the catch rates of *Pristipomoides zonatus* and *Etelis carbunculus* declined during the 13 day fishing experiment, the catch rate of *Pristipomoides auricilla* showed a marked increase. Polovina suggested that the interaction of *P. auricilla* and *Etelis carbunculus* was unlikely to be attributable to the latter species living at greater depths. However, species interaction would most likely occur between *P. zonatus* and *P. auricilla* that were more abundant in the same depth interval (100 — 120 m). Polovina (1986) reasoned that if *P. zonatus* was more aggressive in pursuing fish baits than *P. auricilla*, or in some other way affected the behaviour of the latter, then the initial catchability of *P. auricilla* would be low but would rise as the population of *P. zonatus* was reduced. Polovina (1986) modified the simple Leslie depletion model to account for this species interaction.

Socioeconomic developments

Only one deep-slope fishery of any significance (Tonga) persists in the South Pacific. Despite the initial optimism that was generated by the exploratory surveys on virgin stocks in the Pacific, it was not immediately appreciated that these populations comprised large, slow growing species, and that most countries of the region, by virtue of their size, had limited stocks that could withstand only moderate exploitation. In human terms this meant that deep slope fisheries must remain small and indeed the Tongan fishery has survived only by reducing fleet size by half and maximizing the value of the catch by exporting *P. filamentosus* and *Etelis coruscans* to Hawaii.

The access to overseas markets and the importance this has played in the survival and collapse of deep-slope fisheries cannot be emphasized too strongly. The same is also true of the growing interest in catching large valuable tunas for the Japanese market (see p. 451). PNG has by far the largest resource of deep-slope fish in the region by virtue of the extent of the 200 m isobath. Furthermore, these stocks have been shown to be productive and could probably generate between 500 to 1500 tyr^{-1} at MSY (Dalzell & Preston 1992). However, PNG does not have direct air links to either Hawaii or Japan.

Domestic fish marketing in PNG is poorly developed and only people in the capital, Port Moresby, are prepared to pay relatively high prices for fresh fish. Elsewhere fresh fish is sold for US\$1.0 — 2.0 kg^{-1} , which does not encourage fishermen to invest in the equipment necessary for deep-slope fishing. There have been a number of schemes to transport fish to the capital and encourage fishing on reef, pelagic and deep-slope stocks but these could not be operated at a profit and have never been effective. Another factor that militates against development of deep slope and other fisheries in PNG, and indeed many other countries of the South Pacific, is the availability of cheap fish imports such as barracoutta and hoki. These species are caught in large volumes by trawlers in New Zealand, and can be sold in bulk for a fraction of the cost of fresh fish within the Pacific islands.

Direct air links to Hawaii or Japan are not, however, a guarantee that a deep-slope fishery will be successful. Itano (1991) documented in detail the history of deep-slope fishing in American Samoa from the mid 1960s to the mid 1980s. The limited habitat area meant that catch rates in the nearshore area declined rapidly and fishermen were obliged to venture further offshore to seamounts and banks to maintain profitable catch rates. During the early and mid 1980s fish were shipped to markets in Hawaii via the regular air service between Honolulu and Pago Pago (Fig. 2, 77). However, delays in payments to fishermen in American Samoa acted as a disincentive to fishermen who were already operating on a narrow profit margin. Itano (1991) states that with such a limited resource, deep-slope fisheries in American Samoa are destined to be pulse fisheries operating over short periods on a boom and bust cycle.

The ease with which deep-slope stocks can be depleted is illustrated by examples of fishing on pinnacle reefs in Guam, Fiji and American Samoa. In Guam, one fisherman fished a pinnacle reef for 17 months and drove the catch rates down to zero (Ikehara et al. 1970). Similarly, catch rates on some of the banks and seamounts in the Fijian fishery were driven to zero or near zero levels in less than a year. In American Samoa experimental fishing between February and May 1986, on 2% Bank, a pinnacle reef between Tutuila and Manua (Fig. 2, 53) Islands, resulted in the removal of 78% of the eteline snappers on this seamount (Moffitt 1989). Clearly, promotion of open access commercial fisheries on these limited resources does not make sense. However, development planners promoted these strategies in countries such as Tonga, American Samoa, Vanuatu, Fiji and Tonga by providing easy credit for the acquisition of boats and fishing gear. As a consequence, the deep-slope fisheries in these countries soon became over-capitalized

and most fishing operators who had taken loans to enter the fishery defaulted on repayments (Itano 1991, T. J. H. Adams unpub. data, S. Tulua, Ministry of Fisheries, Tonga, pers. comm.). The fishery in Fiji, which was developing into a more sophisticated commercial operation, simply shifted to targeting large tuna that could realize much better prices on overseas markets that had been established previously for deep-slope fishes (Adams 1990). The Vanuatu fishery has a sizable demand from the hotel and restaurant trade for fresh deep-slope fish but many fishermen have had to target shallow reef species to keep their fishing operations profitable.

Fishing for deep-slope stocks may indeed commence again in Fiji, and be encouraged in PNG, if market demand for deep-slope species improves and markets open in other neighbouring countries such as New Zealand, Australia and Southeast Asia. There are indications that deep-slope fishing is expanding in the Solomon Islands and may offer excellent prospects for domestic and international markets (P. Cusack, South Pacific Commission, pers. comm.). However, it is unlikely that there will be another major expansion of fishing for deep-slope stocks comparable with the increase in effort during the 1980s, particularly where there is now the possibility of fishing profitably for large pelagic fishes (see p. 451).

Nearshore pelagic fisheries

Large pelagic species

Description

Large pelagic fishes, including coastal and offshore species, have always been important in the subsistence diet of Pacific islanders. Tuna forms the basis of artisanal fisheries in Kiribati, PNG and French polynesia, and other large pelagic species, such as Spanish mackerel (*Scomberomorus commerson*), are important components of commercial fisheries in the Western Pacific. Perhaps the commonest method of catching large pelagic fishes is trolling with lures or baits. Other methods of fishing for large pelagic fishes include midwater hand lining and pole-and-line fishing for tuna.

Originally, troll fishermen would fish along the edge of the reef or search for schools of pelagic fishes feeding on the surface and troll around these. More recently, troll fishermen and hand-line fishermen in the Pacific have been increasingly fishing around anchored rafts or buoys, deployed with the objective of aggregating pelagic fishes. Fishermen in all parts of the tropics have known that objects floating on the water surface such as logs, trees, large seaweed mats and even whales and whale sharks may have associated schools of tunas and other pelagic species. For many years, therefore fishermen in Southeast Asian countries such as the Philippines have used this behaviour of pelagic fishes by deploying rafts or fish aggregating devices (FADS) to concentrate schools for capture.

This technology began to be used increasingly with fleets of tuna purse-seiners and pole-and-line fishing vessels in the Western Pacific. It was realized that FADs could benefit small scale artisanal fishermen in the coastal zone. These rafts when anchored in relatively shallow water will aggregate coastal species such as Spanish mackerels, mackerel and bullet tuna, trevallies and rainbow runners. FADs deployed in deeper waters will concentrate schools of oceanic tuna such as skipjack, yellowfin and bigeye, and billfishes such as marlins, sailfish and swordfish. FADs can be constructed from a variety of materials. In Southeast Asia, FADs are often made from floating bamboo rafts with coconut palm fronds suspended beneath.

More modern designs of FADS have been deployed at various locations in the South Pacific and various raft designs and mooring systems are given in Boy & Smith (1984).

In some Pacific island countries the drop-off from the shelf to the abyssal zone can be very close to shore and fishermen may have a tradition of catching oceanic pelagics, either by trolling or hand-line fishing. Cusack (1987) describes a method of midwater hand-line fishing common in the islands of Polynesia and Micronesia, where a hook baited with a small fish, such as a scad, is wrapped around a flat stone and secured with a slip-knot. Pieces of bait are fixed to the stone with a leaf or piece of bait skin. The stone and bait assembly sink rapidly and the fishing line is allowed to run freely without tension. When the required depth is reached the fisherman applies tension to the line to release the slip-knot, allowing the chum to disperse and presenting the unencumbered baited hook. The drop-stone rig is fished at about 25 m to catch rainbow runners (*Elagatis bipinnulatus*) and as deep as 150 — 180 m to catch yellowfin and bigeye tuna.

Pole-and-line fishing in the South Pacific is usually associated with catching skipjack on the open ocean in large (> 60 gr.t) fishing boats. However, a small-scale pole-and-line fishery for skipjack tuna operates within the nearshore waters of Tahiti (Society Islands) to supply the domestic fish market (Chapman & Cusack 1988a). Traditionally, pole-and-line fishing was an important communal fishery where large double canoes were equipped with baskets lashed alongside to keep live bait. The bait fishes were broadcast on the water to attract feeding schools of skipjack within range of the mother-of-pearl lures. With social and economic change and the introduction of modern fishing materials and motorized vessels, the fishery has become a highly developed and competitive local industry to supply fresh tuna to the local markets. Live bait is no longer used in the modern fishery, that uses half-cabin launches about 10 m in length, powered by large diesel engines ranging from 200 to 375 hp. The gear used in this fishery consists of a long bamboo or fibreglass pole, about 7 m in length, with a length of nylon monofilament line attached to which is a pearl-shell lure with a barbless hook. The tuna boats, or bonitiers, are driven at high speed to chase skipjack schools feeding on bait fishes. The objective is to get ahead of the school and anticipate the direction it will move so that it approaches the bonitier from the stern in order that poling can commence. The pearl-shell lures are trailed in the water as the boat moves slowly ahead of the school. When a strike is made the fishermen uses his body weight to heave the fish from the water into the boat. Once an adequate volume of tuna has been caught the bonitiers run at high speed for Tahiti to sell their catch in the afternoon market in Papeete.

A smaller nearshore canoe-based pole-and-line fishery for mackerel tuna (*Euthynnus affinis*) at Timoenai Island (Fig. 2, 102), PNG, has been described by Haines & Chapau (1991). Live bait are caught around reefs and mangrove creeks by drive-in net fishing and kept alive in a basket or the flooded hull of a canoe. The main species of bait fishes are cardinalfishes (Apogonidae). Fishing poles are made from sago palm fronds used with barbless wire hooks. Haines & Chapau (1991) reported that each fishing trip lasts about 4 — 5 h, with fishermen preferring to fish at dawn or dusk. The slow speed of the canoe means that the fishermen can only approach schools that surface close to the fishing vessel and cannot chase schools as they move away.

Troll fishing from small skiffs and dinghies is a common fishing method throughout the Pacific and the various techniques employed are summarized in Preston et al. (1987). In some locations, small pelagic fishes such as halfbeaks or flying fishes are favoured bait and there are specialized fisheries to catch these for bait and food. In the Belep (Fig. 2, 8) islands of New Caledonia, fishermen both troll and hand-line for Spanish mackerels. Hand-lines are baited with sardines caught usually by cast netting on the beach. When not trolling, the fish-

ermen let out surface hand-lines baited with sardines, and drift with currents in the lagoon waiting for a strike. Fishing is conducted from small skiffs 4 — 5 m in length and this fishery catches annually about 15 t of Spanish mackerel which are smoked, canned or sold fresh in the capital Noumea (Chapman & Cusack 1988b).

Spanish mackerel also dominates troll catches in the small-scale, reef associated fishery in the Tigak Islands, northern PNG (Wright & Richards 1985). As in most other Pacific islands, trolling in the Tigak Islands is conducted from small dinghies and powered canoes with island fishermen using halfbeaks (Hemiramphidae) as trolling bait. Troll fishing in the Tigak Islands is usually not a full-time activity, but is part of a repertoire of fishing methods that may be deployed during a fishing trip that also includes bottom hand-lining and spear fishing. Troll fishing increases in frequency in the Tigak Islands during the middle of the year as Spanish mackerel aggregate to spawn and hence the catchability increases.

Spanish mackerel is also the principal target for troll fishermen in Fiji and landings of this species probably exceed 375 t annually (Lewis 1988a, Anon. 1994b). Trolling is conducted along the reef edge employing a wide variety of lures and live bait. Live-bait fishing for Spanish mackerel is carried out seasonally in the northwest of Viti Levu and Western Vanua Levu (Fig. 2, 110). Sardines and mackerels are caught at night in gill nets and used as live bait for drift hand-line fishing. Troll fishing is the most popular method of small boat fishing around Guam and was traditionally practised from man-powered canoes prior to the advent of powered dinghies and skiffs. The major species taken around Guam are mahi-mahi (*Coryphaena hippurus*), Wahoo, skipjack and yellowfin tunas (Fig. 2, Amesbury et al. 1986). The total troll catch around Guam varies but is usually greatest between February — April. As with locations such as New Caledonia, a large proportion of the total large pelagic fish catch comes from recreational fishermen.

Artisanal fishermen operating from Daugo Island near Port Moresby, PNG have traditionally trolled for pelagic fishes along the outer edge of the Papuan Barrier Reef, targeting tuna, Spanish mackerel, jacks and longtoms (Belonidae). Lock (1986a) reported that fishermen adjusted their trolling techniques to take advantage of the seasonal abundance of tuna and longtoms. Most fishermen would also include other fishing techniques to catch reef fish such as netting, hand-lining and spear fishing. The deployment of a FAD on the outer reef slope (Beverly & Cusack 1993), and the resulting abundance of large pelagic fishes, has led to more fishermen concentrating on troll fishing (Dalzell 1993a). Fishing is conducted from fibreglass dinghies with four to six trolllines strung from a boom at the front of the vessel using home-made and commercial trolling lures. The productivity of troll fishing around the FAD has led to a decrease in the number of fishermen targeting coral reef fishes, and presumably to a decrease in the fishing mortality of reef fishes.

The deployment of the FAD in Port Moresby has also been of additional benefit to the game fishing club, which targets large pelagic fishes, more for sport and trophies than for food. In some areas of the Pacific the recreational component of fisheries production can be quite substantial. In New Caledonia, for example, the recreational catch from the nearshore area is thought to be in the vicinity of 2000 t, or about half of the total coastal fisheries production (Anon. 1994a). A substantial portion of the recreational catch is likely to comprise large pelagic species such as tuna, Spanish mackerel, wahoo and billfishes. In Vanuatu, the local game fishing club in Port Vila is one of the major suppliers of large pelagic fishes for the domestic fish market (Anon. 1992b) as local fishermen are not experienced in the capture of coastal pelagic species through trolling.

Large pelagic fishes form the principal targets of fishermen from small high islands lacking any substantial reef and lagoon areas, with catches taken mainly by trolling (Dalzell & Debaio 1994)

Two-thirds of the total landings on Nauru are from trolling, with the catch made up mainly from skipjack, yellowfin tuna and wahoo (*Acanthocybium solandri*). Trolling is conducted from small skiffs deploying on average two trolllines and fishing mainly in the early morning and late afternoon. Although most of the catch might be classed as recreational and subsistence fishing, between half and two-thirds is sold locally. About half of the total fisheries production on Niue was estimated to come from fishing large pelagic species by trolling and hand-lining (Dalzell et al. 1993). Troll fishing is conducted from small skiffs fishing in open water or around FADs. Some Niuean fishermen also fish with midwater hand-lines, or the palu-ahi method, from canoes in open water in areas where large yellowfin and bigeye tunas are known to aggregate, usually around headlands. This method was still very popular until recently in Rarotonga, Cook Islands, for catching large tuna relatively close to shore. FADs have been regularly deployed around Rarotonga since 1980 and have promoted greater catches from troll fishing (Sims 1992a).

Catch composition

The catch composition by family for troll fishing in the Pacific islands is shown in Table 14. The tuna and related species such as wahoo and Spanish mackerel dominate the catches in most locations. The notable exception is Fiji, where substantial amounts of barracudas and jacks are caught along with the tuna-like species. In Fiji, trolling close to reefs attracts reef predator species into the open water, hence 12% of the Fiji catch were groupers, mainly coral trout (*Plectropomus* spp.). Other reef species such as snappers and emperors are also occasionally taken by trolling over the shallow reefs or along the reef edge. Overall, scombrids form about 80% of the troll catch with between 7 and 8% each formed from jacks and barracudas. Very large pelagics such as certain sharks and billfish (Istiophoridae) are occasionally taken, but these are more deliberately targeted by game fishermen rather than artisanal fishermen.

The scombrid component of the large pelagic catch in the major Melanesian islands of the western Pacific is usually far more varied than around the smaller islands of the north and central Pacific. Spanish mackerel dominate troll catches in PNG, Solomon Islands, Fiji and New Caledonia. All these countries have substantial areas of shallow lagoons fringed with extensive mangrove forests, which is nursery habitat for juvenile Spanish mackerel. In Vanuatu, the only Melanesian country that lacks extensive mangrove-fringed shallow lagoon areas, Spanish mackerel are not abundant and are only caught in a few locations. The scombrid catches in the large Melanesian islands contain other coastal scombrids such as the island bonito (*Euthynnus affinis*), bullet tuna (*Ausix* spp.) and shark mackerel (*Grammatorcynus bicarinatus*). Around the coasts of the smaller Pacific islands in the northern and central Pacific, troll catches are dominated more by skipjack (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*). Spanish mackerel are found in Palau, the only islands with sufficient mangrove and estuarine habitats.

Catch rates

Catch rates from troll fishing for large pelagic fishes in various parts of the Pacific are shown in Table 15. Average CPUEs ranged between 1.8 and 8.8 kg line⁻¹ h⁻¹ with an overall average of 4.5 kg line⁻¹ h⁻¹. Table 15 also includes the dominant species in the catches and demonstrates clearly the difference between the large Melanesian islands, where catches are dominated by large coastal pelagic species and reef associated fishes, and the smaller islands of the Pacific

Table 14: Percent composition of catches made by trolling along the coastal margins in the South Pacific region.

Family	Fiji	PNG	New Caledonia	Am. Samoa	Tokelau	Tuvalu	Nauaru	Palau	Niue	Wallis & Futuna	Kiribati (Gilberts)	Tonga	Vanuatu	Cook Islands
Scombridae	29.7	84.6	80.6	86.0	100	79.4	88.5	45.9	85.9	52.9	77.8	98.4	92.9	97.6
Sphyraenidae	33.7		10.8	2.0		1.5	1.8	38.2	1.4	18.6			1.2	
Carangidae	22.4	5.8	5.2			12.7	8.2	2.9		27.1	19.4		1.7	
Istiophoridae			0.2	6.0		1	0.6							
Serranidae	12		1.1			0.3								
Lutjanidae	2.1		1.1			3.8		2.1		1.4	2.8			
Belonidae			0.2			0.8	0.6	0.3						
Coryphaenidae			0.2			0.5	0.2	10.6	1.5			0.7	4	1.6
Others	0.1	9.6	0.5	6.0					11.2			0.9	0.2	0.8

Table 15: Summary of catch rate (CPUE, catch per unit effort) and catch composition data for trolling on coastal pelagic stocks in the South Pacific region

Location	CPUE (kgline ⁻¹ h ⁻¹)		Principal species in catch	Source
	Range	Mean		
Papua New Guinea	3.7 – 6.9	4.9	<i>Euthynnus affinis</i> , <i>Auxis thazard</i> , <i>Scomberomorus commerson</i>	Dalzell & Wright 1986 Wright & Richards 1985, Lock 1986a, Anon. 1984b
Palau	3.7 – 12.6	8.2	<i>Katsuwonus pelamis</i> , <i>Thunnus albacares</i> , <i>Acanthocybium solandri</i>	Anon. 1991b, 1992e
Fiji	1.6 – 16.2	5.7	<i>Sphyræna queni</i> , <i>S. barracuda</i> , <i>S. commerson</i> , <i>Plectropomus</i> sp.	Chapman & Lewis 1982, Lewis et al. 1983
Tuvalu	0.5 – 7.0	2.7	<i>A. solandri</i> , <i>K. pelamis</i> , <i>T. albacares</i> , <i>Istiophorus platypterus</i>	Chapman & Cusack 1988c
New Caledonia	0.0 – 7.3	4.0	<i>S. commerson</i> , <i>E. affinis</i> , <i>A. solandri</i> , <i>T. albacares</i>	Chapman & Cusack 1988b
Tokelau	0.0 – 68.9	8.8	<i>K. pelamis</i> , <i>T. albacares</i>	Taumaia & Cusack 1990
Nauru	0.0 – 20.0	4.7	<i>K. pelamis</i> , <i>T. albacares</i> , <i>Elagatis bipinnulatus</i> , Sphyrænidae	Dalzell & Debaio 1994
Niue	1.3 – 3.8	2.4	<i>A. solandri</i> , <i>T. albacares</i> , <i>K. pelamis</i>	Dalzell et al. 1993
Am. Samoa	0.5 – 6.1	3.2	<i>K. pelamis</i> , <i>T. albacares</i> , <i>Makaira mazara</i> , <i>Coryphaena hippurus</i>	Buckley et al. 1989 Craig et al. 1993
Wallis & Futuna	na	6.0	<i>K. pelamis</i> , <i>T. albacares</i> , <i>Sphyræna queni</i>	Taumaia & Cusack 1988
Kiribati	0.5 – 8.0	3.8	<i>T. albacares</i> , <i>K. pelamis</i> , <i>E. bipinnulatus</i>	Taumaia & Cusack 1989
Vanuatu	0.51 – 14.0	1.8	<i>T. albacares</i> , <i>K. pelamis</i> , <i>C. hippurus</i>	Cillauren 1988
Cook Islands	0 – 12.3	1.8	<i>K. pelamis</i> , <i>T. albacares</i>	Chapman & Cusack 1988d

of the Pacific where oceanic pelagics dominate the catch.

Catches of large pelagic fishes are strongly seasonal, with seasons becoming more pronounced at higher latitudes. Detailed information on catch seasonality is available from Guam in the northern hemisphere of the Pacific (13°N) (Amesbury & Babin 1990) and Niue in the south (19°S) (Dalzell et al. 1993). More species were included in the study in Guam by Amesbury & Babin (1990) but catch data for skipjack, yellowfin and wahoo were included in both studies. Temperature studies at Guam show that there is a year-round permanent thermocline between 120 and 400 m in which temperature drops from 28 to 7°C. In winter, when surface waters are coolest, there is a deep mixed layer from the surface to 120 m. During spring and summer the depth of the mixed layer is reduced and a seasonal thermocline develops before re-establishment of the deep mixed layer with the onset of autumn.

According to Amesbury & Babin (1990) catch rates for skipjack and yellowfin were greater during the summer months when surface waters were warm and the seasonal thermocline had developed. Catch rates for wahoo demonstrated a clear peak in the winter months when the surface waters were cooler and the mixed layer deepest. Catch rates of wahoo south of the equator were highest during the austral winter, between June and August. Yellowfin catches were also greatest in the winter months, in contrast to the seasonal pattern in Guam, while skipjack catch rates peaked in the summer months in common with the seasonality for the same species north of the equator. Other species included in the Guam study were blue marlin (*Makaira mazara*) and dolphin or mahi-mahi (*Coryphaena hippurus*). The CPUE for marlin was similar to that of the two tuna species with peak catch rates in summer, while the dolphin CPUE showed a marked peak during the cooler winter months.

Fisheries biology and stock assessment

The biology and stock assessment of skipjack, yellowfin, bigeye (*Thunnus obesus*) and albacore (*T. alalunga*) have been studied both nationally and regionally in the Pacific. The South Pacific Commission has mounted major regional studies of all four species over the past 20 yr which has resulted in a series of publications on the biology and stock assessment of these species. Much of the information on the population biology of these species has come from large-scale tagging projects conducted throughout the South Pacific by the South Pacific Commission in co-operation with national fisheries departments and other scientific agencies. The most recent reviews of the biology and stock assessment of these four important commercial pelagic species in the South Pacific region are contained in Shomura et al. (1993) and the current status of western tropical Pacific tuna fisheries is summarized in Anon. (1995).

In this paper we are concerned more with the large pelagic species that are confined to the coastal margins. These species have received much less attention in the South Pacific, although they have been the objects of considerable study in South and Southeast Asia where they form the basis of large industrial fisheries. Spanish mackerel populations along the GBR have been studied in detail and information on age, growth, reproduction, early life history and feeding habits are contained in Munro (1942) and McPherson (1987, 1992, 1993). Less information on this species is available from the Pacific islands. Shaklee et al. (1990) examined the stock structure of Spanish mackerel from eastern and western Australia, Fiji and PNG using electrophoretic techniques. Fish to the southeast of Torres Strait form an Australian east coast stock, whereas fish in Torres Strait and the Gulf of Carpentaria (Fig. 2, 120) are part of a northern Australian stock that extends from PNG to the western coast of the continent. Populations from northern PNG (New Ireland) and Fiji were found to be distinct stocks that were effectively isolated.

Lewis (1975) presented some notes on the biology and fisheries for Spanish mackerel in PNG waters and summarized the available information on behaviour, reproduction, spawning sites and feeding habits. Similar information on Spanish mackerel in Fiji is included in a study of several large coastal pelagic species by Lewis et al. (1983), who reported that Spanish mackerel in Fiji appeared to grow more slowly than specimens sampled from the GBR. Lewis et al. (1983) provided biological information on a range of other large coastal pelagic species including shark mackerel (*Grammatorcynus bicarinatus*), dogtooth tuna (*Gymnosarda unicolor*), barracudas (*Sphyraena barracuda* and *S. queni*) and trevallies (*Caranx ignobilis*, *C. melampygus* and *C. papuensis*). Information was given on size distribution, spawning season, size at first maturity and ecology of these species.

The biology of the trevallies *C. melampygus* and *C. ignobilis* from Hawaii were studied in some detail by Sudekum (1984). Sudekum was able to estimate the age and growth of *C. melampygus* from otolith microstructure but gave no details of ageing the other species in the study. Other information presented by Sudekum for these two species includes reproductive and feeding biology. A synopsis of biological data on the amberjack (*Seriola dumerilii*) in Hawaiian waters is given in Uchida & Uchiyama (1986), including information on age and growth. This species ranges from surface waters to depths of up to 250 m and can frequently be caught by deep-slope hand-lining as well as by trolling.

Other large coastal pelagic species for which some biological information is given in, Uchida & Uchiyama (1986) include dolphin (*Coryphaena hippurus*), wahoo and the mackerel tuna or kawa-kawa (*Euthynnus affinis*). The latter species is very common throughout most of the coastal waters of the Pacific, as are the small bullet tuna (*Auxis thazard* and *A. rochei*). Little of the biology of these three inshore scombrids is documented for stocks in the Pacific islands. Wilson (1981a) presents a few notes on the biology of *Euthynnus affinis* from PNG and northern Australia and Lewis et al. (1983) provide similar information for this species in Fiji. A few observations on the biology of *E. affinis* are also given by Haines & Chapau (1991) from specimens captured in Manus, northern PNG, while Mobihia (1993) has recorded the spawning seasonality of both *E. affinis* and *Auxis thazard* from the waters around New Ireland, also in northern PNG. Wilson (1981b) gives an account of the biology of the longtail tuna (*Thunnus tonggol*), a species more commonly associated with extensive shelf zones and found in the Gulf of Papua, where it is taken by gill netters targeting sharks. Wilson provides information on age and growth, from tagging and otolith microstructure, reproductive biology and stock structure around PNG and Australia.

Socioeconomic developments

One of the most notable developments of the last 5 years in the tropical western Pacific has been the development of domestic long-line fisheries for fresh, chilled yellowfin and bigeye tuna to satisfy the Japanese demand for raw fish or sashimi. It was the introduction of monofilament long-lines in the Hawaiian long-line fishery in the early 1980s that led to improved catches of these species (Cook 1989). Deployment of monofilament line can be automated with a line thrower, allowing steeper catenary long-line curves that let this gear fish deeper than kuralon long-lines, and this long-lining method spread rapidly to other parts of the Pacific. Improved airline connections between the Pacific islands and Japan, Hawaii and the continental United States has meant that domestic commercial long-line fisheries have developed (or are developing) in American Samoa, Fiji, Palau, Federated States of Micronesia, Marshall Islands, Guam, French polynesia, New Caledonia and Tonga. A major limiting factor for such fisheries is access to markets, which is dictated mainly by airline schedules and the space available for cargo on commercial aircraft. Catches by these small scale domestic long-line tuna fisheries are classified by the South Pacific Commission's Tuna and Billfish Assessment Programme in the Regional Tuna Bulletins, and are not included in the catch summaries in Appendix 1 (p. 510) and Tables 26 and 27 (p. 499). However, this fishery overlaps significantly with coastal fisheries, particularly where vessels are used for a variety of fishing methods. In parallel with the development of the small-scale, long-line fishery has been experimental fishing for small pelagic stocks to supply bait for long-lining operations. Longlining in the tropical Pacific has relied for the most part on imported bait from Japan. Partial or total replacement of imported bait could decrease operating costs and possibly increase the spread of economic benefits from long-line fishing. Small pelagic stocks (scades,

sardines and herrings) have traditionally featured in the subsistence diet of many Pacific islands and are caught for sale in domestic markets (see also p. 463). Experimental bait fisheries using purse-seines and lift nets have been established in Tonga (King 1993a) and the Federated States of Micronesia (Anon. 1992c), while the potential for local bait supply was investigated in PNG (Dalzell 1993a). Locally available small pelagic species have been briefly tested as long-line bait by commercial boats in Fiji, but were too seasonal and reliable supplies were difficult to obtain (Adams unpub. data). Long-line fishermen are notoriously conservative in their choice of bait. Experimentation is expensive, and local substitutes are likely to be accepted only if good catch rates can be consistently demonstrated.

A further development has been the adoption of a technique first pioneered in Indonesia where live milkfish are used to bait long-lines thereby markedly improving catches. Plans have been made to develop milkfish culture in Chuuk by a long-line fishing company based in the Federated States of Micronesia (Lindsay 1994). Milkfish culture is a tradition in Micronesia and may offer further potential for fishermen to share in the economic benefits of long-line fishing.

Greater emphasis is now given to developing nearshore pelagic fisheries to improve fishermen's incomes, relieve fishing pressure on reef and deep-slope stocks and to improve the supply of fresh fish on domestic markets. In a few areas, such as Port Moresby, Rarotonga (Cook Islands), Apia (Western Samoa) and parts of Vanua Levu (Fiji) there are now some commercial fishing communities that are entirely dependent on FADS for their livelihood. Artisanal fishermen may also receive further economic benefit if they are able to catch high-value sashimi-grade tuna and have a local buyer with access to overseas markets, as in Suva. In urban areas where there is a substantial demand for fish, such as Port Moresby and Apia, the deployment of coastal FADs has been shown to be very successful, and fishermen are able to make substantial earnings from large pelagic catches (Watt & Cusack 1992, Beverly & Cusack 1993).

Small pelagic species

Description

Small pelagic fishes in the South Pacific are important for subsistence and small-scale commercial fisheries. In some areas, where coral reefs are not abundant, small pelagic fish may be a staple source of protein. Small pelagic fishes as defined here refer to mackerel-like and herring-like fishes that rarely exceed 500 g in weight and more typically range in weight from 5 to 100 g. They include small clupeoid fishes such as the anchovies (Engraulidae), sprats, herrings and sardines (Clupeidae), small mackerels of the genus *Rastrelliger*, round scads and bigeye scads (Carangidae), halfbeaks and flying fishes (Hemiramphidae and Exocoetidae), hardyheads (Atherinidae) and fusiliers (Caesionidae).

The taxonomy and identification of small pelagic fishes is problematic, given the close similarities among species and the existence of congeneric pairs of co-occurring species with very similar ecology, e.g. *Encrasicholina devisi* and *E. heteroloba*; *Spratelloides gracilis* and *S. lewisi*; *Amblygaster sirm* and *A. clupeoides*; *Selar crumenophthalmus* and *S. boops*. Furthermore, as Lewis (1990) pointed out, other genera, such as *Herklotsichthys* and *Dussumieria*, contain separate morphs that are likely to prove to be sibling species and is suggestive of fine-scale habitat partitioning. The taxonomy of the clupeoids has been stabilized to some extent by the publication of the FAO species catalogue on these fishes (Whitehead

1985, Whitehead et al. 1988). Similarly, the FAO species identification sheets for the Western Indian Ocean (Fischer & Bianchi 1984), provide reasonable accounts of the non-clupeoid small pelagic species. Some groups of fishes, such as the flying fishes, will continue to provide problems for researchers in the region and will require further studies before these difficulties are resolved.

Artisanal fishing methods for small pelagic species include gill nets, drive-in nets, fish corrals, cast nets, scoop nets and hand-lines. Encircling seine nets, traditionally made from bush materials, are used in the Admiralty Islands of PNG to capture halfbeaks (Hemiramphidae) and other larger pelagics such as trevallies (Carangidae) and mullet (Mugilidae). Gill nets are used in Fiji both actively and passively to catch schools of the mackerels *Rastrelliger kanagurta* and *R. brachysoma*. One of the commonest small pelagic fishes found throughout the South Pacific is the bigeye scad (*Selar crumenophthalmus* and *S. boops*). In PNG, bigeye scads are caught by gill-netting, beach seining, scoop netting and hand-line fishing (Hulo 1984, Dalzell 1993b). Gill nets are also used to catch *Selar* spp. in Palau (Johannes 1981) and in Guam bigeye scads are captured inshore both by a variety of gill nets and by hook-and-line fishing (Amesbury et al. 1986). In Guam, seasonal catches of bigeye scad occur at times when they move inshore where they are a popular target for recreational fishing. The fish captured in the inshore areas are juveniles, however, and the larger adult fish are being caught further offshore in deeper water by using light attraction at night in conjunction with feather jigs. The bigeye scad is highly prized in French Polynesia and is captured by drive-in seine netting, gill netting, hand-lining with feather lures, and in fish corrals (Bagnis et al. 1974, Grand 1985, Morize 1985). In Hawaii, a rather more sophisticated fishery has developed for bigeye scads using spotter planes to direct boats to schools for capturing the fish with surround nets (Shiota 1986).

The gold-spot herring, *Herklotsichthys quadrimaculatus*, is a popular target species for artisanal fishermen throughout its range in the South Pacific. In Palau this species is caught by cast netting when it aggregates to spawn (Johannes 1981). Cast netting is also used to catch this herring in Tarawa (Kiribati) where it forms part of the subsistence catch (Mees & Yeeting 1986). In the North Solomon Islands (Fig. 2, 70) of PNG, fishermen herd schools of gold-spot herring into shallow areas where they are caught with scoop nets and thrown into baskets carried on the back (Hulo 1984).

Scoop nets are also used in the North Solomons to capture flying fishes (Hulo 1984). The fishermen attract the flying fishes on a moonless night by a kerosene pressure lamp or electric lamp mounted on a canoe. This type of fishing is found also in the Micronesian islands of Palau (Johannes 1981), Kiribati (Mees 1985) and most of Polynesia where it is commonly practised. In both French Polynesia and the Cook Islands small generators are used to power electric lights. A high-powered light is fixed to a helmet worn by the fishermen, allowing both hands to remain free to drive the boat and manipulate the scoop net (Gillett & Ianelli 1991). The boats in these areas are designed to be driven from the bow to facilitate scooping the fish and pursuing them at high speeds over the sea surface. Flying fishes may also be caught in gill nets and a description of gill netting for flying fishes in the Gilbert Islands of Kiribati is given by Tebano & Tabe (1993). Gill nets are set outside the reef or in reef passages and schools of flying fishes are then driven towards the net by fishermen in either skiffs or canoes.

In Tahiti, the round scad *Decapterus macarellus* is caught by hook-and-line using coconut pulp as bait (Bagnis et al. 1974) and by netting (presumably gill netting) in reef passes of the Leeward Island. Round scads, particularly *D. macarellus*, are caught by commercial fishermen in Hawaii using hand-lines, surround seines and hoop nets. Gillett (1987) reports the

successful adaptation of the Hawaiian hoop netting technique for round scads around the island of Niue. In the Cook Islands, round scads are chummed to the surface by divers who spit out clouds of chewed coconut flesh, and are then caught with small fishing poles (P. Cusack, South Pacific Commission, pers. comm.). Chewed coconut bait is used to chum round scads to the surface in Niue. Canoe fishermen spit the chewed coconut pulp onto the water's surface then create an eddy with a paddle blade to concentrate the bait. As the scads feed on the chum the canoe fishermen fish for the scads with a short bifurcated fishing pole from which two lines are hung.

Small pelagic fishes are caught in large quantities in two industrial near shore fisheries in the South Pacific; by shrimp trawlers in Papua New Guinea and in baitfish catches at several locations in the Pacific. The trawl fisheries in the Gulf of Papua and South Papuan coast, although targeting penaeid shrimps, catch mainly finfish. Catches are made by 150 gr.t trawlers deploying two 12 fathom (footrope) nets, fishing 24 hday⁻¹ on cruises of 5 — 6 wk duration. Dalzell (1993b) estimated that the finfish by-catch from the Gulf of Papua fishery was about 14000 t, of which about 2000 t comprised anchovies (1400 t) and sardines (600 t). Nearly all of the fish by-catch from the trawl fishery is discarded, with only a few marketable species retained for sale in Port Moresby. Species of little commercial value, such as the anchovies and sardines are simply thrown back into the sea.

The supportive bait fisheries for pole-and-line tuna fishing are conducted at night, using powerful submersible lights to attract the schools of anchovies and sprats. Each pole-and-line vessel has two or three skiffs with generators from which lights are suspended, as well as from the pole-and-line vessel. This gives the vessel the chance to make three to four hauls of the net to fill up the bait tanks. Hauls are usually made between 02.00 and 04.00h prior to the pole-and-line boat heading out on to the open sea to catch tuna. When a haul is made the bait lamp is dimmed and drawn to the surface, which causes the bait school to concentrate around the lamp. The lift net is then deployed to trap the bait fish. The net is lifted until the bait fish are concentrated in one corner of the net and transferred to the bait wells in the tuna vessel by buckets. Catches are measured in numbers of buckets but can be converted to weight by a pre-determined conversion factor.

As stated previously, development of long-line fisheries for large pelagic fishes has generated interest in domestic production of long-line bait from local stocks of small pelagic fishes in Tonga and the Federated States of Micronesia. Trial fishing for round scads and sardines was conducted in Vava'u during 1992 using a 1200 m purse seine with a stretched mesh size of 2.0 cm. As with the pole-and-line bait fishery, the sardine and scad schools were first aggregated around a submersible lamp. A similar type of survey to assess the potential of long-line bait supply was conducted in Chuuk Lagoon between 1991 and 1992. In this instance a dip net was employed, rather than a purse seine.

Like most fisheries within the Pacific islands, small pelagic fisheries are small-scale artisanal activities. Only in Hawaii has fishing for small pelagic species, namely bigeye scads, developed into an industrial scale fishing operation. The target species of small pelagic fisheries in the South Pacific tend to be the larger species such as scads, mackerels and herrings. Rapson (1955) reports a seasonal fishery on the South Papuan coast for "whitebait", which he describes as post-larval anchovies (possibly *Stolephorus* or *Encrasicholina* spp.), using mosquito net or nets made from traditional material. Other than this single reference no other accounts of traditional fishing for anchovies and sprats was found in the literature. Day-time seining for *Encrasicholina purpurea* is conducted in Hawaii, where it is used as live bait for a small-scale pole-and-line fishing fleet.

Catch composition

Information on the composition of small pelagic catches from artisanal fisheries is scarce and it is difficult to condense the information into simple tabular form. The gill net fishery in Rabaul, PNG (Table 7, p. 420) targets large schools of bigeye scads, with the result that catches comprised almost entirely one species, *Selar crumenophthalmus*. Similarly, hoop netting for round scads in the coastal waters of Niue yielded only a single species in the catch, *Decapterus macarellus* (Gillett 1987). Hand-line fishing for bigeye scads in Vanuatu similarly yielded a single species, *Selar crumenophthalmus* (Dalzell 1992b), while fishing with similar gear around shallow water FADs at Vava'u in northern Tonga produced not only bigeye scads, which dominated the catch (73%) but round scads (23%) and other carangid species such as rainbow runner (*Elegatis bipinnulatus*) (Dalzell 1992b).

The beach seine fishing data for coral and lagoon areas reported in Table 8 (p. 421) includes clupeids, atherinids and carangids in the catches. The beach seine sets in Rabaul targeted the same stock of bigeye scads as the gill net fishery. The other beach seine catches reported in Table 8 generally consisted of small pelagic fishes. Catches in Kiribati were predominantly gold-spot herring, the hardyhead, *Pranesus pinguis* (Atherinidae) and the sprat *Spratelloides delicatulus*. *Pranesus pinguis* was the dominant species also in Vava'u, Tonga, along with another atherinid, *Hypoatherina ovalau* and *Spratelloides delicatulus*, and the latter two species also dominated beach seine catches in the Marshall Islands. *S. delicatulus* was one of two species to dominate beach seine catches in Tokelau, the other being the mullet, *Liza vagiensis*. Beach seine catches in French polynesia were predominantly formed from the endemic sardine species *Sardinella marquesensis*.

Scoop netting for flying fishes catches a variety of species although the identity of the species captured is confounded by taxonomic problems. Gillett & Ianelli (1991) list 29 species contained in six genera that are thought to occur in the South Pacific region, but illustrate the taxonomic problems by comparing the discrepancies between identifications of the same sets of specimens by two experienced fish taxonomists. According to Gillett & Ianelli (1991), the six genera of flying fishes thought to occur in the Pacific islands are: *Cheilopogon*, *Cypselurus*, *Exocoetus*, *Hirundichthys*, *Paraexocoetus* and *Pronichthys*. The species identified from flying fish catches from Tonga, Tahiti, Cook Islands, Tokelau and Tuvalu include *Cheilopogonspilonopterus*, *C. atrisignis*, *C. antoncichi*, *C. unicolor* and *Cypseluruspoecilopterus*. These five species were the most frequently identified from catches based on the information presented by Gillett & Ianelli (1991). Other species occurring in fishermen's catches included *Cheilopogonsuttoni*, *C. pilonopterus*, *Cypselurus oligolepis*, *C. angusticeps*, *C. pitcairnensis* and *Paraexocoetusbrachypterus*.

Kailola & Wilson (1978) list a wide range of small pelagic species taken by the shrimp trawlers in the Gulf of Papua. These include 11 sardine, pilchard and herring species, 12 anchovy species, bigeye scads and small mackerels. Dalzell (1986) estimated that the sardines and anchovies formed about 4 and 9% respectively of the trawl by-catch, based on Kailola & Wilson's data, which was collected from trawls made between 1960 and 1968. Watson (1984) made detailed observations on the trawl by-catch in 1983 and his data suggest that sardines and anchovies formed 9 and 34% respectively of the by-catch. The dominant anchovy species were *Setipinna godavari* and *Thryssa setirostris*, while *Sardinella albela* dominated the sardine catch.

The most readily comparable data from fishing for small pelagic species in the South Pacific come from the pole-and-line bait fisheries that have operated at one time or another at several locations in the South Pacific. In addition, the South Pacific Commissions Skipjack Survey and Assessment Programme conducted surveys for tuna bait fish in the South Pacific region

Table 16: Species composition in percent of bait fish catches in the South Pacific region.

Bait fish species		Fiji	PNG	Solomon	Palau	Kiribati	New
Common names	Scientific names			Is			Caledonia
Sprats	<i>Spratelloides</i> spp.	23.2	18.1	11.1		40.5	3.7
Sardines	<i>Amblygaster</i> spp., <i>Sardinella</i> spp.	15.7	5.4	1.0		27.7	15.1
Herring	<i>Herklotsichthys</i> spp., <i>Pelona</i> spp.	14.7		1.2		17.7	
Silversides	<i>Pranesus</i> spp, <i>Hypoatherina</i> spp., <i>Atherinomorus</i> spp.	4.3	1.2	0.3		5.3	0.3
Mackerels	<i>Rastrelliger</i> spp.	6.3	1.1	0.3			
Cardinals	<i>Rhabdamia</i> spp., <i>Archamia</i> spp.	16.5	1.6	0.2		0.8	
Anchovies	<i>Encrasicholina</i> spp., <i>Stolephorus</i> spp., <i>Thryssa</i> spp.	10.3	62.6	724	91.0		62.5
Fusiliers	<i>Caesio</i> spp., <i>Pterocaesio</i> spp.		7.7	0.5			
Scads	<i>Selar</i> spp., <i>Decapterus</i> spp.		1.4				
Others		9.0	0.9	13	9.0	8	18.4

between 1977 and 1980. These surveys suggested that five species, *Spratelloides gracilis*, *Encrasicholina devisi*, *E. heteroloba*, *Herklotsichthys quadrimaculatus* and *Atherinomorus lacunosus*, were both widespread and abundant. Other common species were *Hypoatherina ovalau*, *Selar crumenophthalmus*, *Amblygaster sirm*, *Spratelloides gracilis*, and *Encrasicholina punctifer*. The average catch composition of the tuna bait fisheries from six Pacific islands is shown in Table 16 (from Dalzell & Lewis 1989). At Palau, PNG, the Solomon Islands and New Caledonia, the dominant species caught are stolephorid anchovies⁴, namely *E. heteroloba* and *E. devisi*. The sprats, mainly *Spratelloides delicatulus*, form another important species grouping, particularly in Kiribati where they account for 40% of bait catches. Other important components of the Kiribati catch were the sardine *Amblygaster sirm*, and the gold-spot herring.

Bait catches from Fiji are more evenly spread among the various components and no one family or species show overall dominance. As a group, the clupeoids are the largest fraction of the catch, accounting for nearly two-thirds of the total. A feature of the Fiji bait catch that separates it from others in the region is the large proportion of demersal cardinalfishes (Apogonidae) in the bait hauls. This feature of the Fiji bait fishery began to manifest itself during the mid 1980s when pole-and-line boats began fishing with larger bouke-ami nets that reached to the sea floor, thus increasing the catchability of demersal species such as the cardinal fishes. The dominant cardinal fish in the Fiji bait hauls is *Rhabdamia gracilis*, although in total 10 apogonids are present in the bait catch (Milton et al. 1993).

The dominant species in the nearshore purse-seine fishery at Vava'u, Tonga was the sardine, *Amblygaster sirm*, which formed 69% of catches (King 1992b). Just over 20% of the catch consisted of the round scads, *Decapterus macrosoma* (13.8%) and *D. macarellus* (8.0%). Gold-spot herring formed almost 7% of the balance of the catch with the rest made up of other small pelagic species. The lift net fishery in Chuuk Lagoon was dominated by round scads, which made up half the catch. A further 23% of landings came from bigeye scads with mackerels and sardines forming about 7% each of the total catch (Dalzell 1992b).

4. Originally, all the anchovies now separated into the two genera *Stolephorus* and *Encrasicholina* were contained in the single genus *Stolephorus* and are still known collectively as the "stolephorid anchovies".

Catch rates

Dalzell (1992b) quotes average catch rates of 17.6 fishline⁻¹h⁻¹ or 2.3 kgline⁻¹h⁻¹ for night time hand-line jigging for bigeye scads and round scads at Vava'u, Tonga and 18.3 fishline⁻¹h⁻¹ or 2.4 kgline⁻¹h⁻¹ for the same method of fishing on bigeye scads at Port Vila, Vanuatu. Similar fishing for bigeye scads in Guam produced catch rates ranging from 0 — 4.7 kgline⁻¹h⁻¹, with a mean of 1.9 kgline⁻¹h⁻¹ (Ikehara et al. 1970). Gill nets set on bigeye scad schools in Rabaul, PNG (Table 7, p.000), caught between 0.7 and 6.7 kgset⁻¹ with an average of 3.0 kgset⁻¹, while average catch from beach seining on the same scad stock was estimated to be 350 kgset⁻¹ (Dalzell 1993a). Beach seining for bigeye scads at Kavieng, PNG (Table 8, p. 421) yielded catch rates ranging from 1.0 to 44.6 kgset⁻¹, with an average of 17.3 kgset⁻¹. Beach seining for predominantly small pelagic fishes elsewhere in the Pacific (Table 8), yielded average catch rates ranging from 13.5 to 130.6 kgset⁻¹ with an overall average of 40.0 kgset⁻¹. Catch rates from purse seining around Vava'u for sardines and round scads ranged from 0 to 2000 kgnight⁻¹, with an average of 570 kgnight⁻¹ (King 1992b). The average catch per night from dip net fishing in Chuuk Lagoon was 0 to 211 kgnight⁻¹, with a mean of 74.6 kgnight⁻¹ (Dalzell 1992b). In neither instance was there any information to suggest how many hauls were made per night.

Flying fish catches from scoop netting at a variety of locations in the South Pacific region are summarized in Table 17. Catches by weight were not reported from all locations. Catches in number ranged from 10 to 40 fishh⁻¹ with an average of 19.3 fishh⁻¹. Weight CPUE ranged from 1.1 to 12 kgh⁻¹ or an average of 5.0 kghr⁻¹ for those locations reporting it. The correlation between weight and number CPUEs is highly significant ($r^2 = 0.99$) for the five values in Table 17 and where unknown, weight CPUE of flying fishes can be obtained empirically from the product of CPUE in numbers and 0.245. For example, based on the data of Tebano & Tabe (1993), average catch rates for flying fishes caught by gill netting from skiffs in the Gilbert Islands ranged from 0.8 — 9.0 fishh⁻¹, with a mean of 4.3 fishh⁻¹ or 0.2 — 2.2 kgh⁻¹ and a mean of 1.05 kgh⁻¹. Similarly, the catch rates from canoe fishing with gill nets was 1.0 — 5.0 fishh⁻¹ with a mean of 2.5 fishh⁻¹ or 0.25 — 1.22 kghr⁻¹ with a mean of 0.54 kghr⁻¹.

Catch rates for commercial bait fishing with bouke-ami nets in various locations in the South Pacific are shown in Table 18. These averages are given by country and represent averages over a number of years and between several locations within each country. The conversion factor for raising catch in buckets to kilogrammes was about 2 in all cases, except for Kiribati where a raising factor of 3 is used. This is due to the predominance of larger sized bait fish in the catches at Kiribati, such as sardine (*Amblygaster sirm*) and herring. Catch rate in kgboat⁻¹night⁻¹ is also given, as the number of boat nights was more consistently reported as the unit of effort in some

Table 17: Catch rates from scoop-netting for flying fishes in the South Pacific region.

Country	Catch rate, no. h ⁻¹	Catch rate, kgh ⁻¹	Source
American Samoa	14.9	3.6	Gillett & Ianelli 1991
Niue	40	12	Dalzell et al. 1993
Yap (FSM)	23		Gillett & Ianelli 1991
Salomon Is	15 – 20		Gillett & Ianelli 1991
Fiji	10		Gillett & Ianelli 1991
Tokelau	11	1.1	Taumaia & Cusack 1990
Tonga (Vava'u & Ha'apai)	20.4	5	Rata 1992
Tonga (Vava'u)	17.7	3.8	SPC unpub. data

Table 18: Average catch rates from tuna-bait fisheries in the South Pacific.

Country	Years	Catch rate (kgboat ⁻¹ night ⁻¹)	Catch rate (kghaul ⁻¹)	Source
Papua New Guinea	1970 – 1981	170	71.3	Dalzell 1984a
Fiji	1976 – 1992	117	80.2	Rawlinson & Sharma 1993
Solomon Islands	1981 – 1988	290	109.3	Nichols & Rawlinson 1990
Palau	1964 – 1974	93.3	55.1	Muller 1976
Kiribati	1982 – 1990	116	72	Rawlinson et al. 1992
New Caledonia	1981 – 1983	284	100.8	Hallier & Kulbicki 1985

instances, with effort in hauls only available for a few years. Catch rates were 71.3 — 109.3 kghaul⁻¹, with an overall average of 81.5 kghaul⁻¹. The number of hauls made per night depends on conditions on the bait grounds and to some extent the biting response of the target tuna species. Between one and three hauls per vessel per night is usual, with an overall average from the data sources in Table 18 of two hauls per night.

Lewis (1990) has reviewed catch data from the South Pacific Commission Skipjack Programme's bait fish catches throughout the region. Where bait fishing was conducted, average catch rates ranged from 34 to 291 kghaul⁻¹, with an overall average of 101 kghaul⁻¹. Lewis (1990) showed that the highest catch rates (120 — 291 kghaul⁻¹) occurred predominantly around high islands with extensive areas of sheltered lagoons and embayments. Catch rates from atolls lay mainly in the middle of the range (57 — 100 kghaul⁻¹), with the lowest catch rates (34 — 39 kghaul⁻¹) around high islands with limited lagoon area. Little or no bait fishing was conducted at Pitcairn, Niue, Nauru, Tokelau and Norfolk Islands. Apart from Tokelau, the other four locations are small exposed high islands with limited or no fringing reefs and no lagoon area. Bait lights were hung from the survey vessel to see if there were any indications of suitable small pelagic species and in each instance the results suggested limited stocks of bait fish.

Catch rates of many small pelagic fishes in the South Pacific are strongly seasonal. This seasonality becomes more pronounced at higher latitudes where there are temperature differences of 8 to 10°C between winter and summer. The most consistent observations on fisheries for small pelagic species come from the various Pacific island bait fisheries. Ysabel Passage (Fig. 2, 118), in New Ireland Province, northern PNG, lies just below the equator at 2°30'S and average monthly temperatures in this bait ground range from 29.3 to 30.5°C. However, catch rates are strongly seasonal, with highest CPUEs occurring between June to September (Dalzell & Lewis 1988). A similar observation was also noted for catches from another bait ground, Cape Lambert (Fig. 2, 13), lying about 4°S on the north coast of East New Britain, where CPUEs were highest between June and October (Dalzell & Lewis 1988). Analyses of catch rates for individual species at the Ysabel Passage fishery showed that the CPUEs for the two anchovies, *Encrasicholina heteroloba* and *E. devisi* peaked markedly during July and October. Conversely, the CPUE for the sprat, *Spratelloides gracilis*, peaked in September. The two production peaks for the anchovies are synchronous with the two periods of peak reproductive activity (Dalzell 1987). There was no apparent relationship between reproductive activity of the sprat and the production peak in September.

Based on data presented by Evans & Nichols (1985), the seasonality of the Solomon Islands bait fishery (8°S) was not so marked, but a peak in CPUE was noted during June, and this coincides with a peak in spawning activity for the stolephorid anchovies. The Palau bait fishery (7°N), like those in PNG, the Solomon Islands and New Caledonia was predominantly a fishery

for stolephorid anchovies. Muller (1976) states that over a 10-yr period CPUEs peaked in May — July and November — December, as a result of an influx of recruits. The Kiribati bait fishery is composed of catches at four atolls lying between 1 and 3°N of the equator and is dependent mainly on catches of sprats, sardines and herrings (Table 16). Data presented by Rawlinson et al. (1992) suggest that there are peaks in CPUE during February and between August and September. Rawlinson et al. found no evidence to link these production peaks with peaks in reproductive activity. Catch rates in the Fijian bait fishery (17°S) are distinctly seasonal, with a peak in April and May, declining through June and August to a low during October and November (Sharma & Adams 1990). Sharma & Adams report that there is a strong correlation between surface water temperature and CPUE in the Fijian bait fishery. A similar trend was noted in the bait fish catches from New Caledonia (22°S), with a similar peak in March and April, and a low CPUE between August to November (Conand 1988).

As all fisheries for live bait in the South Pacific have relied on light aggregation prior to capture, the other major influence on these bait fisheries is moon phase. The attractive power of the submersible lamps is diminished at the full moon period when the amount of ambient light is greatest. Kearney (1977) has shown that bait catch rates in PNG were lowest during periods of full moon, while the last quarter catch rates are consistently lower than for new and first quarter catch rates. The catch rates at the full moon are usually so poor that it is common practice for the tuna vessels to take a 2- or 3-day break over this period.

Seasonality of catches of other small pelagic fishes is not as detailed as for the pole-and-line bait-fisheries. Lift-net catches of round scads, sardines and mackerels peaked between September and November in Chuuk Lagoon, while bigeye scads showed two peaks during April and August (Anon. 1992c). Purse-seine catches of round scads were greatest in April in Vava'u, Tonga but declined thereafter while sardines and gold-spot herring increased in dominance in the catch (King 1992b). There are some indications that there may be an inverse relationship between the abundance of round scads and sardines at Vava'u. Catch rates of big eye scads from beach seining between December and June showed a clear peak during February in northern PNG with a steady decline thereafter until schools had disappeared from the shore areas by July. Amesbury et al. (1986) state that bigeye scads can be caught year round beyond the reef at Guam by night-time jigging, but that there is a seasonal run of juveniles between August to November that enter bays and harbours where they can be caught by gill nets, hand-lines and cast nets.

Fisheries biology and stock assessment

Because of their importance as a supportive fishery for pole-and-line tuna fishing, bait fisheries in the Pacific have been studied in some detail. Furthermore, as these are inshore fisheries, bait is caught in lagoons and bays used as fishing grounds by local people. Although the fishers are usually targeting larger reef and lagoon species, conflicts have arisen over access rights to traditional fishing areas and over what people perceive as interactions between bait fisheries and subsistence fisheries.

A number of studies have been conducted on the various component species of the different bait fisheries in the South Pacific. The most intensively studied of these various bait species is the Hawaiian anchovy or nehu (*Encrasicholina purpurea*). Studies of this species include egg and larval production, food and feeding behaviour and population biology, as well as early investigations into the fisheries biology (Nakamura 1970). Later studies included reproduction and fecundity (Leary et al. 1975), tagging with micro-tags (Leary & Murphy 1975), age and

growth from otolith microstructure (Struhsaker & Uchiyama 1976) and further investigations into fisheries dynamics and population biology (Weatherall 1977). Recent studies include further investigations into the reproductive biology of nehu such as fecundity and spawning frequency (Clarke 1987, 1989) and estimation of biomass using the egg production method (Somerton 1990, Clarke 1992).

Investigations into the fisheries biology of stolephorid anchovies and other species used for bait fish have been conducted in Palau (Muller 1976), PNG (Dalzell 1990a), New Caledonia (Conand 1988), the Solomon Islands (Evans & Nichols 1985, Blaber & Copland 1990, Blaber et al. 1993), Kiribati (Rawlinson et al. 1992) and Fiji (Sharma & Adams 1990, Blaber et al. 1993). These investigations have concentrated on the following species: *Encrasicholina heteroloba*, *E. devisi*, *E. punctifer*, *Spratelloides gracilis*, *S. delicatulus*, *S. lewisi*, *Amblygaster sirm* and *Herklotsichthys quadrimaculatus*. Other species that occur regularly in bait hauls and have been studied in some detail include the hardyheads, *Hypoatherina ovalau* and *Atherinomorus lacunosus*; anchovies, *Stolephorus indicus*, *S. insularis* and *Thryssa balaema*; sardine, *Amblygaster clupeioides*; round herrings, *Dussumieria* spp., and ponyfishes, *Leiognathus bindus* and *Gazza minuta* (Conand 1988). Apogonids or cardinalfishes have received some attention as they can form a significant portion of the bait catch. Species include *Archamia zosterophora* in the Solomon Islands (Milton et al. 1990) and *Rhabdamia gracilis* and *R. cypselurus* in Fiji (Milton et al. 1993). Hoedt (1984, 1990) has studied the biology of anchovies in northeastern Australia, including *Stolephorus nelsoni*, *S. carpenteriae*, *S. insularis*, *Encrasicholina devisi*, *Scutengraulis hamiltoni* and *Thryssa setirostirs*.

Conand's (1988) study of bait fishes in New Caledonia also included some of the larger small pelagic species such as the bigeye scad, *Selar crumenophthalmus*, Indian mackerel, *Rastrelliger kanagurta*, and the round scad, *Decapterus resseli*. These species, though important in subsistence and small commercial fisheries, have largely been ignored in the region, apart from Tonga, where the age, growth and mortality of *D. macrosoma* and *D. macarellus* were studied from samples taken with an experimental purse seine (King 1992b). Also included in the Tonga study were the herring, *Herklotsichthys quadrimaculatus*, and the sardine, *Amblygaster sirm*. The biology and fisheries for bigeye scads in Hawaii have been studied by Kawamoto (1973) and Kazama (1977), while the biology and fishery for the round scad *Decapterus macarellus* were studied by Yamaguchi (1953).

The studies of the small pelagic species targeted for tuna bait in the South Pacific have covered most aspects of the life histories of the dominant species. The short life spans of tropical small pelagic fishes have meant that they are relatively easy to age using otolith microstructure and to estimate growth parameters from otoliths, length frequencies or a combination of both. Based on such studies, Conand (1988) and later Lewis (1990) proposed that tropical small pelagic fishes could be separated into two groups based on life history parameters.

Type 1: Species with a short life cycle (less than 1 year), which are relatively small in size (7 — 10 cm max), grow rapidly, attaining sexual maturity in 3 — 4 months, spawn over an extended period and have batch fecundities of 500 — 1500 oocytes per gramme of fish. These include the stolephorid anchovies (*Encrasicholina heteroloba*, *E. devisi*, *E. punctifer*), sprats (*Spratelloides gracilis*, *S. delicatulus*, *S. lewisi*) and silversides (*Hypoatherina ovalau*), all of which are important tuna bait fish species.

Type 2: Species with an annual life cycle (but with some individuals surviving to 2 years of age), which are larger in size (10 — 24 cm max), attain sexual maturity towards the end of the first year, spawn on a restricted seasonal basis and have batch fecundities

in the order of 300 to 500 oocytes per gramme of fish. These include the herrings and sardines (*Herklotsichthys* spp., *Amblygaster* spp., *Sardinella* spp.), the larger anchovies (*Thryssa* spp., *Stolephorus* spp.) and the sharp-nosed sprats (*Dussumieria* spp.).

Dalzell (1993b) considered that a third category was required to include the larger small pelagic species.

Type 3: Species that have life spans of between 2 and 5 yr and that attain sizes of 20 to 35 cm maximum size. These species also exhibit restricted spawning seasons and have relatively low batch fecundities (400 to 600 oocytes per gramme of fish), although flying fish batch fecundities are much lower (50 to 100 oocytes per gramme of fish) in common with Type 2 species. Included in this group are the round scads (*Decapterus* spp.), the bigeye scads (*Selar* spp.), the small mackerels (*Rastrelliger* spp.) and the flying fishes and halfbeaks (Exocoetidae and Hemiramphidae).

As might be expected from the foregoing, the short life spans (0.4 to 4 yr) of these tropical small pelagic fishes give rise to very high mortality rates. According to Gulland (1983), where mortality rates are high it will pay to fish such stocks relatively hard and with a low size at first capture since many fish will die before completing much of their growth.

Not surprisingly, the most consistent sources of data on small pelagic fisheries in the South Pacific are from the tuna bait fisheries in PNG, the Solomon Islands, Palau, Kiribati and Fiji. The simplest approach to managing these fisheries was to attempt to fit simple Schaefer-Fox surplus production models to catch and effort data. With the exception of Palau, the relationships between catch and effort for the entire bait fish production in each country were linear and there was little evidence of curvature. The lack of pronounced curvature in the catch-effort relationship for the PNG, Solomons, Kiribati and Fijian bait catches may be due to the dynamics of these pole-and-line fisheries. When catches in a particular bait ground decline, either through localized over-fishing or through environmental effects, the pole-and-line fleet will usually move to another bait ground. Furthermore, although individual species within a bait catch might decline during a fishing season, there is usually an increase in abundance of one or more of the dominant species in the catch to compensate for the decline.

Muller (1976) fitted both Schaefer and Fox curves to the data from Palau to obtain an estimate of the MSY and optimum fishing effort. Muller's estimate of MSY was 80000 buckets, or 160 t, 90% of which would be *Encrasicholina heteroloba*. For a bait ground of 300 km² this represents a total yield of 0.53 or 0.48 tkm⁻² of *E. heteroloba*. Actual yields from the Palau bait fishery ranged from 0.29 to 0.67 tkm⁻² (mean = 0.44 tkm⁻²). Dalzell (1984a, 1990a) showed that the relationship between catch and fishing effort for stolephorid anchovies from the Ysabel Passage and Cape Lambert bait fisheries did not conform to the linear model for total bait catch. Dalzell (1984a) fitted simple Schaefer surplus production models to the data for catches of *E. heteroloba* and *E. devisi*. Estimates of MSY were initially made with catch data from the Ysabel Passage, but were expanded to incorporate the smaller data set from Cape Lambert. Catch and fishing effort from each bait ground were standardized between the two bait grounds by expressing them on a per unit area basis. An analysis of the *E. heteroloba* data alone gave a predicted MSY of 0.44 tkm⁻¹yr⁻¹, similar to 0.48 tkm⁻²yr⁻¹ for the same species in Palau (Muller 1976). Actual yields ranged between 0.2 to 1.2 tkm⁻²yr⁻¹ (mean = 0.49 tkm⁻²yr⁻¹) in PNG. The MSY for combined catches of *E. heteroloba* and *E. devisi* from Ysabel Passage and Cape Lambert was about 0.65 tkm⁻²yr⁻¹. The combined actual yields of both anchovies ranged from 0.25 to 1.60 tkm⁻²yr⁻¹ with a mean of 0.75 tkm⁻²yr⁻¹.

Nichols & Rawlinson (1990) and Tiroba (1993) have analyzed catch and effort data from individual bait grounds in the Solomon Islands bait fishery and showed that simple Schaefer production curves will fit the data. Nichols & Rawlinson (1990) fitted a Schaefer curve to catch-effort data from 1981 to 1989 for the Munda (Fig. 2, 63) bait ground. Tiroba (1993) repeated this analysis but included additional information on catch and effort from 1990 — 92. Tiroba was also able to fit Schaefer curves to data for bait grounds at Mbili (Fig. 2, 58) and Thousandships Bay (Fig. 2, 99). The MSYs for these bait fisheries ranged from 357 to 535 t yr^{-1} . Information on the areas of these bait grounds was not available. Dalzell & Lewis (1989), however, quote a figure for the whole of the Solomon Islands of 806 km^2 bait fish grounds. The total bait catch in the Solomon Islands varied from 1800 to 2500 t between 1984 and 1988 (Nichols & Rawlinson 1990), suggesting yields of 2.2 to 3.0 $\text{tkm}^{-2}\text{yr}^{-1}$ with a mean of 2.7 $\text{tkm}^{-2}\text{yr}^{-1}$. In terms of stolephorid anchovies only, this represents yields of between 1.6 and 2.2 $\text{tkm}^{-2}\text{yr}^{-1}$. The total average yield from the two main PNG bait grounds, Cape Lambert and Ysabel Passage, was 1.1 $\text{tkm}^{-2}\text{yr}^{-1}$, less than half the average total yield from the Solomon Islands.

The analyses in the previous paragraphs do not take into account the effects of the environment on the productivity of small pelagic stocks and ascribe changes in abundance directly to the variations in fishing effort and thus fishing mortality. There is, however, some evidence to suggest that the production of tropical clupeoids, and possibly other small pelagic fishes, is strongly influenced by environmental effects, particularly wind and rainfall. Dalzell (1984b) investigated the effects of rainfall on catches of the anchovies *E. devisi* and *E. heteroloba* in PNG and suggested yields of these species takes the form of a parabolic function with respect to rainfall, with optimum rainfall for both species of approximately 3000 mm yr^{-1} . Muller (1976) has indicated that rainfall enhances recruitment of *E. heteroloba* at Palau. Thus recruitment, and hence catch rates, of *E. heteroloba* might be expected to decline during the years that are drier than average.

Other investigations of the effects of rainfall on small pelagic species used as bait fishes have been made in Fiji (Ellway & Kearney 1981) and Kiribati (Ianelli 1992). Ellway & Kearney (1981) suggested that rainfall did not markedly affect bait fish catches in Fijian waters. The authors, however, did not investigate the effect of rainfall on individual catch components; rather they used the catch data for all species combined. There was also no significant correlation between rainfall and total catch in the Kiribati bait fishery, although the scatter of points of catch rate versus rainfall presented by Ianelli (1992) suggest an initial increase in catch rates as rainfall increases, but with declining catch rates at the highest levels of precipitation. Ianelli (1992) did find, however, a significant positive correlation between catch rate of *Amblygaster sirm* and *Spratelloides delicatulus* and rainfall. Dalzell (1984b) found no correlation between catch rates of the congener *S. gracilis* from the northern PNG bait fisheries and rainfall.

The analyses of small pelagic catches presented here are concerned mainly with bait fisheries that catch *Encrasicholina* spp. and *Spratelloides* spp. No equivalent data exist for other small pelagic species such as scads, mackerels, flying fishes and halfbeaks. Unfortunately, the data for making these assessments are presently not available for most locations. The standing stock biomass per km^2 of small pelagic species has been estimated by Petit & Le Philippe (1983) for bays and lagoons around New Caledonia to be between 0.04 and 1.84 tkm^{-2} , with a weighted mean of 0.465 tkm^{-2} , consisting primarily of sardines, anchovies and sprats. Estimates of mean standing stock of small pelagic species, primarily anchovies and sprats, for the Ysabel Passage and Cape Lambert bait grounds of PNG (Dalzell 1984a) were 0.59 and 0.29 tkm^{-2} , with an overall weighted mean of 0.42 tkm^{-2} . These limited data suggest that at least around major

high islands in the South Pacific, the biomass densities of small pelagic fishes may be relatively similar.

Socioeconomic developments

Small pelagic fishes will continue to be an important component of subsistence fisheries in the South Pacific, particularly where reef and lagoon areas are limited. For example, Chambers (1984) notes the importance of flying fishes in the diet of people living on the small coral island of Nanumea (Fig. 2, 65), where almost a quarter of all meals contain flying fishes. The limited size of most islands and the surrounding shelf area mean that the small pelagic resources are also limited. Thus small-scale commercial enterprises can survive but large-scale exploitation of stocks is unlikely because of resource limitation. Information on coastal fisheries in Western Samoa suggests an overall decline in the amount of fish sold through Apia market. Some of this decline may be due to fish being exported to neighbouring American Samoa where better prices can be realized; but there is also some indication that some stocks, including bigeye scads, have suffered real declines in abundance, with sales of less than 1.0 t yr⁻¹ through the market in 1990 compared with 12.5 t in 1986 (FAO 1990).

The demand for bait fish for pole-and-line fishing is unlikely to grow and indeed the present trend is one of reduction in this method of fishing for tuna. The last large-scale pole-and-line fishery is in the Solomon Islands, which at its peak in 1985 contained 36 boats but by 1993 was reduced to a fleet of 27 boats, and is expected to be reduced even further as pole-and-line fishing is replaced by purse seining. There is the possibility of using some of the larger pelagic species (scads and sardines) for long-line bait as more countries establish medium-scale long-line fisheries for the export of very high-value tuna. Such supportive bait fisheries have been established in Southeast Asia but, as stated earlier, attempts to use locally available small pelagic species for long-line bait in Fiji were confounded by seasonality of abundance and the unreliability of supplies. Long-line fishing is thus likely to continue to rely on commercially produced bait from Japan despite the cost of purchase and shipping to the South Pacific.

The smaller species such as the stolephorid anchovies are caught and consumed in considerable quantities in Southeast Asia, where production is now approximately 250,000 t yr⁻¹ (FAO 1994). Anchovies are eaten fresh, dried or fermented into fish pastes and sauces (Ruddle 1986). This level of production in Southeast Asia appears to be sustainable, although fishing pressure is very high and, given the low unit value of these fishes in Asia, the possibilities of exporting to this neighbouring region are minimal. Such types of small pelagic fish command very low prices in Asia and a fishery for them based, for example, on a dried product is not profitable under present circumstances, as indicated by the short-lived interest of Asian entrepreneurs entering the Pacific islands region.

Estuarine fisheries

Description

Estuarine fisheries are of importance to only a few countries in the South Pacific region, the majority of islands being small with limited or non-existent estuarine areas. However, in terms of population, a relatively large number of people are dependent on estuarine fisheries resources, given that the major estuarine areas are found in the large island archipelagos of Melanesia. The biggest estuarine area in the South Pacific is the Gulf of Papua. Several major

river systems drain from the highlands southward into the Gulf of Papua, including the Fly-Strickland system (Fig. 2, 25), and the Kikori (Fig. 2, 40) and the Purari (Fig. 2, 82) Rivers. In addition, several major rivers discharge along the north coast of PNG, namely the Markham (Fig. 2, 55), Ramu (Fig. 2, 85) and Sepik (Fig. 2, 92) Rivers, creating smaller but still extensive estuarine areas. The other Melanesian islands have smaller river systems and much smaller estuarine areas. However, in countries like Fiji these estuaries and associated wetlands such as mangrove and Nipa palm forests contain important fisheries resources. In most of the other Pacific high islands, the land masses are too small to have any significant river systems. Usually, only small streams are found and these may be seasonal in occurrence. Islands such as Pohnpei and Kosrae in the Federated States of Micronesia experience prolonged and extensive wet periods, but despite the runoff, are surrounded by well developed fringing reefs and, in the case of Pohnpei, a barrier reef as well.

As described earlier, trawlers fishing for shrimps along the coastal margin and on the coastal shelf of the Gulf of Papua catch predominantly estuarine and soft-bottom associated fishes. Watson (1984) estimates that the annual harvest in this fishery of finfish alone amounts to between 11300 and 17000 t (mean 14000). Elsewhere on the northern PNG coast, limited trawl fishing has been conducted at various sites, either to estimate fisheries resources or as part of investigations into estuarine fish populations. Coates et al. (1984) conducted a 3-month survey of the trawlable grounds at the head of Milne Bay (Fig. 2, 60), which is estuarine in nature due to the numerous streams and rivers that discharge into this region. Survey trawling has also been conducted off the mouth of the Sepik River and within the Murik Lakes (Fig. 2, 64), which form part of the Sepik Delta region (Chapau 1991). The estuarine fish and shrimp stocks of the Markham River estuary have been studied in detail by Quinn & Kojis (1986) using small-scale beam trawling.

Opnai (1984, 1986a) described the fisheries of the northern Gulf of Papua centred around the fisheries centre at Baimuru. As part of a fisheries development project, gill net fishing was encouraged in the estuarine and fresh waters in proximity to Baimuru (Fig. 2, 7) to improve fisheries production and income opportunities in an area where there was little agricultural land. Village fishermen set gill nets from dugout canoes and kept fish in ice boxes to be picked up by a collection vessel for transport to the fisheries center at Baimuru. This fishery produced between 30 and 100 tyr^{-1} (mean = 58 tyr^{-1}). Similar gill net fisheries are found along most of the length of the Gulf of Papua, and around the Fly River mouth. One of the principal targets for these fisheries is the catadromous sea bass, barramundi (*Lares calcarifer*), which occurs naturally in the South Pacific islands only in PNG, with a range that extends from the Irian Jaya border in the west to the south eastern tip of the Papuan coast near Samarai.

The subsistence fisheries of the neighbouring Purari Delta have been described by Haines (1978/79). Traditional methods for catching fishes in the Purari include hand-lines, traps, spears and bows and arrows. Besides fishes, villagers in the Purari region catch mud crabs and a variety of shrimps including the freshwater *Macrobrachium* spp. The finfish catches are dominated by ariid catfishes, barramundi and sharks. Gill nets introduced by fisheries extension officers have gradually replaced traditional fishing methods and are responsible for generating most of the catch. Most of the fisheries production is for subsistence, with only a small amount being traded by those villages without suitable agricultural land. Haines estimated that the average catch of crabs and fishes in the Purari villages amounted to about 40 and 80 gday^{-1} respectively.

The barramundi fishery in the Western Province of PNG is divided into two components; the coastal fishery operating between the Fly River mouth and the mouth of the Binaturi River

(Fig. 2, 10) to the west of Daru (Fig. 2, 18), and the inland fishery based in the Fly River and Lake Murray (Fig. 2, 44) (Opnai & Tenakanai 1987). The two fisheries are based on different aspects of barramundi life history. Briefly, this species spawns in marine coastal waters and larval/juvenile stages migrate into coastal swamps during the wet season. As the wet season finishes and the floodwaters recede, the young-of-the-year fish move upstream to the upper reaches of the river where they remain for 3 to 4 yr. After this period of residency upstream the fish become sexually mature males and migrate to the tidal waters downstream to participate in spawning and to ultimately change into females between the ages of 6 to 8 yr. Following spawning, the females disperse along the coast until the next spawning season. Catches within the Lake Murray area are taken throughout the year due to the presence of pre-spawning year classes that do not migrate to the coast. The coastal fishery experiences low catches of barramundi throughout much of the year, except between October and February when adult fishes migrate to the coastal areas to spawn.

Quinn (1984) described the small-scale subsistence and commercial fisheries of the Markham River estuary on the north coast of PNG. Fishers from the villages on the estuary catch fishes, shrimps and crabs for food and for sale in the nearby town of Lae. Fishermen use bows and arrows, pole-and-line and nets to catch fish. Bow and arrows are used from canoes to catch jewfish, trevallies and eels. Fishermen catch shrimps to be used as bait for pole-and-line fishing for snappers at the mouth of the Markham River. Shrimps are usually caught by a scoop net that is pushed through the water for about 2 to 4 min. Other species caught include juvenile trevallies, and mullet. Beach seines and gill nets are also used by fishers in the Markham estuary to catch trevallies, mullets and crabs. Small oval-shaped nets are also set in among the mangrove roots to catch crabs and gudgeons.

Close to the mouth of the Sepik River is a series of coastal lagoons that connect with the Sepik and open out into the Pacific Ocean, known as the Murik Lakes. The Murik Lakes system covers about 90 km² and the associated mangroves, about 185 km². The fisheries of these lagoons have been studied by Chapau (1991) and are among the most productive coastal fisheries along the north coast of PNG. Production from the Murik Lakes accounts for two-thirds of the commercial fish landings to the nearby urban center of Wewak. The commonest fishing methods employed to catch finfish in the Murik Lakes are hand lining and gill netting from canoes. Besides finfish, the villagers of the Murik Lakes also catch mud crabs in the mangroves and harvest various oysters and clams. A similar area of sheltered coastal estuarine water, Sissano Lagoon (Fig. 2, 93), is found further west along the northern coast of PNG. Sissano Lagoon covers an area of about 11 km² and is formed by the drainage of a large mangrove swamp that is restricted by coastal sand bars. As with the Murik Lakes, Sissano Lagoon is one of the few areas of sheltered coastal water on the northern PNG coast where fishermen can fish all year round. The fisheries of Sissano Lagoon are broadly similar to those of the Murik Lakes, with finfish catches being made predominantly by gill nets and hand-lines (Ulaiwai 1992a, b).

Little information is available on estuarine fisheries elsewhere in the South Pacific. Lauvi Lagoon (Fig. 2, 47) on the south coast of Guadalcanal (Fig. 2, 31) in the Solomon Islands is a coastal lagoon of 3 km² in area, similar to the Murik Lakes and Sissano Lagoon in PNG. Unlike the PNG lagoons, Lauvi Lagoon is mostly fresh water for most of the year, being completely enclosed by sand bars that are broken only during the rainy season (July — August). Gray (1974) describes the fish fauna of Lauvi Lagoon and from other fresh and brackish waters on the Solomon Islands, while Hinds (1971) provides some details of fish catches made there with gill nets. Batty (1987) gives some details of eel catches made with fyke nets on Guadalcanal, although these were predominantly in fresh rather than brackish waters.

The fresh water and estuarine fisheries of Fiji's main island, Viti Levu, have been described by Lewis & Pring (1986) and more recently by Rawlinson et al. (1994). These authors list about 35 fishes that might be considered euryhaline or brackish water species. These include such species as the introduced exotic freshwater cichlid or tilapia, *Oreochromis mossambicus*, and the jungle perch, *Kuhlia rupestris*, which is a catadromous species like the barramundi in that adults swim down to the sea to spawn. This species is widely distributed in the Pacific and can be found on most high islands where there are permanent streams or rivers. Lewis & Pring noted that it was difficult to assess just what quantity of fish are produced from estuarine waters in Fiji, as some species are taken in both brackish and coralline environments. The total annual commercial catch of estuarine species listed by Lewis & Pring is about 1100 t, of which, they suggest, only 10% is taken in brackish waters. Rawlinson et al. (1994) state that the most frequently reported fish species caught in rivers and estuaries were tilapia, eels, jungle perch and the snapper, *Lutjanus argentimaculatus*.

David & Cillauren (1989) report no estuarine fishing in Vanuatu, but there is a small freshwater fish catch of about 50 t yr⁻¹. Exploitation of estuarine resources in New Caledonia appear to be mainly limited to mud crabs (see p. 488). Fishermen in Noumea will occasionally catch tilapia and mullet in tidal creeks and inlets using cast nets and gill nets (Dalzell, pers. obs.). The fish fauna of mangrove systems and estuaries in proximity to extensive reef systems in the New Caledonia lagoon have been studied by the French scientific organization, ORSTOM. Wantiez (1993) has conducted a series of experimental trawl fishing surveys of areas of the New Caledonia coast with two types of trawl net, one of which was designed to target shrimps. Thollot (1992) has sampled populations of estuarine fishes in mangrove lagoons at several sites in New Caledonia, using principally gill nets but also with trammel nets and barrier nets.

As this is a review of coastal fisheries, we have touched only obliquely on freshwater fisheries production. As with estuarine fisheries production, freshwater fisheries are of limited importance in most locations in the South Pacific. In all but the largest high islands, streams and rivers in the South Pacific are short and in some cases seasonal, depending on rainfall regime. As is clear from the foregoing the largest rivers are found in the Melanesian islands, and the largest rivers in the South Pacific flow through the mainland of PNG. The freshwater fauna of the South Pacific is very impoverished, with much of it secondarily derived from marine fishes. It is therefore not surprising that the major freshwater fish stocks of PNG are all introduced species, tilapia (*Oreochromis mossambicus*), common carp (*Cyprinus carpio*) and the rainbow trout (*Oncorhynchus mykiss*). The scale of freshwater fish production from PNG is unknown, but for the Sepik River flood plain alone, Coates (1985) estimates a total annual yield of between 3000 and 5000 t.

Catch composition

Descriptions of the mangrove and estuarine fish fauna are given for PNG by Kailola & Wilson (1978), Collette (1983), and Quinn & Kojis (1986), for the Solomon Islands by Gray (1974) and Blaber & Milton (1990) and for New Caledonia by Thollot (1992), Kulbicki & Wantiez (1990) and Wantiez (1993). The catch compositions from fishing in estuarine locations in PNG, New Caledonia and Fiji are shown in Table 19. Hinds (1971) does not give the relative amounts of each species caught in Lauvi Lagoon, Solomon Islands, by gill net fishing but states that the catches included milkfish (*Chanos chanos*), trevally (*Caranx ignobilis*), mullet (Mugilidae), tarpon (*Megalops cyprinoides*) and mangrove jack (*Lutjanus argentimaculatus*). A feature of the estuarine and soft-bottom catches in the South Pacific is the extreme variability in the

relative contributions by the different fish families. There are large numbers of species captured in other coastal demersal fisheries such as from reef and deep-slope stocks, however the majority of the catch tends to be formed from the same combination of families. This does not appear to be the case with estuarine fisheries, although this may be partly because of the variety of gears being deployed, which range from simple hand-lines and spears to large scale trawls, and the different types of location, which include small localized estuaries, coastal estuarine lagoons and a large estuarine-influenced continental shelf.

Trawl catches on the coastal shelf of the Gulf of Papua are dominated by jewfishes, clupeoids (anchovies and sardines) and ponyfishes. Kailola & Wilson (1978) have compared the fish fauna of the eastern and western sectors of the Gulf of Papua. They showed that in the east the trawl finfish catches are dominated by ponyfishes, bream (Nemipteridae), grunters (Theraponidae), snappers, jacks and silver biddies (Gerridae), while in the west there are comparatively higher percentages of catfishes (Ariidae), jewfishes, threadfin salmon (polynemidae), anchovies and bombay ducks (Harporontidae). Kailola & Wilson state that in the west, muddy water from the deltas of the northern Gulf create conditions of low visibility, favouring those fishes that show adaptations typical of muddy water forms, such as sensory barbels, projecting snout and adipose eyelids. To the east, where the waters are generally less turbid, those species associated with shallow coastal waters and sandy beaches are found.

Both the catches from Milne Bay (Coates et al. 1984) made with an otter trawl, and from the Markham River estuary (Quinn & Kojis 1986) made by small-scale beam trawling from an outboard powered dinghy, contained predominantly ponyfishes. However, the Milne Bay catch also contained significant quantities of hairtails (Trichiuridae) and javelinfishes (pomadasidae), while the balance of the Markham River catch were the toadfishes (Tetraodontidae) and snappers. Quinn & Kojis (1985) also found that ponyfishes formed over three-quarters of small beam trawl catches at a small estuary, Mis Inlet (Fig. 2, 61), adjacent to a major reef system near Madang (Fig. 2, 50), northern PNG. A similar small scale trawl deployed in the lagoon of Tongatapu, the main island of Tonga, caught a range of estuarine and coral reef associated species. The catch was dominated, however, by snappers, ponyfishes and silver biddies (Braley 1976).

Commercial gill net catches around Baimuru in the northern Gulf of Papua (Anon. 1985) comprised mainly barramundi, with threadfin salmon, catfishes and jewfishes making up most of the remainder of the catch. Subsistence catches in the neighbouring Purari Delta comprised mainly catfishes, barramundi, threadfin salmon and sharks (Haines 1978/79). Subsistence catches with gill nets along the north coast of PNG were dominated by jacks, snappers, milkfishes and threadfin salmon at the Murik Lakes (Chapau 1991), and sardines, mullet, silver biddies (Gerridae) and ponyfishes at Sissano Lagoon (Ulaiwi 1992b). Handline catches at the Murik Lakes comprised mainly javelinfishes, jacks and snappers (Chapau 1991).

Experimental catches by gill nets in mangrove lagoons in New Caledonia comprised mainly mullet, rabbitfishes, snappers and sardines (Thollot 1992). Catches made in similar locations with a fish corral or barrier net were dominated, in terms of weight, by groupers, grunts (Haemulidae), silversides and rabbitfishes. Due to the small mesh sizes employed, however, the silversides formed about two-thirds of the fish corral catch by numbers. Experimental trawl catches on soft-bottoms adjacent to mangrove estuaries in New Caledonia were dominated by the ponyfishes, goatfishes and emperors (Kulbicki & Wantiez 1990).

The composition of the estuarine catch from Fiji is based on those species defined by Lewis &

Table 19: Percent catch composition of estuarine and soft bottom fisheries in the South Pacific region.

Family	Location and fishery											
	Gulf of Papua trawl	Milne Bay trawl	Baimuru gill net catch other gears	Purari Delta gill nets and other gears	Markham River mouth trawl	Murik Lakes gill net	Murik Lakes hand-line	Sissano Lagoon gill net	New Caledonia gill net	New Caledonia fish-coral	New Caledonia trawl	Fiji gill net and other gears
Sciaenidae	22	0.8	9.4									
Engraulidae	15			3								
Leiognathidae	10.3	42.8			66.9			12.1	1.6	3.7	42	2.7
Trichiuridae	7.8	13.3										1.1
Harpontidae	6.8											
Clupeidae	5.7							19.8	8.6	1.4		
Pomadasyidae	4.8	9.8				11.7	48					
Mullidae	4.6	5.9							1.9		14	2.5
Ariidae	3.6	1	8.1	23.5								
Theraponidae	2.9											
Polynemidae	1.8	2.3	13.8	12	2.7							
Sauridae		6.7										
Carangidae		2.6				38.8	12.9	8.3	1.1			37.7
Sphyraenidae							0.6	4.8	3	1.9		
Centropomidae			59.7	15.3								
Eleotridae				3								
Lutjanidae					3.9	16.5	14.1	2.2	8.8	1.9		8.2
Chanidae						13						
Mugilidae						5		27.9	19.5	1.2		43.2
Scatophagidae						43.8						
Haemulidae					1		7.6	1.9	8.7	17.6		

Table 19 (continued)

Family	Location and fishery											
	Gulf of Papua trawl	Milne Bay trawl	Baimuru gill net catch other gears	Purari Delta gill nets and other gears	Markham River mouth trawl	Murik Lakes gill net	Murik Lakes hand-line	Sissano Lagoon gill net	New Caledonia gill net	New Caledonia fish-coral	New Caledonia trawl	Fiji gill net and other gears
Serranidae							5.1		3.3	25.6		
Gerridae							1.9	13.3	5.9	4.5	2.2	
Lethrinidae							1.7	1	2.7	3.6	9.8	
Tachysuridae							0.9					
Megalopidae							0.7					
Siganidae								1.4	12.5	11.3		
Scaridae									3.2			
Sparidae									3.9			
Plotosidae									2.1			
Siliganidae									2.1	1		
Muraenidae									1.4	2.6		
Atherinidae										14.3		
Apogonidae										2		
Monodactylidae										2		
Platycephalidae										1.5		
Synodontidae											3.7	
Nemipteridae											1.3	
Tetraodontidae					14.5						1.1	
Bothidae												
Hemiramphidae								2.8				
Lactaridae					1.1			3.1				
Sharks			4.7	24.6								
Others	14.7	14.8	4.3	18.6	9.9	10.7	2.7	1.4	9.7	3.9	25.9	4.6

Pring (1986) and contemporary catch statistics (Anon. 1994b). Fishes are caught with gill nets and a variety of other gears such as fish corrals, hand-lines and spears. Based on the available information, mullet, jacks and snappers comprise most of the commercial estuarine and brackish water catch in Fiji. Rawlinson et al. (1994) report that the most important subsistence fish catches from rivers and estuaries include tilapia (*Oreochromia mossambicus*), eel (*Anguilla obscura*), mangrove snapper (*Lutjanus argentimaculatus*), jungle perch (*Kuhlia rupestris*) and assorted jacks (Carangidae).

Catch rates

Watson (1984) reported that catch rates of finfish in the Gulf of Papua shrimp fishery ranged from 83 to 690 kg h^{-1} with an average of 209 kg h^{-1} . Survey fishing in Milne Bay with similar trawl gear produced catch rates ranging from 60 to 550 kg h^{-1} with a mean of 152 kg h^{-1} , comparable to the Gulf of Papua. Commercial trawl surveys have also been conducted in the coastal waters adjacent to the Murik Lakes (Chapau 1991) although no details of catch composition, other than shrimp weight and fish weight, are available. Catch rates of fish in three separate surveys ranged from 12 to 600 kg h^{-1} with an overall mean of 92 kg h^{-1} . From their experimental trawl fishing survey of New Caledonia's estuarine and soft bottom areas, Kulbicki & Wantiez (1990) reported an average catch rate of 51 kg h^{-1} . The average catch rate of finfish and shrimps from trawling in the Markham River estuary with a small 3 m beam trawl, amounted to 3.4 or 3.1 kg h^{-1} of finfish only. Quinn & Kojis (1985) present no weight data for similar beam trawl catches from the Mis Inlet, but state that average catch rates by numbers were not significantly different from those in the Markham River mouth. The same type of trawl gear was deployed within the Murik Lakes and in the immediate coastal waters (Chapau 1991) and experienced finfish catch rates of 0.0 — 0.53 kg h^{-1} (mean = 0.12 kg h^{-1}) and 0.15 — 4.24 kg h^{-1} (mean = 1.60 kg h^{-1}) respectively.

Catch rates for small-scale commercial gill netting in the estuaries of the northern Gulf of Papua, as described by Opnai (1986a), ranged from 3.6 to 77.5 kg set^{-1} , with an average of 14.5 kg set^{-1} (Anon. 1985). Nets were usually set in the evening and hauled in the morning. Haines (1978/79) does not present specific information on catch rates for the subsistence fisheries of the Purari Delta, but based on his data it is possible to make a rough estimate of the average gill net catch rate of 3.3 $\text{kg net}^{-1}\text{day}^{-1}$. Gill net catch rates in the Murik Lakes ranged from 3.5 to 6.5 $\text{kg net}^{-1}\text{day}^{-1}$, with an overall mean of 5.3 $\text{kg net}^{-1}\text{day}^{-1}$. Hand-line catch rates in the same location amounted to between 1.3 and 4.9 kg day^{-1} , with a mean of 3.0 kg day^{-1} . Catch rates for set gill net fishing in Sissano Lagoon ranged from 0.18 to 0.75 $\text{kg man}^{-1}\text{h}^{-1}$, with a mean of 0.45 $\text{kg man}^{-1}\text{h}^{-1}$. This was equivalent to an average catch rate of 3.1 $\text{kg net}^{-1}\text{day}^{-1}$. Catch rates for surround gill netting, where the net does not fish passively but fish are driven into it by fishermen, ranged from 0.02 to 4.23 $\text{kg man}^{-1}\text{h}^{-1}$, (mean = 0.59 $\text{kg man}^{-1}\text{h}^{-1}$), equivalent to an average catch rate of 7.3 $\text{kg net}^{-1}\text{day}^{-1}$.

Thollot (1992) does not give explicit details of catch rates from gill net fishing or fishing with a barrier net and fish corral in New Caledonia. From his data, however, it is possible to estimate average catch per set and per hour. Altogether a total of 115 sets of 6 duration were made, generating a total catch of 1114 kg, or an average catch rate of 9.7 kg set^{-1} of 1.6 kg h^{-1} . Similarly, a total of 69.1 kg of fish were caught by the barrier net and fish corral, from 24 sets of 12 h duration. This gives an average catch rate of 2.9 kg set^{-1} or 0.24 kg h^{-1} .

Fisheries biology and stock assessment

Estuarine resources in the South Pacific are mainly limited to PNG, with limited importance in the other Melanesian islands. Most of the studies on estuarine fish biology have been conducted in PNG. Barramundi is the most commercially important of the finfish caught along the southwest and central Papuan coast and the biology of this species has been studied in some detail in PNG, in Australia and Southeast Asia. Reynolds (1978) gave a detailed account of the biology and population dynamics of barramundi from observations conducted on populations from the Fly River system and the coastal areas around southwest Papua. Reynolds estimated age and growth, mortality rates and yield per recruit of barramundi and suggested that the levels of commercial and subsistence catch prevalent at that time (early 1970s) were about optimum as suggested by the yield per recruit analysis.

Further research on barramundi in PNG has been conducted by Moore (1979), who confirmed an earlier observation by Reynolds (1978) that barramundi were protandrous hermaphrodites. Moore (1982) has also described in detail the reproductive biology and early life history of barramundi, while Reynolds & Moore (1982) and Moore & Reynolds (1982) have produced further studies on age and growth of barramundi and discussed the results of tagging experiments designed to determine the migration routes of this species. Commercial landings data between 1971 and 1991 from Daru, the main urban centre of southwest Papua, indicate that barramundi production was 200 — 400 tyr^{-1} between 1971 and 1981, but then steadily declined thereafter with annual production in the range 1.0 to 60 tyr^{-1} . The exact cause of this decline is unknown, and a number of factors have been implicated including pollution from mining tailings disposal from a copper mine upstream, over-fishing of the barramundi stock, or simply a decline in the infrastructural support for fisheries development.

Coates (1987) gives an account of some aspects of biology of the ox-eye herring or tarpon, *Megalops cyprinoides*, from the Sepik River. Coates (1988) has also studied the fecundity of ariid catfishes on the Sepik River. Coates noted that the very low fecundities and breeding behaviour of these species suggest that recruitment is likely to be highly density dependent and the stocks vulnerable to increased mortality, i.e. from fishing. In Fiji, the biology of the catadromous jungle perch, *Kuhlia rupestris*, has been studied in some detail as this species has importance for sport fishing and tourism. A synopsis of the results of these studies is given by Lewis & Hogan (1987).

Few other estuarine fisheries or species have received much attention from fishery biologists in the South Pacific region. Despite the large volume of fish caught each year in the Gulf of Papua trawl fishery, no biology or stock assessment studies have been conducted, other than Watson's (1984) initial investigations. Given Watson's estimate of average annual finfish production of 14000 t for the Gulf of Papua trawl fishery, this amounts to a yield of 1.46 tkm^{-2} , based on a total swept area of 9600 km^2 (Gwyther 1982). present yields of finfish from the smaller artisanal estuarine fisheries on the northern coast of PNG range from 0.75 tkm^{-2} at the Murik Lakes (Chapau 1991) to 3.1 tkm^{-2} at Sissano Lagoon (Ulaiwai 1992b). Information on yields from other estuarine fisheries in the South Pacific are not available. The studies conducted in New Caledonia on mangrove and estuarine species by Wantiez & Kulbicki (1991), Thollot (1992) and Wantiez (1993) were experimental observations concerned mainly with community dynamics and changes in population structure in temporal and spatial dimensions. These studies did, however, permit estimation of biomass of fishes on soft-bottoms in two locations in New Caledonia that ranged from 0.83 and 4.31 tkm^{-2} .

Socioeconomic developments

The region's largest catches of estuarine and soft-bottom species are from the Gulf of Papua shrimp fishery. Watson (1984) estimates that the annual harvest of finfish is between 11300 and 17200 t (mean = 14000 t) almost all of which is dumped back in the sea. It is uneconomical for the fishing companies to give over freezer space to the fish by-catch which could only be sold in PNG for a fraction of the shrimp value. The size of the by-catch and the demand for fresh fish in PNG periodically stimulates demands from politicians that more of the finfish catch from the trawlers is recovered for human consumption. However, it is likely that the economics of the fishery will continue to dictate that the by-catch will be discarded.

Estuarine and brackish water fisheries will continue to form important components of subsistence diets, particularly along the central and Southwestern coast of PNG and the rural areas of Viti Levu in Fiji. Lewis & Pring (1986) note that brackish water species are of less value than reef and pelagic fishes in Fiji, however estuarine fisheries remain the most important target species for the rural population of Viti Levu (Rawlinson et al. 1994). Barramundi is probably the single most economically valuable estuarine species in the region but some form of management initiative is required to see if the decline in production is caused by the collapse of the stock or related to other factors such as decline in fishing effort for this species.

In French Polynesia, barramundi has been cultured successfully for domestic markets but this culture was not economically feasible and has since been discontinued (Anon. 1994c). Aquaculture of barramundi in PNG might offer the potential to replenish over-fished populations if this was the reason for the decline in production. Barramundi and other riverine and estuarine species such as *K. rupestris* may have other intrinsic value in terms of sports fishing and tourism, as is also the case with species such as the snappers, *Lutjanus goldeii* and *L. johnii*, that frequent river mouths and estuaries.

Invertebrate fisheries*Echinoderm fisheries**Description*

Sea-cucumbers (Holothuroidea) and sea-urchins (Echinoidea) form part of the subsistence diet of some Pacific islanders and can be easily collected during low water by picking them off the reef, or free diving in shallow waters. This form of reef fishing is often conducted by women and children during the day while the men are at work elsewhere or out fishing on the reef or open sea. Sea-urchins are harvested for the gonads or roe, which are found adhering to the inside test wall. Sea-cucumbers can be eaten fresh, cooked or pickled in lime juice. Mathews & Oiterong (1991) and Smith (1992a) report that pickled sea-cucumbers are sold in the markets of Palau and Pohnpei, respectively, while Zoutendyk (1989) states that species of sea-cucumber are locally important in the Cook Islands for subsistence purposes. Fermented sea-cucumber roe is commonly on sale by the roadside in Western Samoa, and is said to be a tonic, particularly during pregnancy, and the expressed Cuvierian tubules of certain *Bohadschia* species are used by Palauan youngsters to coat the soles of the feet and protect them while walking on the reef (Adams et al. 1994). In Fiji, only the sandfish, *Holothuria scabra*, is commonly eaten as a subsistence food source (Adams 1992a), and in the Solomon Islands it appears that sea-cucumbers are not traditionally eaten at all (Adams et al. in press).

Harvesting sea-cucumbers for processing into bêche-de-mer (or trepang) is among the oldest of the commercial fisheries in the South Pacific and dates back to the early 1800s when traders followed the first explorers into the region (Ward 1972). The major producers of bêche-de-mer were, and still are, PNG, Solomon Islands, New Caledonia and Fiji. Current export production from the region ranges between 1500 and 2000 t annually of dried product (equivalent to 15 — 20000 tFW). Production figures for some locations such as Kiribati and Tonga are unavailable, but are minor. The main consumers of bêche-de-mer are Chinese and the majority of bêche-de-mer is exported to Hong Kong, Singapore and Taiwan, where much of the lower grades are re-exported to the Republic of China. Small volumes of bêche-de-mer are also sent to speciality Chinese markets in Canada, USA, New Zealand and the UK.

Methods of fishing for, or collecting, bêche-de-mer are straightforward and there are few differences between countries in terms of the methods employed. In many situations, holothurians can be harvested by gleaning at low tide, keeping the collected animals in a dinghy or floating container. Crean (1977) describes a method by which surface swimmers can catch sea-cucumbers in deep water. A heavily weighted barbed hook attached to a string can be dropped on the animal to pierce and snag the tough integument so that it can be retrieved. The sea-cucumbers are processed soon after capture by cooking the animals, usually removing the viscera, and sometimes smoking the remaining somatic tissue and integument and then drying. Following this procedure, the animals will lose about 90% of their body weight and shrink by about 50% or more in length. The processing facilities are usually adjacent to the harvesting areas and do not require much capital investment, each consisting of simple cauldrons for boiling, drying racks and a smoke house. Such structures are easily constructed so that processors can move on to other harvesting areas once the current area of operations is exhausted.

Catch composition

Mathews & Oiterong (1991) list several echinoderms caught and used both for subsistence and for sale in commercial markets on Palau, including the sea-cucumbers *Stichopus variegatus*, *Actinopyga miliaris*, *A. echinites*, *Holothuria scabra*, *H. verrucosa*, and the sea urchins *Tripneustes gratilla*, *Hemicentrotus pulcherrimus*, *Strongylocentrus pileolus*, *Toxopneustes pileolus* and *Diadema setosum*. Smith (1986) reports that echinoderm species, such as the sea-urchins *Tripneustes gratilla* and *Echinometra mathaei*, and sea-cucumbers, such as *Stichopus horrens* and *Holothuria atra*, are also part of the subsistence diet on Guam. Preston (1990b) notes that *H. scabra* is harvested for food as well as bêche-de-mer production in Fiji. Approximately 7 t of sea-cucumbers are sold for food through produce markets and stores each year in Fiji (Anon. 1994b), and the sea-urchin *Heterocentrotus mammilatus* can be seen occasionally for sale in both Fiji and Tonga. Conand (1989) notes that sea-cucumbers are eaten raw in Wallis and Futuna and grilled in PNG, but no details of species are given. In the Cook Islands, Zoutendyk (1989) reports that *Actinopyga mauritania*, *Holothuria leucospilota* and *H. cinarescens* are part of the subsistence diet in Rarotonga. Richards (1993) also notes that subsistence diets in the Cook Islands include the roe of sea-urchins such as *Heterocentrotus mammilatus* and *Tripneustes gratilla*.

Although gross statistics on commercial exports of bêche-de-mer are usually good, making this one of the most easily quantifiable of fisheries in the South Pacific, this information is not necessarily very useful for management. Over 22 species are now commercially traded in western Melanesia and while these all occupy different habitats they are usually classified only as “bêche-de-mer” when exported (Adams 1993b). Preston (1993) lists 17 species that

Table 20: Commercially exploited sea-cucumbers in the South

Scientific name	Common name
<i>Actinopyga echinites</i>	Deep-water redfish
<i>A. leconora</i>	Stonefish
<i>A. mauritania</i>	Surf redfish
<i>A. miliaris</i>	Blackfish
<i>Holothuria atra</i>	Blackfish
<i>H. fuscogilva</i>	White teatfish
<i>H. fuscopunctata</i>	Elephant's trunk fish
<i>H. nobilis</i>	Black teatfish
<i>H. scabra</i>	Sandfish
<i>H. edulis</i>	Pinkfish
<i>Stichopus chloronotus</i>	Greenfish
<i>S. variegatus</i>	Curryfish
<i>Thelenota ananas</i>	Prickly redfish
<i>T. anax</i>	Amberfish
<i>Bohadschia marmorata</i>	Chalkfish
<i>B. argus</i>	Leopardfish
<i>B. vitiensis</i>	Brown sandfish

are commercially harvested and these are given in Table 20. The species most sought after are the black and white teatfish (*Holothuria fuscogilva* and *H. nobilis*), the sandfish (*H. scabra*) and the prickly redfish (*Thelenota ananas*) (Anon. 1994f). However, as demand for bêche-de-mer has continued to grow, low-value species that were originally not considered worth processing into bêche-de-mer are now being harvested. Recently, a very low value species, *Holothuria atra*, has begun to attract the interest of processors as supplies of the other species diminish.

Unlike finfish fisheries in the Pacific where selectivity by the common gears is relatively broad, harvesting of sea-cucumbers involves visually searching for and selecting particular species. The first harvests from unfished islands are likely to consist of the high-value species such as teatfish or sandfish. As harvesting progresses and the high-value species populations are reduced, other less valuable species will then be harvested. Dalzell (1990b) reported that bêche-de-mer production from the Carteret Islands of eastern PNG was based mainly on *H. nobilis*. Similarly a pilot bêche-de-mer fishery in Tuvalu targeted *H. nobilis* (Pita 1979), while production of bêche-de-mer on Ontong Java (Fig. 2, 73) in the Solomon Islands, was based on a mix of *H. nobilis* and *Actinopyga miliaris* (Crean 1977). This latter species (or species assemblage, see Preston 1993) was the main target of bêche-de-mer processors in Fiji in the late 1980s (Preston 1990b), where harvest levels rose rapidly in the same decade from 20 — 30 t of dried product in 1984 to over 1000 t in 1988 (Adams 1992b).

Catch rates

Catch rates in terms of sea-cucumbers usually refer to the number of individual animals collected by one collector in a unit time period, or pieces $\text{man}^{-1}\text{h}^{-1}$. Some catch or collection rates for various sea-cucumber species are summarized in Table 21. Shelley's (1981) estimates do not refer to commercial or subsistence catches, but to counts made during unit times of 1 h in Bootless Bay (Fig. 2, 11) on the South Papuan coast. Mathews & Oiterong (1991) reported that average catch rates for *Actinopyga* spp., *Holothuria scabra* and *Stichopus variegates* in Palau

Table 21: Catch rates of sea-cucumbers for bêche-de-mer processing in the South Pacific region.

Location	Species	CPUE (piecesh ⁻¹)		Source
		range	mean	
Palau	<i>Actinopyga miliaris</i> and <i>A. echinites</i>	18.5 – 118.0	68.2	Mathews & Oiterong 1991
Palau	<i>Holothuria scabra</i>	42.9 – 100.0	65.5	Mathews & Oiterong 1991
PaJau	<i>Stichopus variegatus</i>	48.8 – 71.4	61.7	Mathews & Oiterong 1991
Palau	<i>Holothuria</i> spp.	18.4 – 680	47.1	Mathews & Oiterong 1991
Ontong Java (Solomon Is)	<i>H. nobilis</i>	6.0– 19.2	11.1	Crean 1977
Fiji	<i>H. fuscogilva</i>	12 – 20	16	Gentle 1979
New Caledonia	<i>Thelenota ananas</i>	5 – 110	42	Conand 1990
New Caledonia	<i>H. nobilis</i>	3 – 190	31	Conand 1990
New Caledonia	<i>A. echinites</i>	90 – 150	118	Conand 1990
Papua New Guinea	<i>T. ananas</i>	1.5 – 70	10	Shelley 1981
Papua New Guinea	<i>H. nobilis</i>	1.5 – 190	15.1	Shelley 1981
Papua New Guinea	<i>H. fuscogilva</i>	1.5 – 9.0	4.5	Shelley 1981
Papua New Guinea	<i>H. scabra</i>	1.5 – 500	103	Shelley 1981
Papua New Guinea	<i>A. echinites</i>	1.5 – 700	110	Shelley 1981

were very similar. However, the catch rate for other *Holothuria* spp. were significantly lower. The highest average catch rates were for *Actinopyga echinites* from PNG and the Solomon Islands, and for *Holothuria scabra*, also from PNG, with mean CPUEs in excess of 100 piecesman⁻¹hr⁻¹. Catch rates of other species from the Solomon Islands, Fiji, New Caledonia and PNG ranged between 10 and 40 piecesman⁻¹hr⁻¹. The catch rates for the lowest value species can be extremely high in the earliest stage of exploitation. Adams et al. (in press) record catch rates as high as 519 piecesman⁻¹hr⁻¹ for limited populations of *H. atra* in the Western Province of the Solomon Islands, and there are even denser populations in parts of eastern polynesia (Adams unpub. data). Of course, since these are in very shallow water the density will quickly fall subject to fishing.

No estimates of catch or harvest rates for sea-urchins were found from the Pacific islands. Mathews & Oiterong (1991) state that in Palau only a few people collect them because of the effort required to prepare them for consumption. According to these authors several individuals working as a group can collect up to 1000 sea-urchins per day.

Fisheries biology and stock assessment

Two major studies on the biology and stock assessment of sea-cucumbers have been done in the South Pacific, in New Caledonia by Conand (1989) and PNG by Shelley (1981). Conand (1990) and Preston (1993) have both reviewed various aspects of the biology, stock assessment, production and marketing of sea-cucumbers and bêche-de-mer in the region. Conand (1989, 1990) describes the general biology of *H. scabra*, *H. nobilis*, *H. fuscogilva*, *Actinopyga echinites*, *A. miliaris* and *Thelenota ananas*, including morphometrics, reproduction and growth, from the New Caledonia lagoon. Shelley (1981) conducted similar observations on *Actinopyga echinites* and *Holothuria scabra* from around Bootless Bayon the South Papuan coast.

Both Shelley (1981) and Conand (1989) faced several problems in determining the growth

of sea-cucumbers because of their plasticity, which meant that obtaining linear measures size to obtain size frequencies was difficult, and tagging was also difficult as tags or marks on the integument led to localized necrosis and loss within a few weeks or months. However, Shelley was able to estimate growth of *Actinopyga echinities* from length size frequency data by tracing monthly modal progressions. Shelley states that a probable modal progression was also observed through part of the data set for *Holothuria scabra*, but was not sufficient to fit a growth curve. Conand (1989) also estimated age and growth of *Actinopyga echinities* as well as *A. mauritania* by tagging data, and *Stichopus chloronotus* and *Thelenota ananas* by tracing modal progressions in weight frequency distributions. Ebert (1978) conducted a study of the growth of the small sea-cucumber, *Holothuria atra*, at Enewetak Atoll (Fig. 2, 21) by injecting individual animals with tetracycline and measuring the increase in growth of the plates of the calcareous ring at the beginning of the pharynx. The plates of marked animals showed a fluorescent mark under ultra-violet light and the growth increment with time could be measured. This data was then used to fit a von Bertalanffy growth curve to the plate increment data, and plate size was related to length and weight of *H. atra* to give a growth curve for the whole animal.

The results of these various growth estimations suggest that *Stichopus chloronotus* has a life span of about 5 yr, while *Thelenota ananas*, *Actinopyga mauritania* and *A. echinities* have life spans in excess of 12 yr. Conand has estimated natural mortalities of populations of *A. chinites*, *A. mauritania*, *Stichopus chloronotus* and *Thelenota ananas* in the New Caledonia lagoon and found survival rates ranged from 17 to 60% annually, Ebert (1978) estimated a natural 40% survival rate for *Holothuria atra* at Enewetak Atoll in the Marshall Islands. Based on these simple data alone sea-cucumber populations appear capable of sustaining only light to moderate exploitation.

Stock assessments of sea-cucumber populations have been made at a number of locations in the Pacific, by visual census techniques, by simply laying transects on the reef at low water or by underwater counts using snorkel or SCUBA. The results of some of these biomass studies are shown in Table 22, Based on this limited data set it is apparent that there are large differences in densities among locations. Some of these differences may be attributable to past and present exploitation, but as harvest levels from different locations are unknown it is not possible to gauge the effects of removals on stock densities. That some populations can achieve very high densities is apparent from Table 22. Ebert (1978) reports densities of *H. tra* at Enewetak Atoll of between 5 and 35 ind.m⁻², which is equivalent to between 50 000 and 350 000 ind.ha⁻¹.

Some work has been done on the reproductive biology of Pacific Island holothurians, in the Solomon Islands (Holland 1994) and Guam (Richmond in press), with the aim of developing mariculture techniques for the higher-value species, but little has yet been published.

Socioeconomic developments

Small subsistence fisheries for echinoderms are likely to persist in the South Pacific islands, although there may be competition from bêche-de-mer processors as they turn to less valuable species with the decline in stocks of the favoured target species. As stated earlier, however, items such as sea-cucumbers and sea-urchins are delicacies rather than staples in the diets of Pacific islanders, so temporary declines in stock sizes and availability are not likely to have any serious effect on nutrition, except in areas like Fiji where bêche-de-mer become an important food item when gardens are damaged by hurricanes. There is a considerable demand for sea-urchin roe in Asia, and Japan in particular (Conand & Sloan 1989). Specialist

Table 22: Standing stock densities or biomass of commercially harvested sea-cucumbers in various locations in the South Pacific.

Cuntry	Mean species density (no ha ⁻¹)											Source
	<i>Holothuria scabra</i>	<i>Holothuria fuscogilva</i>	<i>Holothuria nobilis</i>	<i>Holothuria atra</i>	<i>Thelenota ananas</i>	<i>Thelenota anax</i>	<i>Actinopyga echinites</i>	<i>Actinopyga mauritania</i>	<i>Actinopyga miliaris</i>	<i>Stichopus chloronotus</i>	<i>Stichopus variegatus</i>	
Papua New Guinea (Manus)	19.1	3.5	9.8		1.6	4.1	105.5	9.5	3	16	8.6	Lokani & Chapau 1992a
Papua New Guinea (West New Britain)	245	54	176			211	705		31.5	1703	360	Lokani unpublished
Fiji (Viti Levu)									2580			Preston et al. 1988
Tonga (Ha’apai Is)		8.6	4.6		13.7	2.4						Preston & Lokani 1990
Niue				182	10.7							Dalzell et al. 1993
New Caledonia (Grande Terre)	683	11	13	545	18	14	847	866	512	286		Conand 1989

fisheries for sea-urchins have developed in countries such as Australia (Kailola et al. 1993) specifically to export sea-urchin roe to Japan. There may be the possibility of developing similar industries in the South Pacific, but careful research would be required to test consumer response to tropical species before any serious development was considered, and the extremely high quality and freshness standards required by the Japanese market would probably make commercial development uneconomical.

Bêche-de-mer fisheries in the South Pacific have been characterized by cycles of heavy exploitation followed by “fallow” periods during which the resource has had the chance to recover. Exploitation declined in the latter half of the 19th century probably because of over fishing, whereas a slump in trade after 1930 was due to the embargo in trade into China caused by the Sino-Japanese war, followed by the continued restrictions on external trade under the Chinese communist government. The present expansion of harvesting effort for bêche-de-mer in the South Pacific began in the late 1980s, partly as a result of declines in production from other bêche-de-mer producers in Southeast Asia and as a result of the easing of restrictions on trade with China (Preston 1993). Bêche-de-mer is much sought after in China and has apparently been useful recently as a barter item to circumvent currency transfer restrictions (Adams 1992a).

The current boom in bêche-de-mer export began around 1985 and was first evident in Fiji, followed by the Solomon Islands and PNG. Suddenly there appeared to be a demand for lower-value, easy to collect species as well as the higher-value “traditional” species (black and white teatfish, sandfish). Even though export volumes boomed (the increase in Fiji was over 1000% in the 3 years to 1988) prices did not fall, and this has been one of the main characteristics of the bêche-de-mer trade: demand is apparently insatiable or, in economic terms, highly in-elastic. The volume of bêche-de-mer export sustained by most islands was definitely unsustainable in the short term, and supplies are now becoming scarce, even in the remoter areas. Middlemen, often of Chinese origin, are now branching out from their bases in Melanesia and looking at Polynesia and Micronesia as higher prices start to balance the higher cost of trade in these areas. The ease with which bêche-de-mer can be harvested and the open access nature of this type of fishery means that unless there is strong intervention by government, as is the case in some locations with molluscs such as trochus (see p. 484), then The boom and bust cycle is likely to be perpetuated.

Mollusc fisheries

Description

A large range of marine molluscs are used both for subsistence and commercial purposes in the Pacific, including bivalves, gastropods and cephalopods. Some molluscs are harvested purely for meat, while some yield meat and shell for mother-of-pearl production and also pearls. Some shells, such as the cowries and olive shells are important for the specimen shell industry, catering to tourists and conchologists (Parkinson 1984), while others in Melanesia may be burned to produce lime for chewing with betel nut. Other uses for mollusc shells include decoration, tools such as scrapers and as traditional currency, which is still used in parts of Melanesia. The importance of molluscs in subsistence diets in the South Pacific may be gauged by some of the shell middens that have been built up over 2000 years along parts of the South Papuan coast (Swadling 1982).

Lewis (1988b) gives a general introduction to the mollusc resources of the South Pacific and notes the importance of molluscs in the subsistence diet of some of the islands in the region.

Yields of 50 and 250 kg ha⁻¹ yr⁻¹ are quoted by Richard (1983) for molluscs in the subsistence diets of French Polynesian atoll dwellers and those living on high islands. Over 50 species of mollusc have been reported by Yamaguchi (1992) as being used for food and in some cases for ornamental purposes in Tonga and similar numbers are reported to be collected from reefs and mangroves in Palau (Mathews & Oiterong 1991), PNG (Swadling 1982, Wright et al. 1983), Fiji (Rawlinson et al. 1994) and Guam (Amesbury et al. 1986). In Fiji and Kiribati harvests of certain species constitute a significant fraction of total fisheries production. The clam *Batissa violacea* is found throughout Melanesia in rivers under tidal influence, but only in Fiji is it known to be harvested in appreciable quantities with current commercial production exceeding 1500 t (in shell) annually (Anon. 1994b). Similarly, the harvests of the cockle *Anadara maculosa* and other bivalves in the Gilbert Islands of Kiribati provide a cheap staple source of protein, particularly in urban areas. Bolton (1982) estimated that the total harvest of *A. maculosa* was over 1800 t yr⁻¹ for Tarawa Atoll, while Lewis (1988b) quotes a figure of 3,286 t yr⁻¹ for the total mollusc harvest in the Gilbert Islands.

The molluscs that are the most important foreign exchange earners for the region, exported to markets in Asia and Europe, are trochus (*Trochus niloticus*), green snail (*Turbo marmoratus*), the black-lip pearl oyster (*Pinctada margaritifera*) and the gold-lip pearl oyster (*P. maxima*). All four species yield high quality mother-of-pearl, which is used in the fashion industry to make shirt buttons and in the furniture industry for decorative inlay work. Wild pearl oysters, as their name suggests, may also contain pearls. However, pearls can be induced to form by artificially seeding a nucleus into these oysters and this has led to successful pearl culture industries in Australia (based on *P. maxima*) and French Polynesia (based on *P. margaritifera*). The success of the French Polynesian culture industry has led many Pacific nations to try to develop their own pearl culture industries, but only the Cook Islands has so far succeeded with the establishment of commercial operations at Manihiki and Penrhyn Atolls. It is notable that the northern Cook Islands is the only South Pacific island group, apart from French Polynesia, with significant remaining wild stocks of *P. margaritifera*, and thus able to accumulate large quantities of natural seedstock.

The top shell *Trochus niloticus* was originally found in the South Pacific in Melanesia, Fiji, Wallis and the Western Caroline Islands (Palau and Yap). Because of the demand for mother-of-pearl for button manufacture, trochus has been harvested extensively in the South Pacific since the start of the 20 th century (Nash 1993). Furthermore, there have been over 50 separate transplantations of trochus in the South Pacific to islands beyond its natural range in an attempt to extend the economic benefits of trochus harvesting (Gillett 1993). Most of these transplants have generated successful fisheries in locations such as Aitutaki (Fig. 2, 1), Tahiti, Pohnpei, Enewetak, Guam and Rota (Fig. 2, 89), and it is estimated that between 6500 and 12000 t of extra trochus have been harvested over the past 50 yr as a result of these transplantations (Adams unpub. data).

Trochus are usually found on the windward margin of coral reefs, living in the intertidal and subtidal zones (Nash 1993). The green snail or turban shell, *Turbo marmoratus*, is also found in the same general environment but extends into deeper waters than trochus. Production of green snail is restricted to Melanesia, specifically PNG, Solomon Islands and Vanuatu. Specimens from Vanuatu were successfully transplanted to French Polynesia, but unsuccessfully to New Caledonia. Although much less common than trochus, green snails are highly prized for their size (up to 2.0 kg) and yield of high quality mother-of-pearl used for buttons and especially in decorative furniture inlays. Like trochus, green snail has been commercially harvested from the Pacific islands since the start of the 20 th century.

In common with bêche-de-mer, there is a long history of harvesting the black-lip pearl oyster,

Pinctada margaritifera, and the search for the elusive pearl brought many outsiders to the Pacific in the last century, particularly to eastern Polynesia (Sims 1993). Most of the production in the South Pacific region is black-lip pearl oyster, which is most abundant in the clear shallow waters of lagoons and sheltered bays to a depth of about 40 m. The gold-lip oyster is much more restricted in distribution, confined to the deeper waters of shelf areas of continents and the large islands of western Melanesia. At present the most productive areas are the lagoons of the Tuamotu and Gambier (Fig. 2, 28) Archipelagos in French Polynesia, the northern Cook Islands and, to a lesser extent, the Solomon Islands, Fiji and PNG. As an example of the relative productivity of these areas, the harvest of black-lip pearl shell from French Polynesia has averaged over 450 tyr^{-1} for the 100 yr before 1980 (Intes 1986), whereas the average export of pearl shell from Fiji has been around 20 tyr^{-1} for the past 15 yr.

Among the subsistence molluscs eaten by Pacific islanders are the giant clams (Tridacnidae), which include the largest species of all the shell-bearing molluscs. As well as being of great commercial value within and outside the Pacific region, the giant clams have attracted considerable interest because of their autotrophic nature, relying on nutrients generated through photosynthetic symbiotic blue-green algae in the mantle. These symbionts, known as zooxanthellae, are incorporated into the clam mantle shortly after settlement from the larval phase. As these animals are autotrophs, it is thought that there might be considerable potential for aquaculture of giant clams. Furthermore, in some Pacific locations, giant clam populations have been severely depleted and in some instances harvested to extinction. Re-seeding from aquaculture has been thought to offer a solution to this problem. Giant clam hatcheries have been established in Cook Islands, Federated States of Micronesia, Fiji, Marshall Islands, Palau, Solomon Islands and Tonga (Adams & Dashwood 1994).

Most of these shell-bearing molluscs are caught or harvested by simply picking them off the reef or searching in sand and mangrove mud for burrowing species. In deeper water, fishermen can free dive for molluscs or use SCUBA gear to improve catch rates. No commercial fisheries using dredges or rakes are employed for molluscs in the Pacific islands, although Lewis (1988b) notes that significant quantities of the scallop *Amusium pleuronectes* are taken in the Gulf of Papua shrimp trawl fishery and discarded. Cephalopods such as octopus, squid and cuttlefish are also captured and used mainly for subsistence in the Pacific islands, although about 7 t of octopus annually is sold through commercial outlets in Fiji (Lewis 1988b) and a similar amount in New Caledonia (Anon. 1994a). Octopus can be captured at low tide on the reef by inserting a wire hook into their burrows and gently exciting them. Octopus, squid and cuttlefish can all be caught by spears, either from the surface or by spear guns, and squid and cuttlefish can also be jigged on multibarbed lures used with a rod and reel.

Catch composition

Apart from *Trochus niloticus*, *Turbo marmoratus* and *Pinctada margaritifera*, other shells that are occasionally collected for mother-of-pearl are other turbo species such as *Turbo setosus* and the pen shell *Pteria penguin*. Subsistence composition of mollusc catches has only been examined in a few locations in the Pacific islands. Swadling (1982) reports that along the southeast coast of PNG the main mollusc species gathered for subsistence are the bivalves *Geloina coaxans*, *Anadara granosa*, *A. antiquata*, *Asaphis violascens*, *Atactodea striata*, *Anodonta philippina*, *Codakia punctata*, *Gafrarium tumidum*, *Hippopus hippopus*, *Tridacna crocea*, *T. squamosa*, *Lucina corrugata*, *Placuna placenta* and the gastropods, *Strombus canarium*, *S. gibberulus gibbosus*, *S. urceus*, *S. luhuanus*, *Lambis lambis*, *Littorina scabra*, *Turbo crassus* and *Nerita* spp. In northern PNG Wright et al. (1983) list *Strombus*

luhuanus, *S. gibberulusgibbosus*, *S. lentiginosus*, *Lambis lambis*, *L. truncate*, *Nerita ornata*, *N. peloronta*, *Tridacna* spp., *Anadara granosa* and *Polymesoda coaxans* among the molluscs harvested for food in New Ireland. In the Murik Lakes region of the Sepik River delta, villagers regularly harvest the mud clams *Batissa violacea* and *Periglypta purpurea* (Chapau 1991). Gina-Whewell (1994) lists the following molluscs commonly collected for subsistence in the Solomon Islands: *Nerita* spp., *Chama sordida*, *Spondylus nicobarius*, *Neotia ponderosa*, *Tridacna crocea*, *T. maxima*, *Strombus luhuanus*, *Lambis lambis*, *Batissa fortis*, *Telescopium* spp., *Anadara granosa*, *Gafrarium tumidum* and *Crassostrea rhizophorae*.

Apart from *Anadara granosa*, the other regularly harvested molluscs in the Gilbert Islands of Kiribati include *Gafrarium pectinatum*, *Asaphic violascens* and *Spisula* spp. (Bolton 1982). The molluscs most commonly harvested from reefs, estuaries and mangroves in Fiji include *Anadara cornea*, *Batissa violacea*, *Gafrarium tumidum*, *Lambis lambis*, *Pinctada margaritifera*, *Trochus niloticus*, *Tectus pyramis*, *Turbo chrysostomus* and *Tridacna squamosa* (Rawlinson et al. 1994). In neighbouring Tonga, the commonest species sold through commercial produce markets include *Turbo setosus*, *T. crassus*, *T. argyrostomus*, *Lambis lambis*, *Anadara antiquata*, *Modiolus philippinarum*, *Codakia tigerina*, *Fimbriata fimbriata*, *Tridacna maxima*, *Gafrarium tumidum* and *G. pectinatum*. In French Polynesia, Richard (1983) states that four gastropod species (*Nerita plicata*, *Tectarius grandinatus*, *Enosania olevata*, *Mitra mitra*) and four bivalve species (*Tridacna maxima*, *Arca ventricosa*, *Chama isotoma*, *Cardium fragum*) are the most important molluscs in the subsistence diet.

The commonest molluscs collected by women in Palau during reef gleaning are *Anodontia edentula*, *Tridacna* spp., *Atactodea striata*, *Anadara* spp., *Barbitia reeveana*, *Nucula rugosa*, *Nerita maxima* and *Nerita undata* (Mathews & Oiterong 1991). In Guam the commonly harvested nearshore molluscs include: *Acanthopleura gemmata*, *Trochus niloticus*, *Tectus pyramis*, *Turbo argyrostomus*, *T. setosus*, *Nerita plicata*, *N. polita*, *Strombus gibberulus*, *S. luhuanus*, *Lambis lambis*, *L. chiragra*, *L. truncata*, *Vasum turbinellus*, *Modiolus auriculatus*, *Chama* spp., *Ctena bella*, *Codakia punctata*, *Cardium fragum*, *Tridacna maxima*, *T. squamosa*, *Quindinipagus palatum*, *Scutarcopagia scobotinata*, *Asaphis violascens*, *Gafrarium pectinatum* and *G. tumidum* (Smith 1986).

According to Lewis (1988b) the cephalopods most commonly taken by coastal fishermen include the common octopus *Octopus cyanea* and, except in eastern Polynesia, the lagoon squid *Sepiateuthis lessoniana*. The chambered nautilus, *Nautilus pompilius* and *N. belauensis* have been captured in traps set for deep-slope fishes (Blanc 1988) and in traps specifically set to catch nautilus (Saunders 1984). Despite the potential value of nautilus shells for the tourist souvenir market, this has not led to the development of a trap fishery in any of the Pacific islands.

Catch rates

Harvesting techniques for molluscs in the coastal zone are basic and unchanged since pre-history. Emergent species lying on the lagoon floor or on coral reefs can simply be picked up. Burrowing species in sand, silt and mud may be found with the feet and hands, or with a stick. Species attached to a rock substratum such as mangrove oysters will need to be prised off with a knife or iron bar. Few estimates of harvesting rates for molluscs have been recorded in the Pacific from either subsistence or commercial fisheries. Dalzell & Debaio (1994) report a harvest rate of about 1.0 kg h⁻¹ for shellfish and octopus from observations on Nauru. Mathews & Oiterong (1991) have observed catch rates in numbers of giant clams and are shells on Palau. Catch rates of *Tridacna* spp. and *Hippopus hippopus* ranged from 9.0 to 18.5 ind.h⁻¹, with

a mean of 13.8 ind.h⁻¹, and for collection of *Tridacna crocea*, 16.0 to 31.4 ind.h⁻¹ and a mean of 22.5 ind.h⁻¹. Harvest rates of mud clams in the Murik Lakes of PNG were 1.0 — 2.8 kgman⁻¹ day⁻¹ or an average of 1.9 kgman⁻¹ day⁻¹.

Lokani & Chapau (1992b) estimated catch rates for landings of trochus, green snail and black- and gold-lip pearl oysters over a 4-yr period at Manus in northern PNG. Their unit of effort was one fishing week, when a family unit would collect the various molluscs for cash income. Average catch rates of trochus and green snail were 18.6 and 5.0 kgwk⁻¹, with catch rates of both molluscs declining over the 4-yr period by between 64 and 80%. The average CPUE of black-lip oyster remained steady at about 6.0 kgwk⁻¹ over the 4-yr period while the catch rate of gold-lip oyster increased from an average of 3.3 kgwk⁻¹ between 1987 and 1989 to 11.5 kgwk⁻¹ in 1990. This increase was directly related to an increase in the buying price for this oyster during 1990.

Catch rates of nautilus in Z traps in Vanuatu ranged from 0 to 2.6 nautilustrap⁻¹set⁻¹, with a mean of 1.2 nautilustrap⁻¹set⁻¹ (Blanc 1988), where traps were set for between 24 and 48 h. The best catch rates (2.6 nautilustrap⁻¹set⁻¹) were experienced at depths in excess of 300 m. Photographic records of trap catches of nautilus in Palau suggest that wire mesh traps may catch in excess of 10 nautilustrap⁻¹ (Saunders 1984). Catches were made in cubic wire mesh traps with soak times ranging from 5 and 16 h and a mean of 8 h.

Fisheries biology and stock assessment

Few studies have been made on subsistence mollusc fisheries from the perspective of stock assessment and management. Occasional declines in *Batissa violacea*, or kai, harvests in Fiji arouse concern, but, Lewis (1988b) has suggested that in general kai stocks are not being over-exploited and that increased siltation in Fiji's rivers through agriculture and deforestation may actually be beneficial to kai populations. Adams (1992b) illustrates the possible correlations between fluctuations in kai harvests and unusual flooding events, as well as dredging. Butler (1983) has studied some aspects of the biology and ecology of the ark shell *Anadara cornea*, or kaikoso, another important subsistence mollusc in Fiji. Unlike *Batissa violacea*, which is essentially riverine in habitat, *Anadara cornea* is found in more estuarine conditions. Butler suggested that the scale of fishing effort in parts of Fiji is such that few specimens reach maximum size due to harvesting pressure. Butler also suggested that *A. cornea* populations recruit throughout the year but in a discontinuous manner and with fluctuating densities. The population biology and ecology of the cockle *A. maculosa* in Kiribati has been described by Tebano (1990). Tebano considered that the absence of *A. maculosa* from the southern islands of the Gilbert group may be the result of periodic droughts that affect this area causing elevated water temperatures and salinities and a decrease in dissolved oxygen beyond the tolerance of this species. Based on studies of the reproductive biology, Tebano (1990) recommended a legal size limit for this species of 42.5 mm.

Richard (1981) conducted some initial studies on the biology and abundance of four mollusc species in French Polynesia, including the smallest giant clam, *Tridacna maxima*, the bivalves *Arca ventricosa* and *Cardium fragum*, and the gastropod *Tectarius grandinatus*. Growth rates were observed from marking individuals and measuring their growth increments whereas biomass was estimated from underwater visual census counts. The longevities of these molluscs ranged from about 3 yr for *Cardium fragum* to 23 yr for *Arca ventricosa*. From the biomass densities determined from the transects, Richard (1981) determined the standing stocks of the four mollusc species at different atolls in French Polynesia.

The estimated density of *Tridacna maxima* at Takapoto Atoll (Fig. 2, 97), in the Tuamotu Archipelago, was 1400 ha⁻¹ or 67 kgha⁻¹, while the density of the ark shell *Arca ventricosa* in the same location was over three times that of *Tridacna maxima*, with nearly 6000 ha⁻¹ or 43 kgha⁻¹ww. In the smaller lagoon of neighbouring Anaa Atoll (Fig. 2, 126), the density of the cockle *Cardium frugum* was estimated to be 240,000 ha or 460 kgha⁻¹ww. Similar very high densities (500000 ha⁻¹, 11 kgha⁻¹ww) of the gastropod *Tectarius gradinatus* were observed at Fangataufa atoll (Fig. 2, 24).

Because of the interest in aquaculture of giant clams, a considerable amount of study has been conducted on these species in the South Pacific during the past 15 yr. Much of this work has been reported in the proceedings of two regional workshops (Copland & Lucas 1988, Fitt 1993) and two reviews (Munro 1993, Lucas 1994) on giant clam biology, stock assessment and aquaculture. Studies of the growth and mortality of captive and cultured clams have been conducted in a number of locations within the region. Growth studies such as those in PNG by Munro & Gwyther (1981), in Fiji by Adams et al. (1988) and on the Great Barrier Reef (GBR) by Pearson & Munro (1991) suggest that the longevity of giant clams is well in excess of 20 yr, even for small species such as *Tridacna maxima*. Lucas (1994) reports that a 500 kg specimen of *T. gigas* was estimated to be 63 years old. Munro & Gwyther (1981) state that natural mortality of giant clams in their study (*T. gigas*, *T. squamosa*, *T. maxima*, *Hippopus hippopus*) was extremely low and was virtually confined to small clams in the 5 — 15 cm range. Observed natural mortalities of unexploited tagged clam populations on the GBR ranged from 3.4 to 10% for *Tridacna gigas* and 4.4% for *T. derasa* (Pearson & Munro 1991). Average annual total mortalities in natural populations of *T. maxima* and *T. squamosa* in Tonga ranged from 30 to 46% and 46 to 88% respectively with means of 31 and 68% (Chesher 1991). Chesher (1991) suggests that half of the observed mortality in *T. maxima* was attributable to fishing, while the very high mortality of *T. squamosa* was due in part to fishing and high mortalities in small (< 4.0 cm) specimens.

Munro (1993) states that stock densities of giant clams in the South Pacific vary enormously, attributable not only to the effects of exploitation but also to natural causes such as episodic recruitment and juvenile habitat preference. Table 23 records some stock densities of various giant clam species in the Pacific. Stock densities of small species such as *T. maxima* and *T. crocea* can reach very high concentrations, particularly in isolated reefs and lagoons. The figure for the extremely high stock densities for *T. maxima* at Beveridge Reef (Fig. 2, 9) is the average of a range of stock densities from several different locations on the reef with a minimum of 2500 ha⁻¹ and a maximum of 200000 ha⁻¹. Beveridge Reef is an isolated oval shaped reef that is entirely awash at high tide, and encloses a lagoon of about 14 km². The reef lies about 280 km to the southeast of Niue and is rarely visited by Niueans. In some parts of Beveridge Reef the populations of *T. maxima* are so dense that clams are growing on the shells of other clams. Very high concentrations of *T. maxima* of up to 54000 and 60000 ha⁻¹ have also been reported from parts of Aitutaki (Sims & Howard 1988) and Takapoto Lagoon (Richard 1981), respectively, although the overall mean densities were much lower. Indeed, *T. maxima* in Polynesia appears to have a markedly different community structure compared with the same species further west, where populations are much less dense, with a larger average individual size. It is not known whether this is a genetic difference or, as appears likely, a release from competition by certain other reef borers as biodiversity decreases towards the eastern Pacific (Adams 1988).

Descriptions of the biology of trochus are given by Bour (1990, 1992), and detailed descriptive accounts of the biology of trochus, green snail and pearl oysters in the South Pacific and elsewhere are given by Nash, Yamaguchi and Sims respectively (all in Wright &

Table 23: Standing stock densities of giant clams in various Pacific islands.

Location	Giant clam densities (clams ha ⁻¹)						Source
	<i>T. maxima</i>	<i>T. gigas</i>	<i>T. derasa</i>	<i>T. crocea</i>	<i>T. squamosa</i>	<i>H. hippopus</i>	
Niue	89.0				14.1		Dalzell et al. 1993
Beveridge Reef	75 000						Anon. 1987
Palau				1390		30 – 90	Hardy & Hardy 1969
Helen Reef (Fig. 2, 34)		50	33				Hardy & Hardy 1969
Cook Islands	18 000						Sims & Howard 1988
Kiribati		1			1.0	1.3	Munro 1988
Great Barrier Reef		5	5				Munro 1993
French Polynesia (Takapoto)	1 400						Richard 1981
Tuvalu					0.7 – 1.4		Braley 1988
Tokelau					< 6.0		Braley 1989
Vanuatu	8.9			0.14		3.5	Zann & Ayling 1988

Hill 1993). Growth of trochus has been observed from mark and recapture studies at Guam, Palau, New Caledonia and Vanuatu. Growth is relatively uniform with a maximum life span of about 12 yr and maximum sizes ranging from 11 to 15 cm (shell diameter). Mortality rates have also been estimated from tagging and size frequency data and indicate that natural mortality rates are generally low with annual survival rates of between 50 and 90% (Nash 1993), although the extremely heterogeneous age structure of trochus subpopulations on different sections of a single reef indicate that caution must be exercised when estimating mortality rates from size frequency data in this species (Nash et al. 1995).

Stock assessments of trochus have been conducted in a number of locations through counts along transects and in quadrats on the reef. usually, such exercises are carried out prior to the setting of harvest levels in islands where trochus stocks are limited such as Aitutaki and Rarotonga in the Cook Islands, and Yap and Pohnpei in Micronesia. Trochus harvests in these locations take place over a few days or a few weeks at most and, because of the open access nature of the fisheries, a total catch needs to be set from which quotas are allocated. In the larger Melanesian islands where the resource is not an exotic species, harvesting has traditionally continued throughout the year with little regulation other than the setting of a minimum allowable size and, in Vanuatu and Ontong Java in the Solomon Islands, occasional moratoria (Adams & Dalzell 1995). Nash et al. (1995) used the occasion of a trochus harvest in Aitutaki to compare three methods of estimating the population size and hence setting a quota on the total harvest. The three methods were strip transects, the Petersen mark-recapture method (Ricker 1975) and the change-in-ratio (for different size classes) method (Kelber in Krebs 1989). Nash et al. (1995) concluded that the mark and recapture method was more accurate than the strip transect for this fishery and more useful and robust than the change-in-ratio method. The disadvantage of this method is that the trochus population is determined during harvesting, as tags are returned by harvesters and thus an accurate quota is not set before trochus collection begins.

The biology and population dynamics of *Pinctada margaritifera* in Manihiki Lagoon (Fig. 2, 52) in the Cook Islands has been described by Sims (1992b, c). Growth parameters suggest that like trochus, this species has a longevity in excess of 10 yr and that natural mortality rates are low. Sims (1992c) estimated an annual natural survival rate of about 90%, with recruitment at about 9%. The relatively slow turnover of black-lip oyster populations means that they can withstand only moderate exploitation. Sims (1992c) surveyed populations of black-lip oysters at Penrhyn and Suvarrow Atolls (Fig. 2, 95) in the Cook Islands that were over-fished in the last century and where populations have not yet recovered to former levels. Similar stock collapses have been reported from French polynesia (Intes 1986) and from Kiritimati Island in the Line Islands (Sims et al. 1989).

The biology of the nautilus, *Nautilus belauensis* and *N. pompilius*, has received attention. Following the discovery of a new species of nautilus in Palau (Saunders 1981), studies were done on the biology and populations of *N. belauensis*. Tagging studies suggested that this species grows about 3.7 cm yr^{-1} in terms of shell increment but this rapidly decreases at the onset of sexual maturity. Saunders (1983) estimated that the average longevity of *N. belauensis* exceeds 20 yr, and that unlike most other cephalopods, it does not die after breeding but may live for between 5 and 10 yr following maturity.

Socioeconomic developments

Between 1500 and 2000 t of trochus were harvested annually from the Pacific islands in the period 1990 — 92, although this may vary considerably from year to year depending on demand, stock sizes and the occasional moratoria that area feature of trochus fishery management in many islands. Trochus markets are greatly dependent on the demand for mother-of-pearl buttons for the fashion industry in Europe and Asia, and trends in the garment (particularly shirt) manufacturing industry will probably dictate the future of trochus fisheries in the region. The switch from shell to plastic buttons in the 1950s caused a decline in the demand for trochus that did not recover for two decades. It is also possible that demand (and prices), could plummet rapidly if trochus is ever promoted as an endangered species by conservation groups. Unlikely as it sounds (since trochus is undoubtedly the best-managed commodity fishery in the Pacific) trochus has apparently found its way onto one endangered species list already by being lumped together with other mother-of-pearl producing shells, such as green snail and gold-lip pearl shell (Adams et al. 1994).

Over the past 10 years, hatchery methods for trochus aquaculture have been optimized and it is relatively easy to produce and rear juvenile specimens. It is unlikely, however, that trochus mariculture could ever be economically feasible in the Pacific islands, but it has been hoped that cultured juveniles might be used to re-stock depleted reef areas and recruitment enhancement is being tested. Experiments have been carried out in Palau, Vanuatu, Fiji and New Caledonia, but it will be some time before it is known if these experiments were successful or not. In the meantime, the as yet untested premise that reefs can be re-stocked has a negative side in that it can be cited by unscrupulous buyers and politicians as a panacea for over-fishing.

Total black-lip oyster shell production from the South Pacific region currently amounts to about 400 t yr^{-1} with about two-thirds of this volume being produced by French Polynesia. Production of mother-of-pearl from wild stocks of black-lip oysters is confined to the Melanesian islands. Shell production from black-lip oysters in French Polynesia and the Cook Islands is no longer from wild stocks, but from oysters cultured for pearl production. It should be stressed, however, that cultured oyster populations originate from recruits from wild stocks, survival of which is

enhanced through deployment on spat collectors on which the transforming larvae settle out. Closed-system aquaculture of pearl oysters is still in the process of being developed, but there are promising indications from a private company in Hawaii (N. Sims, Black pearls Inc. Hawaii, pers. comm.). The large number of sheltered lagoons in French polynesia, coupled with naturally dense oyster populations and generous financial support from the French Government has led to the development of an extensive pearl culture industry based on *Pinctada margaritifera*. By the mid 1990s over 3000 inhabitants of 40 islands in the Tuamotu, Society, Gambier and Marquesas archipelagos derived their income from pearl culture (Anon. 1994c). The 1993 production of pearls in French Polynesia amounted to about 2200 kg yr^{-1} , worth over US\$78,000 000, and in 1994 reputedly earned well over US\$100,000 000 (R. Newnham, Ministry of Marine Resources, Cook Islands, pers. comm.). Pearl cultivation is still a developing industry in the Cook Islands and at present only a small amount of pearls is produced each year.

The success of pearl oyster cultivation in French polynesia has generated much interest in the resource-poor atoll micro-states in the Pacific such as Tuvalu, Kiribati and the Marshall Islands. Surveys conducted by the South Pacific Commission (Sims et al. 1989, Preston et al. 1990, Dashwood 1990) in some of the atolls of all three states have demonstrated insufficient levels of natural stocks to support pearl culture, the result in some cases of gross over exploitation of wild stocks in the previous and early parts of this century. Transplantation of stocks from other parts of the Pacific might be considered, although Benzie & Ballment (1994) have shown that Pacific populations of *P. margaritifera* are quite highly differentiated genetically, and that care needs to be taken before initiating transfers so that this genetic variation is preserved.

Crustacean fisheries

Description

Crustaceans such as lobsters, shrimps and crabs form part of the subsistence catch in the South Pacific and form the basis of limited commercial fisheries. The trawl fishery for penaeid shrimps in the Gulf of Papua is the only large-scale commercial crustacean fishery in the region at present. Fishing techniques for crustaceans caught for subsistence are simple and include setting traps, using nets and spears and simply collecting and gleaning from reef flats, mangroves and estuaries.

The lobster resources of the Pacific include spiny lobsters (Palinuridae) and the slipper or shovel-nosed lobster (Scyllaridae). Four spiny lobster species, *Panulirus penicillatus*, *P. longipes*, *P. versicolor* and *P. ornatus* are found on the reefs of the tropical Pacific islands. On the subtropical margins, north (Hawaii) and south (Rapa (Fig.2, 87), Pitcairn and Easter Island) are found *P. marginatus* and *P. pascuensis*, respectively. The slipper lobster resources in the South Pacific are less well documented but *Parribaccus caledonensis*, *P. antarcticus*, *P. holthuisi* and other *Parribaccus* spp. are found on the tropical reefs of the Pacific in the same general locations as the spiny lobsters. On the subtropical margins are found species such as *Scyllarides haani* and *S. squammosus* which, like the spiny lobsters, are commercially valuable.

A feature of the behaviour of the four tropical spiny lobsters is their apparent reluctance to enter traps or pots, which are used to great effect with subtropical and temperate spiny lobsters elsewhere in the Pacific and beyond. Prescott (1988) reports that traditionally manufactured traps have been used to capture *Panulirus penicillatus* and *P. longipes* in various parts

of the Pacific, using bait such as chitons and sea-urchins. The introduction of underwater torches and dive gear has turned Pacific island fishermen away from traditional methods of catching spiny lobsters. Furthermore, commercially manufactured fish traps, used to catch *P. marginatus* in Hawaii and *P. cygnus* in Western Australia have been tried in many parts of the Pacific with little success. Consequently, the basis of all commercial and subsistence fishing for lobsters in the Pacific remains diving with spears and hand-nets, and collecting on reef flats at night during low tides. Innovations such as the use of SCUBA or hookah gear may be introduced to improve the efficiencies of dive fishermen but essentially the methods remain similar throughout the region. Certain practices, such as the use of tangle nets on the fore-reef, and the use of compressed air to flush lobsters out of holes, are generally discouraged as they may be considered destructive of reefs.

Zann (1985) gives a good description of a small-scale commercial lobster fishery in Tonga that targets *P. penicillatus*. Fishermen are active in the week before and after new moon, or between 15 — 18 nights per month. Divers work at night in pairs, starting at about 20.00h, usually working until 04.00h. The divers systematically work a given area of reef then unload their catch, change torch batteries and continue searching until 04.00h when fishing is terminated and the catch is landed at a processing facility. Grandin & Chauvet (1994) and Chauvet & Farman (1994) describe lobster fisheries of Lifou (Fig. 2, 49) and Isle de Pins (Fig. 2, 36) in the French territory of New Caledonia. Originally, *P. penicillatus* was caught at Lifou using traps made from plant fibres baited with sea-urchins, but as is the case elsewhere, trap fishing has been superseded by night-time dive and spear fishing. This is also the case in the Cook Islands where lobsters (mainly *P. penicillatus*) are captured by reef walking at night either side of low tide or free diving on reefs with torches at night (Passfield 1988).

At Yule Island (Fig. 2, 119) in the Gulf of Papua, fishermen dive during the day to catch *P. ornatus* by hand (Prescott 1988). Coral bommies are also surrounded by tangle nets to snare lobsters when they are frightened from their refuges. Gill nets set to catch fish at Yule Island will also take *P. ornatus*. The same species is the target of Australian and PNG fishermen in the Torres Straits. Divers work singly or in pairs during the day catching *P. ornatus* by hand or with short spears (Kailola et al. 1993). An unusual feature of the *P. ornatus* fishery of the Torres Strait and Gulf of Papua is that this species is susceptible to trawls. *P. ornatus* undertakes a long spawning migration from reefs in the Torres Strait at the western edge of the Gulf to Yule Island in the east. Crossing the Torres Strait and the Gulf of Papua they walk through areas fished by commercial shrimp trawlers. For several years in PNG, this lobster by-catch was seen as a useful seasonal bonus by the trawl fleet, but eventually was banned owing to concerns about the reduction of spawning stocks and the concomitant effects on subsequent recruitment of *P. ornatus* to the northern GBR and Torres Strait.

The portunid crab *Scylla serrata* is found throughout most of the tropical Pacific wherever there are areas of muddy substratum with stands of mangrove trees (Brown 1993). Like spiny lobster it has been caught by Pacific islanders for subsistence purposes and forms the basis of small commercial fisheries in some countries of the region. Mangrove crabs are caught in the South Pacific in baited wire mesh traps or, more commonly, by carefully pulling crabs from their burrows with a metal or wooden hook. If crabs can be extracted carefully without damage to the burrow then the vacated burrow will soon be re-occupied and crabs can continue to be captured at the same site for many years (Swamy 1994).

In Fiji, mudcrabs are caught using both methods. Along the drier north and western zones of Viti Levu, crabs are caught in the mangroves mainly from burrows. A piece of mangrove

stick is inserted into the burrow and is seized by the crab. The stick and crab are careful removed from the burrow that is blocked on extraction of the crab to prevent escape and re-entry. According to Swamy (1994), the fishers who regularly catch crabs in this fashion know the locations of several burrows within a mangrove system. These locations are well guarded secrets as they will continue to produce crabs if not damaged during harvesting activities. On the wetter south side of Viti Levu, crabs are caught predominantly in dilly traps set in the intertidal mangroves. The dillies are made of a gill net fastened to a circular steel hoop. They are baited with meat or fish and set in mangrove streams at low tide. Unlike pots or cage traps, the dillies are not left unattended, but raised regularly to see if there are crabs feeding on the bait.

Some pot fishing is also conducted in Fiji, where wire basket traps are left baited and unattended, and emptied every 6 h, although according to Swamy (1994), this method is not very popular among local fishermen. This method of crab fishing is used in Palau (Nichols 1991) as well as more traditional methods such as hand collection and spearing. Capture of mudcrabs on Pohnpei is mainly by fishers searching for them in the swamps, looking for crabs in burrows, hiding in between mangrove roots or submerged in puddles (Peirine 1978). Some crabs are also caught on sandy reefs up to a kilometre from the mangroves, hiding in seagrass and seaweeds. Crabs are also caught this way in Guam but the predominant method of capture is with baited dillies and in traps (Amesbury et al. 1986). In New Caledonia a range of methods are used to catch mudcrabs including traps, removal from burrows and, occasionally, seine nets (Delathiere 1990).

Penaeid shrimp capture fisheries are not of any economic significance except in PNG where the Gulf of Papua trawl fishery produces between 1000 and 1300 t of shrimps annually. Fishing is conducted in waters between 5 and 40 m deep with little fishing on the deeper slopes. Shrimp fisheries elsewhere in PNG and the Pacific islands are more modest. The Orangerie Bay fishery on the southeast Papuan coast generates between 5 and 78 t annually (Anon. 1994d). Along the north coast of PNG penaeid shrimps have been captured by smallscale beam trawls in the Markham (Quinn & Kojis 1986) and Sepik estuaries (Frusher 1985a, Chapau 1991). Similar exploratory fishing in the seagrass beds adjacent to the Nggurambusu River (Fig. 2, 68) (Guadalcanal) in the Solomon Islands revealed populations of *Penaeus semisulcatus*, including significant numbers of gravid females (Delaune 1989). Although it was thought not economically viable to fish this stock commercially, it might form a valuable source of brood stock for shrimp farming and culture.

Small-scale shrimp fishing is conducted in Fiji, with an annual production of between 3 and 5 t (Choy 1988), although there are occasionally years with higher catches on unusually dense spawning aggregations (M. Lagibalavu, Fisheries Division, Fiji, pers. comm.). Shrimps are caught with spears, hand nets, scissor nets and seines (Choy 1981, 1988). Gill net fishing in the lagoon of Tongatapu, the main island of Tonga, generates a small by-catch of penaeid shrimps, mainly *P. semisulcatus* and *Metapenaeus ensis*. Braley (1979) conducted a series of beam trawls in Tongatapu lagoon to assess the feasibility of this small-scale method of catching shrimps and to collect information on the principal species in the subsistence catch.

Other crustaceans that are collected mainly for subsistence purposes in the Pacific include the three spot reef crab (*Carpilius maculatus*) and the red reef crab (*Etisus splendidus*). Amesbury et al. (1986) state that these crabs are captured by hand on reefs in Guam. Dalzell et al. (1992) also reported subsistence consumption of these crabs on Niue. Land crabs are also important throughout the Pacific, particularly the common purple land crab *Cardisoma* spp. These species swarm at certain times of the year in a spawning migration to release eggs in the sea and can

simply be collected in large numbers by parties driving along roads at night and picking them up. The coconut or robber crab, *Birgus latro*, may be very common in some Pacific islands and is caught in substantial quantities in Vanuatu, both for subsistence, but more recently for the local tourist industry (see contributions in Brown & Fielder 1991).

The burrowing mud lobster, *Thalassina anomala*, is commonly found in mangrove areas of the Pacific and is caught in appreciable quantities in Fiji, where it is regarded as a delicacy. The lobster is caught in a snare trap inserted into the burrow and triggered by the movement of the lobster. Burrowing mantis shrimps (Stomatopoda) that live in seagrass meadows are also caught for subsistence by snare traps. The snare is inserted into the burrow attached to a baited stick that protrudes from the burrow. When the shrimp attacks the bait the stick vibrates and the snare is tightened by the fisher. An even simpler method for mantis shrimp capture has been reported from New Britain in PNG (M. Chapau, Dept. of Fisheries & Marine Resources, PNG, pers. comm.) where bait is loaded into a nylon stocking that is pushed into the burrow. The shrimp attacks the bait but gets its claws tangled in the stocking and can then be extracted from the burrow.

Some mention should also be made of the freshwater prawns, *Macrobrachium* spp. Although normally found in fresh water, *M. rosenbergii* uses the mangroves of the Gulf of Papua as a nursery and berried females may be caught in waters with salinities as high as 15 — 18‰ (Frusher 1983). Furthermore, many of the Pacific islands rivers are short, and freshwater species such as *Macrobrachium* are caught in the vicinity of the coastal margin. A description of traditional fisheries for freshwater prawns on the Sepik River of PNG is given by Robertson (1983). *Macrobrachium* can be caught on baited hook-and-lines or in traps and the methods described by Robertson for PNG are similar to those used elsewhere in the South Pacific. Although only a minor item in the diet of most Pacific islanders, *Macrobrachium* prawns have attracted interest for their aquaculture potential.

As with finfish, the crustacean fauna of the outer reef slope has attracted some interest owing to the presence of pandalid shrimps and geryonid crabs, both of which are catchable in traps. King (1993b) summarized the information on pandalid shrimps and surveys of populations in the Pacific. It was initially hoped that in resource-poor countries without extensive estuarine areas, trap fisheries based on pandalid shrimps might develop as another source of income for fishermen. This hope has only been realized in Hawaii, however, and these fisheries have not persisted because of poor returns from catches (Polovina 1993). Trial fishing with traps in both Palau (Hastie & Saunders 1992) and the Marquesas Islands in French Polynesia (Poupin et al. 1991) have revealed populations of the geryonid crabs, *Chaceon granulatus* and *Chaceon* species nova that are readily caught in crab pots. Both surveys suggest that populations might support small-scale fisheries.

Catch composition

Apart from the lobster fisheries of Yule Island and the Torres Strait, the dominant lobster in catches in the South Pacific islands is *Panulirus penicillatus* (Pitcher 1993). The data presented in Table 24 from various locations in the Pacific confirm the dominance of *P. penicillatus* throughout much of the region. The next most important species would appear to be *P. longipes*. Exact numbers of species at different locations were not always obtainable, for example Pitcher (1993) states that *P. ornatus* makes up virtually 100% of the Torres Straits lobster catch, although *P. versicolor* is not uncommon. Similarly, the Yule Island lobster catch is composed almost entirely of *P. ornatus* with the occasional capture of other species.

Table 24: Percent species composition of spiny lobster catches from various locations in the South Pacific region.

Location	<i>P. penicillatus</i>	<i>P. longipes</i>	<i>P. versicolor</i>	<i>P. ornatus</i>	Source
Lifou (New Caledonia)	80.0	15.0	4	1	Grandin & Chauvet 1994
Isle des Pins (New Caledonia)	60.7	38.8	0.4	0.1	Chauvet & Farman 1994
Niue	72.5	25.4	2.1		Dalzell et al. 1993
Yule Island (PNG)	< 1.0			> 99.0	Anon 1984b
Torres Strait (PNG/ Australia)	< 1.0			> 99.0	Pitcher 1993
Tsoi Islands (PNG)	98.0	1.0	1.0		Hair & Aini 1994
Kiribati	90.7		9.3		Prescott 1977
American Samoa	100.0				Saucerman 1994
Western Samoa	> 99.0		< 1.0		King & Bell 1991
Fiji	95.5		1.4	3.1	Richards 1994
Tonga	67.9	27.5	4.6		Prescott 1993

King & Bell (1991) examined over 1000 spiny lobsters in Western Samoa between September and November 1989 and found only two specimens of *P. versicolor*, with the remainder being *P. penicillatus*. Saucerman (1994) lists only *P. penicillatus* from American Samoa and this appears to be the only species present.

According to George (1974) and Pitcher (1993) the distribution of spiny lobster species is a function of several physical variations, such as coral cover, wave energy, water quality and turbidity. *P. penicillatus* is largely restricted to the reef crest and reef slope, preferring oceanic water that is clear and well oxygenated by constant wave action, and habitat with plenty of coral cover for protection. The same general habitat is preferred by *P. longipes* but this species can be found in deeper waters and extends on to the reef plateau into more sheltered waters. *P. versicolor* ranges from the reef crest and slope to the well developed coral gardens on the reef plateau. *P. ornatus* is found in the widest range of habitats from sheltered, moderately turbid waters of back-reef lagoons to the very turbid silty areas near rivers and mangroves. It is the commonest species on broad continental shelves and can be found at a depth > 200 m.

Between 50 and 60% of the shrimp catch in the Gulf of Papua shrimp fishery consists of a single species, *Penaeus merguensis*, or banana shrimp. Other common catch components are tiger shrimps (*P. monodon*, *P. semisulcatus*), which form about 12% of the catch, and endeavour shrimps (*Metapenaeus* spp.) constituting a further 20% (Gwyther 1980). Banana shrimps dominate the Orangerie Bay shrimp fishery in southeast Papua, where they form between 80 and 90% of landings, with the balance of the catch including *Penaeus monodon*, *P. semisulcatus* and *Metapenaeus* spp. (Anon. 1994d). About half the landings of experimental catches of shrimps in Milne Bay was *Penaeus merguensis*, with a further 22% comprising *P. monodon* and *P. semisulcatus* (Coates et al. 1984). Commercial-scale shrimp trawling surveys around the mouth of the Sepik River were dominated by banana shrimps (*P. merguensis*, *P. indicus*), which formed over half the catch with another 40% comprising endeavour shrimps (*Metapenaeus affinis*, *M. ensis*, *M. dobsoni*, *M. demani*) and the balance made up from tiger shrimps (*Penaeus monodon*, *P. japonicus*, *P. semisulcatus*) (Frusher 1985a).

Shrimp catches by small-scale beam trawling in the Markham River estuary were almost entirely *Metapenaeus demani* (Quinn & Kojis 1986), with occasional amounts of *Penaeus*

semisulcatus. Shrimp catches using a similar type of gear along the coast of Guadalcanal caught only the giant black tiger shrimp, *P. monodon* (Delaune 1989). Small-scale otter trawling in the Tongatapu lagoon caught almost equal quantities of the tiger shrimp, *P. semisulcatus* (46%) and the endeavour shrimp, *Metapenaeus ensis* (54%) (Braley 1976, 1979). In Fiji, the dominant shrimp captured by small-scale fishermen using spears and nets is *Penaeus canaliculatus*, which forms 85% of the catch around Suva (Choy 1988). The balance comprises a mixture of *P. latisulcatus*, *P. monodon*, *P. semisulcatus*, *Metapenaeus anchistus* and *M. elegans*.

Catch rates

Catch rates for spiny lobsters are infrequently reported from most of the Pacific and are not expressed in a uniform manner. Catches may be recorded as numbers or weight, and may be expressed per hour, per day or per trip. For example, the average catch rate for spiny lobsters reported by Grandin & Chauvet (1994) from the New Caledonian island of Lifou is 3.2 kg h^{-1} , but 12.1 kg day^{-1} was reported from the Isle de Pins (Chauvet & Farman 1994). Even where catch statistics are reliable, problems occur because improvements in technology have increased fishing efficiency. Catch rates of dive fishermen based at Daru catching lobsters in the Torres Strait prior to 1985 ranged from 6.0 to $13.9 \text{ kg}^{-1} \text{ man}^{-1} \text{ day}^{-1}$, with a mean of $7.9 \text{ kg}^{-1} \text{ man}^{-1} \text{ day}^{-1}$. The introduction of hookah gear has led to a major increase in CPUE that peaked in 1989 at $36.3 \text{ kg}^{-1} \text{ man}^{-1} \text{ day}^{-1}$ (Anon. 1994d). Catch rates in the Tongan fishery during the early and mid 1980s ranged from 0.5 to $4.9 \text{ kg man}^{-1} \text{ h}^{-1}$ (mean = $1.5 \text{ kg man}^{-1} \text{ h}^{-1}$) or 2.4 to $16.4 \text{ kg night}^{-1}$ (mean = $8.5 \text{ kg night}^{-1}$) (Zann 1985). Lobster catch rates from several atolls in the Gilbert Islands ranged from 0.6 to $21.3 \text{ lobsterman}^{-1} \text{ h}^{-1}$ or a mean of $11.3 \text{ lobsterman}^{-1} \text{ h}^{-1}$ (Prescott 1977). Assuming a mean weight similar to lobsters in the neighbouring Marshall Islands (Ebert & Ford 1986) of 0.45 kg , then these catch rates translate to 0.27 — $9.6 \text{ kg man}^{-1} \text{ h}^{-1}$, or a mean of $5.1 \text{ kg man}^{-1} \text{ h}^{-1}$.

Unlike the lobster fisheries of the tropical Pacific, catches of the Hawaiian lobster, *Panulirus marginatus*, in the commercial lobster fishery of the subtropical Northwest Hawaiian Islands were made by trapping in plastic lobster pots. Average annual catch rates in the Northwest Hawaiian Islands commercial fishery, expressed as $\text{lobstertrap}^{-1} \text{ haul}^{-1}$, declined from $2.75 \text{ lobsters trap}^{-1} \text{ haul}^{-1}$ in 1983 to $0.56 \text{ lobstertrap}^{-1} \text{ haul}^{-1}$ in 1991, with an overall mean of $1.4 \text{ lobstertrap}^{-1} \text{ haul}^{-1}$, or 1.65 to $0.34 \text{ kg trap}^{-1} \text{ haul}^{-1}$ with a mean of $0.84 \text{ kg trap}^{-1} \text{ haul}^{-1}$ (Polovina 1993). About 80% of the catch is formed by *P. marginatus*, with most of the balance comprising the slipper lobster, *Scyllarides squammosus*. A small recreational dive fishery for *Panulirus marginatus* at Midway Atoll (Fig. 2, 59) was monitored between 1975 and 1978 by MacDonald (1987). Catch rates were expressed as $\text{lobstersdiver}^{-1} \text{ trip}^{-1}$ and varied from 0.6 to $4.5 \text{ lobstersdiver}^{-1} \text{ trip}^{-1}$ with a mean of $2.8 \text{ lobstersdiver}^{-1} \text{ trip}^{-1}$, or 0.53 to $4.0 \text{ kg diver}^{-1} \text{ trip}^{-1}$ with a mean of $2.5 \text{ kg diver}^{-1} \text{ trip}^{-1}$, based on the mean lengths of male and female lobsters in the catch and length-weight equations given by Uchida et al. (1980).

Clarke & Yoshimoto (1990) report the results of an intensive depletion fishing experiment on an unexploited stock of *Scyllarides squammosus* on Laysan Bank (Fig. 2, 48) where catch rates for legal sized lobsters ranged from 1.2 to $3.6 \text{ lobstertrap}^{-1} \text{ haul}^{-1}$ and a mean of $2.34 \text{ lobstertrap}^{-1} \text{ haul}^{-1}$. A small percentage of slipper lobster catches in the Northwest Hawaiian Islands is formed by the slipper lobster *S. haani*. This species comprised the majority of lobsters caught in traps around the Pitcairn Islands group in the extreme southeast of the South Pacific region. Average catch rates ranged from 0 to $8.1 \text{ lobsterhaul}^{-1}$ with a mean of

1.54 lobstertrap⁻¹, or 0 to 9.3 kg and a mean of 1.35 kg from fishing at Oeno, Ducie and Henderson Islands (Dalzell 1994, Sharples 1994). The best fishing conditions were experienced at Ducie Island, where catch rates ranged from 0.7 to 8.1 lobstershaul⁻¹ (mean = 2.75 lobstershaul⁻¹) or 0.81 to 9.3 kghaul⁻¹ (mean = 3.14 kghaul⁻¹). The maximum and minimum catch rates mark respectively the initial and final CPUEs from the start and finish of a 15 day-period of intensive fishing. This decline, however, is more likely to be the influence of the lunar periodicity, with catches declining markedly at around the time of the full moon towards the end of the fishing period. Other species taken in small quantities, included *Panulirus penicillatus* and *P. pascuensis*.

As with the spiny lobsters, catch and catch rate data for mudcrabs in the South Pacific are sparse and not uniform. Swamy (1994) describes methods of catching mud crabs in Fiji but does not include information on CPUE from traps or by harvesting crabs from burrows. Commercial catch statistics for crab catches from Palau are relatively crude and refer to catch per trip. Nichols (1991) reports that between 1984 and 1990 the CPUE ranged from 8 to 22 kgtrip⁻¹ with a mean of 14 kgtrip⁻¹ or roughly equivalent to 14 crabstrip⁻¹. Mathews & Oiterong (1991) report an average catch rate of 0.7 crabstrip⁻¹ or 0.7 kgtrap⁻¹ from nightly trapping for mudcrabs in Palau during new moon by a single individual. Perrine (1978) gives no information on catch or harvest rates from the traditional mudcrab fishery on Pohnpei but does include some information on trials with wire and plastic crab traps set in the man groves. The average catch rate from these experiments in two separate trials was about 0.6 kgtrap⁻¹. Delathiere (1990) reported an average catch rate from New Caledonia of 5.08 kgind⁻¹day⁻¹ for commercial harvests during the permitted fishing season (February to November), mainly from women fishers catching crabs directly from their burrows.

Mudcrabs are caught by hand in the Murik Lakes, northern PNG, with the CPUE for commercial harvesting ranging from 1.4 to 6.2 kgind⁻¹day⁻¹ or a mean of 3.6 kgind⁻¹day⁻¹ (Chapau 1991). Chapau (1991) suggested that subsistence catch rates were likely to be lower, in common with those in the Purari Delta at the apex of the Gulf of Papua, which ranged from 0.0 to 0.08 kgind⁻¹day⁻¹. (Haines 1978/79). Trial catch rates in the same area with chicken-wire crab pots ranged from 0.2 to 1.25 crabstrip⁻¹ or 0.08 to 0.5 kgtrap⁻¹ for a 4-h soak (Anon. 1980). Gill nets and beach seines were also tested, and returned catch rates of 2 to 3 crabs per 1-hr soak and 0.4 to 0.75 crabs per haul respectively, or 0.8 to 1.2 kgsoak⁻¹ and 0.16 to 0.3 kghaul⁻¹ (Anon 1980). The most effective method of capture, however, was by hand and stick and averaged about 5.5 crabshman⁻¹h⁻¹ or 2.2 kgshman⁻¹h⁻¹. Matsuoka & Kan (1989) reported on the catches made with different trap types set in mangrove swamps adjacent to the Markham river mouth. The most productive design was a hemispherical trap, with an entrance at the top. The trap caught an average of 0.4 crabstrip⁻¹ or in terms of weight, 0.14 kgtrap⁻¹.

Catch rates of all shrimp species in the Gulf of Papua trawl fishery ranged from 11.5 to 24.1 kgh⁻¹ with a mean of 15.8 kgh⁻¹ between the years 1974 and 1993 (Evans & Opnai 1994a). Catch rates for the banana shrimps were 6.0 — 15.2 kgh⁻¹ (mean = 8.3 kgh⁻¹) during the same period. Catch rates for all shrimps in the Orangerie Bay fishery in southeast Papua showed a much greater range (8.0 to 35.8 kgh⁻¹) and a higher mean CPUE (27.0 kgh⁻¹) between 1981 and 1993. More modest shrimp catch rates were encountered during the trawl survey of Milne Bay (Coates et al. 1984), where the CPUE range was 1.2 to 11.6 kgh⁻¹ with a mean of 6.2 kgh⁻¹. Three commercial shrimp surveys in the Sepik River mouth encountered catch rates ranging between 0.0 — 15.6 kgh⁻¹ with an overall mean of 6.4 kgh⁻¹ (Chapau 1991), similar to those for Milne Bay.

Catch rates for small-scale beam trawling in the Markham River mouth are not given by

Quinn & Kojis (1986), but a mean CPUE of 0.7 kg h^{-1} can be computed for *Metapenaeus demani*, which made up most of the shrimp catch. Catch rates from the deployment of similar gear in and around the Murik Lakes in the Sepik Delta produced catch rates ranging from 0.0 to 1.89 kg h^{-1} or a mean of 0.5 kg h^{-1} (Chapau 1991). Braley (1976, 1979) does not give catch rates in terms of kg h^{-1} , using instead the numbers caught per standard 20-min period of trawling. However, the data are sufficient to re-estimate the CPUE in terms of weight, and based on his data this ranges from 0.3 to 2.4 kg h^{-1} with a mean of 1.0 kg h^{-1} . Choy (1988) reports average monthly catch rates from combined spear and hand-net fishing in Laucala Bay (Fig. 2, 46), Fiji, in terms of numbers per minute for juveniles and adults. Taking combined catches and raising these to catch per hour gives a range of 78 to 222 shrimp h^{-1} or a mean of 124 shrimp h^{-1} . Assuming an average shrimp weight of 2.3 g (Choy 1981) then this translates to an average CPUE of about 0.29 kg h^{-1} .

Fisheries biology and stock assessment

Considerable attention has been given to the biology and stock assessment of the two lobster species that constitute the Northwest Hawaiian lobster fishery, *Panulirus marginatus* and *Scyllarides squammosus*. The biology of both species has been summarized in Uchida & Uchiyama (1986). The catch and fishing effort data for this fishery, based on log books kept by commercial fishermen, were used to estimate the MSY and optimum fishing effort using a dynamic production model (Schnute 1977). The model provided a good description of the fishery between 1983 and 1989, but then catch rates declined markedly in 1990 and 1991. Polovina (1993) stated that fishing effort alone was not sufficient to cause these declines and that instead the decline is the result of poor recruitment attributable to oceanographic conditions (Polovina et al. 1994) at some banks, which resulted in a concentration of fishing effort at the remaining banks where recruitment was strong. More recent research has revealed that recruitment of *Panulirus marginatus* at two of the more productive banks in the Northwest Hawaiian Islands is related to relative sea level height, which is in turn linked to the ENSO event (Polovina & Mitchum 1992).

Less attention has been given to the slipper lobster, *Scyllarides squammosus*, which constitutes an average of between 10 and 50 per cent of lobster landings in the Hawaiian fishery. As stated earlier, Clarke & Yoshimoto (1990) conducted an intensive fishing experiment to obtain biomass estimates through localized depletion and application of the Leslie method. The biomass estimate and catchability coefficient obtained from the intensive fishing experiment were then used to estimate the biomass from other banks and islands where fishing had been conducted and there were data on catch rates.

A detailed descriptive summary of the biology of *Panulirus penicillatus* is given by Prescott (1988) and Pitcher (1993). *P. penicillatus* populations have been studied in Palau (MacDonald 1982, 1988), the Solomon Islands (prescott 1988), Marshall Islands (Ebert & Ford 1986), Tonga (Zann 1985, Prescott 1990, Munro 1992), Western Samoa (King & Bell 1991) and New Caledonia (Chauvet & Farman 1994, Grandin & Chauvet 1994). Growth of this species has been determined from tagging data (Enewetak, Solomon Islands) and from length frequency data (Tonga, Western Samoa, New Caledonia), suggesting life spans in excess of 10 yr. The abundance of *P. penicillatus* has been determined in the Solomon Islands and Enewetak by mark and recapture experiments and from Lifou (New Caledonia) by cohort analysis (Grandin & Chauvet 1994). Relative densities of *P. penicillatus* in the Solomon Islands ranged from 111 to 128 lobster km^{-1} of reef edge (mean = 120 lobster km^{-1}) and between 35 and 164 lobster km^{-1} (mean = 126 lobster km^{-1}) in Enewetak. Grandin & Chauvet estimated a total fishable

stock of *P. penicillatus* at Lifou of 410000 lobsters. A rough estimate of the coastline length of this island and hence reef edge is 207 km, which suggests a relative density of 1980 lobsterskm⁻¹, or nearly 20 times those observed in the Solomon Islands and Enewetak.

Ebert & Ford (1986) used yield per recruit analysis to estimate the optimum harvest size for *P. penicillatus* at Enewetak, suggesting that 40% of the adult population could be harvested annually. Adams & Dalzell (1993) have used the relative biomass estimates of Ebert & Ford (1986) and Prescott (1988) to suggest that an annual harvest rate of 20 kg of lobsterkm⁻¹ of reef may be sustainable and should be used as an initial approximation or rule of thumb when trying to determine the size of lobster resources on a given island or reef. The disparity between biomass estimates in Lifou and Enewetak and the Solomon Islands may be due to differences in methodology or indeed reflect the much higher productivity of the *P. penicillatus* population at Lifou. Grandin & Chauvet (1994) note that the annual harvest of lobsters from Lifou is about 15 000 lobsters, which represents only 3.7% of the fishable stock. These few data serve to show the uncertainty that still exists over the scale of Pacific spiny lobster resources.

Growth rates of *P. longipes* from Tonga (Munro 1992) and New Caledonia (Chauvet & Farman 1994) have also been determined from length frequency data and suggest maximum life spans of over 5 yr. Some aspects of the biology of *P. versicolor* from Palau, mainly reproductive biology and fecundity (see Pitcher 1993), have been given by MacDonald (1982, 1988).

A considerable research effort has been conducted on the populations of *P. ornatus* in the Torres Strait and the Gulf of Papua. During the 1970s and 1980s, it was established through tagging programmes that the lobsters that formed the basis of a seasonal fishery at the eastern edge of the Gulf at Yule Island between November and March originated from reefs in Torres Strait (Moore & MacFarlane 1984, Bell et al. 1987). Indirect evidence from the seasonal appearance of lobsters in the Gulf of Papua trawl fishery indicated the Torres Strait as the likely point of origin. MacFarlane & Moore (1986) suggested that the migratory population that spawned on arrival at Yule Island is the major source of larval recruitment in the western Coral Sea, including the east coast of Queensland and Torres Strait. These findings led to the imposition of a ban on trawling for lobsters in the Gulf of Papua. Other aspects of the biology of this species from the Torres Strait, such as growth and mortality, are given by Pitcher (1993).

A synopsis of the biology of *Scylla serrata* and a review of the limited amount of study conducted within the region is given by Brown (1993). Mudcrab biology and populations within the South Pacific have been studied in Pohnpei, Fiji, New Caledonia and PNG. Swamy (1994) gives an account of two populations of mudcrabs on the southeast and the northwest coasts of Fiji. The two locations are physically distinct in that the northern site experiences about half of the rainfall (1500 mm) normally falling in the south. Growth, mortality and recruitment parameters for both populations were described from length frequency data. The biology of *S. serrata* in New Caledonia has been examined in detail by Delathiere (1990) to provide information for managing this resource. Estimates of the total habitat occupied by mudcrabs were determined using remote sensing techniques, and the biological observations, including growth, mortality, recruitment and feeding, were made on captive and wild populations. Aspects of the biology of *S. serrata* in Pohnpei and in Guam are described by Dickinson (1977).

The biology and stock assessment of mudcrabs in PNG have been described for populations in the Gulf of Papua (Frusher 1983, Opnai 1986b) and in the Murik Lakes (Chapau 1991). Densities of crabs at two sites in the Purari Delta ranged from 10.4 to 21.4 crabsha⁻¹ or 2.5 to 4.7 kgha⁻¹, with means of 16 crabsha⁻¹ and 3.6 kgha⁻¹ respectively. In the Murik Lakes,

mudcrab densities in four sites ranged from 13 to 39 crabtrap⁻¹ with a mean of 23 crabs trap⁻¹ or 3.6 and 8.5 kg ha⁻¹ and a mean of 6.0 kg ha⁻¹. Perrine (1978) estimated that a minimum estimate of the crab standing stock on pohnpei was 3000 crabs in a mangrove area of 5400 ha⁻¹ or 0.6 crabtrap⁻¹ or 0.25 kg ha⁻¹. Perrine suggested that the true density may be two to three times this estimate. Delathiere (1990) estimated the abundance of mudcrabs in mangroves in New Caledonia to be 7900 crabtrap⁻¹ or a biomass of 1.04 tha⁻¹. As with the spiny lobsters, there appears to be major differences between the biomass estimates of crabs in New Caledonia and the other Pacific islands. This may be due to much greater densities of mudcrabs in New Caledonia or, as is more likely, differences in sampling techniques and the size and locations of sample areas. Delathiere (1990) counted crabs in a relatively small area (48 m²) most of which were juveniles. Density estimates in pohnpei and PNG were based on counts of adults made over much larger sampling area as of several hectares.

The biology and stock assessment of shrimps in the Gulf of Papua are addressed in studies by Gwyther (1980,1982), Tenakanai (1980), Branford (1982), Frusher (1985b), Frusher et al. (1985), polovina & Opnai (1989), Waffy (1990) and Evans & Opnai (1994a, b). The biology and ecology of the most important species in the fishery, the banana shrimp *Penaeus merguensis*, has been described by Gwyther (1980), Frusher (1983, 1985b) and Frusher et al. (1985). Aspects of the biology and ecology of the endeavour shrimps (*Metapenaeus* spp.) are described by Tenakanai (1980), Frusher (1983) and Waffy (1990). Gwyther (1980, 1982) made the first serious attempts to estimate the MSY from the Gulf of Papua shrimp fishery using the Fox (1970) surplus production curve to model catches for the whole shrimp fishery and for catches of *penaeus merguensis* only. Gwyther's analysis considered only 6 yr of data (1974 — 1979) to estimate an annual MSY for the shrimp fishery of 1200 and 570 t for catches of banana shrimps only. Evans & Opnai (1994a) fitted a Fox curve to catch and effort data for the years 1974 to 1993 to determine a total fishery MSY of 1500 t and a banana shrimp MSY of 620 t. Evans & Opnai suggested that the maximum economic yield for the fishery is between 1350 and 1400 t with an optimum fleet size of 15 vessels.

Polovina & Opnai (1989) showed an inverse relationship between the minimum monthly rainfall between September and December and Gulf of Papua shrimp catches in the subsequent year. When a monthly rainfall term was incorporated into the Fox production curve, more of the variation in catch could be explained than by an effort-only production model. Polovina & Opnai (1989) suggested that heavy rainfall may create extensive areas of low salinity water extending beyond the coastal mangroves that cause the post-larval shrimps to settle out before reaching their nursery grounds within the mangrove environment. Alternatively, heavy rainfall may create a constant outflow from the mangroves, negating any inshore tidal flow and preventing post-larvae from being carried inshore. The inverse relationship with catch and rainfall is the opposite of that observed in the banana shrimp fishery in the neighbouring Gulf of Carpentaria in northern Australia (Staples 1985), where the correlation between rainfall and subsequent fishery catches is positive. However annual rainfall in the gulf of Carpentaria is about 900 mm compared with 2700 mm in the Gulf of Papua.

Evans & Opnai (1994b) have made a detailed examination of the relationship between shrimp CPUE and rainfall. They suggest that the true relationship between rainfall and yield of banana shrimps is parabolic rather than linear, with an optimum annual rainfall of around 1200 mm. They suggest that low rainfall is critical immediately following the major annual post-larval settlement, and during the period of offshore recruitment in February to March.

The biology of the witch shrimp *Penaeus canaliculatus* in Laucala Bay, Fiji has been described by Choy (1981, 1988). Choy used length frequency data to estimate growth and mortality and described the reproductive biology and recruitment of this species. The standing stock of

P. canaliculatus was determined from Beverton & Holt's (1957) swept area method and this was used in turn with the natural mortality rate to compute potential yield. Some observations on the biology of *P. semisulcatus* and *Metapenaeus ensis* from Tongatapu Lagoon are reported by Braley (1979). Catches of the two species were inversely correlated but the CPUE for both species was reduced during the fullmoon. Both species undertook spawning migrations outside the lagoon between January and March.

The biology of deep water pandalid shrimps in the South Pacific region has been summarized by King (1987, 1993b), and includes details of those countries where resource surveys of deep water shrimps have been conducted. Stock assessment of pandalid shrimp populations have been made in the Northern Mariana Islands (Ralston 1986) and Hawaiian Islands (Ralston & Tagami 1992) using Leslie depletion fishing methodology. Estimates of standing stocks ranged from 2.4 kgha⁻¹ in Hawaii to 5.5 kgha⁻¹ in the Northern Mariana Islands. Both studies suggest that there was a limited resource of pandalid shrimps and that this could be easily over-exploited by trap fishing.

The biology and stock assessment literature on other crustacean resources in the South Pacific includes the coconut crab from Vanuatu, where it is economically important in the tourist trade (see contributions in Brown & Fielder 1991). A synopsis of the biology of this species in the South Pacific region is given by Fletcher (1993). No other biological or stock assessment studies appear in the literature on other land crabs in the South Pacific region. Some aspects of the biology of the deep water geryonid crabs from Palau and the Marquesas Islands are given by Hastie & Saunders (1992) and Poupin et al. (1991).

Socio-economic developments

The lobster fisheries of the South Pacific Continue to require divers to capture animals because of poor performance using pot or traps. The dominant species comprising most of the catch in Pacific island lobster fisheries, other than the Southern Papuan coast, will undoubtedly be *Panulirus penicillatus*, which occupies a relatively narrow band of the outer reef crest. This habitat area is limited in many Pacific island countries because of the small size of most of the islands in the region. Despite these obvious limitations, a number of ventures have tried to establish commercial lobster fisheries on a relatively large scale in a number of Pacific countries, usually without much success. Adams & Dalzell (1993) discussed the apparent and true potential of lobster fisheries based mainly on *P. penicillatus*. They catalogued a history of failed commercial enterprises in the region that had not taken account of the true economic potential for these fisheries.

Some small-scale operators do derive incomes from *P. penicillatus* fisheries, such as in northern PNG where buyers collect lobsters from village fishermen and air-freight them to restaurants and hotels in urban areas (Hair & Aini 1994). Overheads are kept to a minimum and these small-scale fisheries are able to return a profit. The *P. ornatus* fishery in the Torres Strait is also based on divers spearing lobsters, but fishermen are able to sell into the more lucrative Australian market where prices for fresh lobsters range from 30 to 70 A\$kg⁻¹, far more than could be realized in most of the Pacific islands. The introduction of hookah gear into this fishery markedly increased catch rates and doubled the volume of the fishery from 30 — 40 to 70 — 80 t yr⁻¹. The effects of such an obvious increase in efficiency in the *P. ornatus* fishery will only be known in the long term. Commercial fishing interests have approached Pacific island governments with the intention of using hookah gear to harvest *P. penicillatus*. Given what is thought to be the limits of the resource, this increase in efficiency would probably only lead to more rapid depletion of limited stocks.

Fisheries for shrimps outside of PNG are clearly very limited, but there is growing interest in mariculture of shrimp in the South Pacific region. Mariculture of penaeid shrimps has been successfully developed in New Caledonia, with annual production of over 600 t. The cultured stock is not from the South Pacific but is *Penaeus stylirostris*, originally imported from the USA (Eldredge 1994). A smaller amount of maricultured shrimp ($\approx 60 \text{ t yr}^{-1}$) is produced in French polynesia, where *Macrobrachium* spp. are also cultured with an annual production of between 15 to 20 t (Anon. 1994c). Fiji has several small-scale penaeid shrimp farms with a total annual production of around 10 t. These were based, until recently, on post-larvae imported from Australia but there are now increasing quantities of post-larvae coming from local hatcheries (Anon. 1994b).

As with spiny lobster fisheries, mangrove crab fisheries will probably continue to be small-scale enterprises, given that most production in the South Pacific region is probably from collection rather than trapping. Live lobsters and crabs command much better prices and there may be potential for some small export fisheries to parts of Asia to cater for specialized high-quality, high-value markets for live seafood. This has already been demonstrated from the Melanesian islands for selected reef fish species, and trial air-shipments of live spiny lobster have been sent from PNG to Hong Kong (Richards 1993). However, local prices are often sufficiently high that export is not an economically attractive option, particularly in areas where overseas tourists are common.

Shrimps, mudcrabs, coconut crabs and spiny lobsters are the most commercially valuable crustaceans in the South Pacific. Other edible resources such as mud lobsters and land crabs have some local market value but are not in demand worldwide. However, large immigrant Pacific island communities are found in New Zealand, Hawaii, Guam and Australia, and can generate considerable demand for traditional delicacies, including items such as fish and shellfish. For example, Schiller (1989) estimated that the annual export of coconut crabs from Niue in 8 months between 1987 and 1988 amounted to between 3200 and 5900 animals. All these crabs left Niue as passenger luggage en route to New Zealand, where the majority of Niueans now live. There is enormous demand for coconut crab in Asia also, and stocks of this species in every part of the Pacific can now be considered depauperate, if not endangered. Other resources such as pandalid shrimps have attracted initial government enthusiasm for their development, but the resource has failed to meet expectations and the only commercial fisheries, in Hawaii, have ceased production. Similarly, it is likely that fisheries on deep water geryonid crabs are not economically feasible in the region and, if they do become so in future, Pacific island governments would be wise to have management measures in place for what promise to be fisheries with a low sustainable exploitation rate (Adams & Dalzell in press).

Coastal fisheries production

Having reviewed the various sources of coastal fisheries production we attempt here to estimate the volume of landings from various coastal fisheries and to estimate the value of this production. As far as possible, estimates of landings have been taken from annual reports, technical reports or other papers published between 1989 and 1994. Information on landings prior to 1989 was used in some instances where data from recent landings were not available. Most countries have some estimate of commercial fisheries production and these are usually published in some form of technical document. Furthermore, estimates of total fisheries pro-

duction for most countries are included in the FAO Yearbook of Fisheries Statistics. These figures range in quality and accuracy and may include landings from offshore tuna fisheries. Accurate estimates of subsistence fisheries production were usually not available. In some cases subsistence fisheries production had to be estimated from nutritional data as the product of *per capita* food consumption and population size. In the few instances where no estimate of national subsistence fisheries production was available at all (PNG, Tuvalu, Western Samoa), then the FAO figure was used (FAO 1994) as a nominal total, and subsistence production estimated as the difference when known commercial landings were subtracted. The various sources used for each country are listed in Table 25. Many of the sources used here fall in to the “grey literature” category, i.e. departmental technical memos, unpublished manuscripts and in some cases simply personal communications from individuals who have access to production records. The annual fisheries production summaries for each Pacific island country from the

Table 25: Sources of data used to estimate the volume and value of national subsistence and commercial coastal fisheries production for the South Pacific Islands.

Country	Data sources and notes
American Samoa	Commercial and subsistence production from Hamm et al. 1994 and Craig et al. 1993.
Cook Islands	Subsistence catch based on nutritional data in Mategna-Smith et al in press and J. Dashwood (SPC Fish. Prog. pers. comm.). Commercial finfish production in 1988 from Zoutendyk & Paulo 1989. Trochus landings from Nash et al. 1995 and pearl shell production from Cook Is unpublished records
Federated States of Micronesia	Subsistence catch in based on nutritional information in Elymore et al. 1989. Commercial landings adapted from Smith 1992a
Fiji	Subsistence and commercial production based on Anon. 1994b
French Polynesia	Subsistence and commercial production from Anon. 1994c
Guam	Commercial and subsistence production from Hamm et al. 1992. 1994
Kiribati	Commercial and subsistence production from Anon. 1991c
Marshall Islands	Commercial catch figures from Smith 1992b, subsistence production based on nutritional data in Anon 1991e
Nauru	Subsistence and commercial production from Dalzell & Debaio 1994
New Caledonia	Subsistence and commercial production from Anon. 1994a
Niue	Subsistence and commercial catches based on Dalzell et al 1993
Northern Marianas	Commercial fisheries production in Hamm et al. 1994, Subsistence fisheries production based on nutritional data for urban Micronesians in Elymore et al. 1989
Palau	Commercial and subsistence production from Anon. 1993b
Papua New Guinea	Total coastal fisheries production from FAO 1994, commercial landings from Anon. 1989
Pitcairn Island	Subsistence fisheries production based on average monthly numbers of fish reported between 1973 and 1992 in Pitcairn Miscellany, the island's newsletter
Solomon Islands	Subsistence and commercial production figures from Skewes 1990 and Richards et al. 1994. Note about 2,500 t yr^{-1} of bait fish (mainly anchovies and sprats) also caught in coastal lagoons by domestic pole-and-line fleet Nichols & Rawlinson 1990
Tokelau	Subsistence fisheries production based on observations by Hooper 1983
Tonga	Total coastal fisheries production from Anon 1991f, commercial finfish production in Munro 1990 and commercial lobster production in Zann 1985 and Prescott 1990
Tuvalu	Total coastal fisheries production from FAO 1994. Commercial fisheries production from Patiale & Dalzell 1990 and unpublished
Vanuatu	Total coastal fisheries production from David & Cillauren 1989, commercial fisheries production in Anon. 1991g, Anon 1992b and Anon. 1992d
Wallis & Futuna	Total coastal fisheries production from Anon. 1994e and commercial fisheries production from A. Ledreau pers. comm.
Western Samoa	Total coastal fisheries production from FAO 1994 and Zann et al. 1991. commercial fisheries production on Upolu from Helm 1992

Table 26: Mean annual coastal fisheries production in the South Pacific 1989 — 94.

Catch	Weight (t)	Value (US\$)
Commercial reef and deep-slope fish	10 414	27,258 964
Commercial coastal pelagic species	4252	14,028 423
Commercial estuarine fish	1688	3,417 745
Commercial crustaceans	1839	14,250 593
Commercial bêche-de-mer (processed to 10% fresh wt)	1604	10,070 966
Other echinoderms	30	31 087
Commercial trochus, green snail, pearl-shell	2495	10,995 145
Other molluscs	2003	1,747 741
Total commercial catch	24 325	81,800 664
Total subsistence catch	83 914	179,914 623
Total coastal fisheries catch	108 239	261,715 287

sources listed in Table 25 are given in Appendix 1 (p. 510). These data sources were used to compile the annual catch volumes and values for subsistence and commercial landings in each of the countries and territories of the region and these are included in Table 25.

A summary of the totals in each sector is given in Table 26 and the subsistence and commercial catches by country are summarized in Table 27. For some countries such as Fiji, New Caledonia and French Polynesia, the annual catch refers to the most recent annual report of fisheries statistics, usually 1993 or 1994. For most other countries the production figures are a mix of information on various resources from various years between 1989 and 1994 as noted in Table 25. The total coastal fisheries production in the South Pacific during the early 1990s is

Table 27: Mean annual subsistence and commercial production from coastal fisheries for the countries and territories of the South Pacific between 1989 and 1994.

Country	Subsistence fisheries production (t)	Nominal Value (US\$)	Commercial fisheries production (t)	Value (US\$)	Total fisheries production(t)	Nominal Value(US\$)
American Samoa	215	814 238	52	178 762	267	993 000
Cook Islands	858	3,047 683	124	314 761	982	3,362 444
Federated States of Micronesia	6243	11,237 400	637	1,483 544	6880	12,720 944
Fiji	16 600	45,767 395	6653	18,340 043	23 253	64,107 438
French Polynesia	3691	14,468 720	2352	14,371 469	6043	28,840 189
Guam	472	1,935 632	118	456 413	591	2,392 045
Kiribati	9084	13,373 667	3240	4,770 000	12 324	18,143 667
Marshall Islands	2000	3,103 213	369	714 504	2369	3,817 717
Nauru	98	219 600	279	628 605	376	848 205
New Caledonia	2500	9,000 000	981	3,968 650	3481	12,968 650
Niue	103	471 504	12	54 720	115	526 224
Northern Marianas	2825	12,280 427	141	613 804	2966	12,894 231
Palau	750	1,805 192	736	2,410 059	1485	4,215 251
Papua New Guinea	20 588	41,176 000	4966	22,096 908	25 554	63,272 908
Pitcairn Islands	8	16 000	0	0	8	16 000
Solomon Islands	10 000	8,405 660	1150	4,343 811	11 150	12,749 471
Tokelau	191	104 509	0	0	191	104 509
Tonga	933	1,901 208	1429	2,806 641	2362	4,707 849
Tuvalu	807	657 781	120	97 811	927	755 592
Vanuatu	2045	1,953 360	467	1,514 364	2512	3,467 724
Wallis & Futuna	621	3,105 360	296	2,316 729	917	5,422 089
Western Samoa	3281	5,070 074	208	319 066	3489	5,389 140
Total	83 914	179,914 623	24 327	81,800 664	108 241	261,715 287

estimated to be about 108 000 tyr^{-1} , worth US\$261,715 287 (Table 26). The population of the South Pacific region is about 6,500 000 people giving an annual per capita coastal production of 16.6 kg. If the large inland population of 2,700 000 in PNG is discounted then the annual per-capita production is about 28.4 kg. This coastal fisheries production estimate is not equivalent to fish consumption, since it does not take account of canned fish imports, tuna consumption, or exports. Depending on the island group, actual seafood consumption will tend to be at least 25% higher than domestic coastal fishery production, because of the status of canned mackerel as a non-perishable rural staple, and much higher than this in highly developed, densely-populated islands like Guam that have limited domestic catches.

In the South Pacific 80% of the catch from inshore fisheries, whether from reefs, estuaries or fresh water, is estimated to be taken for subsistence purposes with the remainder (20%) being directed to commercial markets. Most of the commercial finfish goes to domestic markets, and most of the commercial invertebrates are exported. Subsistence fisheries production was estimated to be about 83 900 tyr^{-1} , and would have been worth US\$179,900 000 if sold in domestic markets. In most instances, the value of the subsistence catch is based on the average figure for commercial fish landings. Commercial fisheries landings amount to about 24300 tyr^{-1} , worth US\$81 800 000. Not included in this total is the production from aquaculture which, among other items, would add another US\$78,000 000 from the production 2200 kg of pearls from French Polynesia in 1993 and US\$7,280 000 from shrimp farming in New Caledonia during the same year.

Discussion

In this contribution we have tried to document the characteristics of fisheries in the Coastal Zone of the South Pacific islands, on reefs, deep reef slopes, the pelagic zone, and estuaries. We have made some mention of freshwater production which is significant in both Papua New Guinea and Fiji, by the volume of finfish caught and, especially in Fiji, by the volume of molluscs harvested. In both locations most of the freshwater finfish catch comprises exotic species such as tilapia and common carp (*Cyprinus carpio*) with respect to the coastal fisheries resources, our focus has been largely on the fisheries rather than on the biology and ecology of the target species. However, relevant biological literature for work accomplished in the Pacific is also reviewed. Many of these resources are common to neighbouring Southeast Asia and as far to the west as East Africa. A few extend across the Pacific to the western coast of Central America, while others have a circumtropical distribution. However, we have generally omitted references to studies outside of the South Pacific in order to document fully the work conducted on coastal species in the region. Information on the comparative biology of coastal fish and invertebrate species within and outside the region is given in many of the reviews contained in Wright & Hill (1993) and the various literature cited therein. Similarly, the reviews of reef fish biology in Sale (1991), Polovina & Ralston (1987) and Polunin & Roberts (1996) take a global perspective and contain comparative information on fish populations and species on Atlanto-Caribbean, Indian Ocean and Pacific reefs and reef slopes.

Most of the countries of the South Pacific are by definition developing economies, which implies low industrial output, a small proportion of the population involved in manufacturing and, in some countries, drift to urban centres of landless poor who are obliged to fish for income and sustenance. The amount of fisheries research conducted in most locations is

minimal and the administrations of most South Pacific countries are not well versed in modern methods of fishery management (Adams & Dalzell in press). It will be clear from this paper that, with the possible exception of PNG, the focus of most fisheries research in the region is in developed countries, or in overseas territories where economies are supported by metropolitan administrations. Thus much of the work quoted here has been conducted in northern Australia, New Caledonia, Hawaii, French Polynesia and Guam. All these are locations where there has been considerable effort expended on marine biological research, especially on coral reef species, although much of it is not directly applicable to fisheries stock assessment and management. Unfortunately, it is the poorer states in the region, with few economic opportunities and populations increasing at between 2 — 3% per year, that tend to develop unsustainable fisheries, and that urgently require improved quantitative information about the status of their coastal fisheries (Adams et al. 1995).

The present state of knowledge about most of the coastal fisheries resources represents a fraction of what is known about the same or similar resources in neighbouring South and Southeast Asia. However, the accumulation of information on the biology of coastal fisheries resources in the South Pacific has accelerated, particularly over the past 20 yr. The factors responsible for this accumulation include a greater awareness of the importance of coastal fisheries resources, improved recruitment and training of national fisheries biologists in some countries, introduction of new techniques for studying tropical fish populations and the realization that some old established techniques used in temperate water fisheries are also applicable in the tropics. The advances made during the past 20 yr in electronic micro-processor technology have made computers readily available to fisheries biologists throughout the region. Apart from the convenience of being able to manage large databases on a daily basis, a whole range of different fisheries stock assessment applications has been developed by several institutions. Although not designed exclusively for tropical fisheries, the motivation to develop these programs has often arisen from experience in trying to analyze data from tropical fisheries. Conventional approaches to estimating population parameters through age and growth data developed for temperate fisheries often have not been applicable in the tropics.

This problem led initially to development of length-based stock assessment methodologies that were in turn incorporated into many of the computer applications. The basis for several of these routines was the estimation of growth parameters from length frequency data and subsequent estimation of other life history information such as mortality rates, recruitment and relative or absolute yields. Such algorithms are based on the premise that growth of a cohort or year class can be traced through successive length frequencies, usually monthly samples, and that growth curves can be fitted to the length data through some iterative routine given seeded values of the curve parameters. Many of these length based-methods are included in Pauly & Morgan (1987) and are reviewed by Rosenberg & Beddington (1988). Useful though length-based methods are, they have not received universal acclaim and have frequently attracted much justified criticism when applied without taking their constraints into account (see for example Hilborn & Walters 1992). One major problem has been the inability of several of these programs to calculate confidence limits around the estimates that they generate. However, length-based methods have proved effective with short-lived species, particularly the small pelagic fishes used for tuna bait. These specialized fisheries software packages allied to commercial software developments in database, spreadsheet and graphical programs have made a significant contribution to the expansion of information on coastal stocks in the South Pacific.

Another important development in tropical fisheries science that had an influence on fish stock assessment in the South Pacific region was the appreciation that the microstructural

increments observed in fish otoliths were, in most cases, laid down on a daily basis and so provided a means of ageing fish when annuli were not discernable (Campana & Nielson 1985). Various examples are given in the previous sections of fishes aged through otolith microstructure. In all but the smallest species, the otoliths must be sectioned or ground to the required thickness and polished to display the growth surfaces by transmitted light, and further treatment such as acid etching and vacuum coating with gold are required for scanning electron microscopy. Where the fish have reached a considerable age and the otoliths are dense and crystalline, the record of growth is incomplete leading to the method proposed by Ralston (1981) where incomplete counts are used to interpolate mathematically the entire growth record. The various studies of ageing reef, deep slope and small pelagic fishes using otolith microstructure have been documented above.

In temperate water species the distinct seasons during the year are reflected in the growth record of fishes in the form of yearly annuli on scales, bones and the otoliths. Ageing of fishes is therefore relatively easy and fisheries administrations in Europe and the USA routinely age many tens of thousands of fish each year to determine the age structure of the population. Ageing fish through observations of the yearly increments on the otoliths and scales has not been seriously attempted in many locations in the region, usually due to the assumption that tropical species do not possess yearly annular marks. However, an increasing body of evidence is emerging to suggest that yearly annuli are present in otoliths and scales of tropical fishes and these have been validated from New Caledonia (Loubens 1980, Coutures 1994), the GBR (Walker 1975, McPherson 1992, McPherson & Squire 1992) and from Hawaii (Morales-Nin & Ralston 1990). While these are all on the subtropical margins of the South Pacific, there is also evidence that yearly annuli are detectable in fishes such as nemipterid breams (Chapau 1993), emperors (Dalzell et al. 1992) and snappers (Dalzell unpubl. data) in near-equatorial locations. Current research in northern PNG is in the process of validating the periodicity of annular marks in some of these species (Chapau pers. comm.).

Hillbom & Walters (1992) state that age estimation is the most important information obtained from sampling fish catches and in this review we have narrowed our focus to those studies concerned mostly with age and allied parameter estimation such as mortality rates. Other aspects of life history, such as reproductive biology, food and feeding behaviour, have not received much attention and information on these for most of the species and resources discussed here can be found in Polovina & Ralston (1987), Sale (1991) and Wright & Hill (1993). If ageing of many of the coastal fishes in the Pacific is achievable through the use of long established simple techniques for reading yearly annuli then this will be a major step forward for coastal finfish stock assessment in the region. However, one other major area of ignorance in the fisheries biology of most of the coastal fisheries in the South Pacific (and indeed in most of the other oceans) is the relationship between stock and recruitment. This is fundamental when deciding the allowable exploitation rate for a stock of marine organisms.

This question is particularly pertinent to the commercial invertebrate fisheries of the region, especially giant clam, green snail, pearl oyster and coconut crab, where capture is straightforward and populations can be depleted to the point of extinction. As stated earlier, there are a number of examples of pearl oyster populations in the South Pacific that were severely depleted between 50 and 100 years ago and have not recovered. The present boom in *bêche-de-mer* processing means that holothurian populations are being reduced markedly in inshore waters, with little understanding of the recruitment processes or recovery rates, although most *bêche-de-mer* species and trochus are probably proof against ultimate extinction given their cosmopolitan nature and cryptic habits. Other possible examples of recruitment over-fishing include the Torres Strait-Yule Island lobster population and deep-slope fish stocks

on seamounts. The failure of the annual spawning migration to Yule Island following trawling on previous migrating stocks led to a ban on catching lobsters in trawls in 1984. The ban has been maintained since then and the Yule Island fishery has recovered. The highly concentrated populations of deep-slope snappers and groupers on seamounts can be fished down very rapidly without the possibility of recovery from new recruitment. The Tongan deep-slope fishery rotates between different seamounts, leaving areas that have been heavily exploited to recover (Latu & Tulua 1991) while seamounts that have been left unexploited have accumulated fishable populations. The process of recruitment of snappers and groupers to seamounts is poorly understood. Some seamounts when depleted do not recover within a few years such as the Haputo Pinnacle at Guam, where deep-slope stocks were fished to virtual extinction in the late 1960s (Ikehara et al. 1970) and have never recovered.

Investigation of stock and recruitment for coastal fish populations in the South Pacific islands has been confined to small pelagic species, namely *Encrasicholina heteroloba* in Palau (Muller 1976) and *E. heteroloba*, *E. devisi* and *Spratelloides gracilis* in PNG (Dalzell 1984a). Both authors attempted to fit two basic stock and recruitment models developed by Ricker (1954) and Beverton & Holt (1957) to data generated by bait fisheries in these two locations. Both authors found that although these simple models would explain some of the variation in recruitment with respect to parental stock biomass, other factors such as rainfall and standing stock biomass of other species also influenced recruitment (Muller 1976, Dalzell 1984a, b). Recruitment of coral reef species has attracted a great deal of interest, mainly from ecologists, and several relatively long-term investigations have been conducted on reef fish recruitment on the GBR. Much of this work has been conducted on small economically unimportant species, such as damselfishes and small wrasses, that can be easily observed underwater. Recruitment to a particular reef with respect to spawning stock biomass may be confounded by the planktonic larval stages of most reef species, which means that they may be dispersed far from their natal reef (Doherty 1991). This has led to one school of thought that believes that biomass densities of fish on coral reefs are mainly a function of recruitment and that post-recruitment processes are not of any great importance (Doherty 1991). Conversely, other workers have acknowledged the impact of recruitment on reef fish populations but also regard post-recruitment processes as equally important in determining abundance (Jones 1993). From a management perspective it is unlikely that for Pacific island multispecies reef fisheries recruitment processes will ever be sufficiently understood to be incorporated into detailed management initiatives.

In giant clams, it is likely that there is no smooth relationship between stock and recruitment, but rather an abrupt cut-off below a certain parental density. Giant clams maximize fertilization success by spawning in synchrony in response to current-borne pheromones, thus there is likely to be a certain population density below which synchronous spawning becomes unlikely and fertilization becomes rare. However, even in dense natural populations of giant clams producing, presumably, enormous quantities of fertilized eggs, recruitment is very sporadic and appears to depend far more on environmental conditions and available settlement sites than on parental stock biomass (Adams et al. 1988, Pearson & Munro 1992).

One area where a great deal more work needs to be done is on the “catchment areas” for recruitment of different species and communities. Some species, such as trochus and giant clams, have short-lived larvae and are probably locally recruited, at the level of the individual reef. The restricted natural distribution of trochus, despite its proven ability to become established on almost every reef to which it has been introduced, is an indication that natural long-distance transport of trochus larvae is not common. Yet the larvae of other species may be carried in the plankton from country to country and even from region to region before

settlement. Arising from observations on the rate of recovery of damaged reefs, there are indications that certain Western Australian corals and reef fish populations may be dependent on Indonesian sources for replenishment (D. Williams, Australian Institute of Marine Science, pers. comm.). The parameters affecting recruitment will obviously have a large bearing on the approach to managing different fisheries — there may be little point in trying to maintain fishable trochus stocks through the medium of one large reserve, but rather through a series of small reserves on the local scale. There may be little point in maintaining a reserve at all if it cannot be placed upstream of a target (“larval sink”) area. For coastal species with longer-lived larvae it may be necessary for management to be coordinated on a national, or even regional, basis if it is to be effective.

It will be clear from the data presented in this review that catch rates of artisanal fishermen in the coastal zones of the South Pacific islands are very low, usually of the order of a few kilogrammes for several man-hours of work. Only the trawl fishery in the Gulf of Papua catches fish in amounts comparable to other tropical shelf fisheries in Asia but retains only the shrimp element of the catch, dumping the greater finfish component back into the sea. Catches of bait fish by the other industrial-scale fishery in the region, the pole-and-line tuna fishery, are modest, amounting to between 100 and 200 kg/night¹. However, even with limited small-scale fishing gears, people can have a severe impact on fish and invertebrate populations, where numbers of fishers are sufficient to generate high fishing mortalities. Russ (1991) has noted that even when populations are not driven to extinction, the effects of fishing pressure may modify the behaviour as a response to heavy fishing pressure in shallow reef areas. Russ cites as an example parrotfish, normally associated with the lagoon and reef flat in the Philippines, moving away from their preferred habitat down the reef slope into deeper waters to escape fishing pressure. In the Pacific, Johannes (1981) states that following the widespread spear fishing at night of *Bolbometopon muricatum* in Palau, this species sought dormitories away from the shallow reef flat on the deep reef slope. Dalzell & Debao (1994) report that fishermen on Nauru believe that spear fishing has had a similar effect on shallow reef populations of snappers and groupers, which have retreated into deeper waters through constant fishing by SCUBA equipped spear fishermen. Furthermore, Nauruan fishermen report that spear fishing has markedly reduced snapper and grouper populations and that large reef snappers and groupers are seldom seen. The decline in catches from reefs in the lagoon of Woleai Atoll following the widespread introduction of underwater spear fishing prompted a ban on this fishing method (Smith & Dalzell 1993). Spear fishing is not conducted with SCUBA gear at Woleai but fishermen equipped only with goggles can be highly efficient at reducing fish populations on reefs.

New types of fishing gear may be introduced to an island and rapidly become very popular, so much so that fishing effort rapidly increases but without sufficient documentation to assess the effects on reef and lagoon fish populations except at a gross level. Yeeting & Wright (1989) review such a development in Tarawa Atoll, Kiribati, during the 1970s and 1980s, but were only able to make fairly crude analyses based on collective catch and effort. Fishermen in Kiribati have become concerned about the decline in bonefish (*Albula glossodonta*) catches. This has occurred over the period of the expansion in gill net fishing but is also confounded by the construction of causeways between the atoll islands that have had a deleterious effect on the spawning migrations of this species. Whether this decline in stocks is due chiefly to over-fishing or to environmental effects through causeway construction is unknown, although recent data on the bonefish stocks certainly suggest that survival of this species in Tarawa Lagoon is at a critical stage with no recently observed spawning migrations (Anon. 1993d). Management under these circumstances is particularly difficult, given that bonefish is

traditional subsistence food on Tarawa, and there is little information to judge whether fishing or causeway construction has the greatest negative influence on bonefish populations.

The population of the South Pacific presently amounts to around 6.5 million people, 62% of those living in PNG. Of the 4 million people in PNG, only one-quarter of the population lives on the coast. The total coastal population of the region is therefore approximately 3.25 million people, equivalent to the population of a medium sized city in Europe or the USA, but spread over an area of 29 million km² of ocean. Most of the countries and territories of the South Pacific are thus heavily dependent on aid to maintain their economies. The typical island state is small and it has few natural resources. Trade among islands is also limited because what one island can offer, namely the products of subsistence farming and fishing, can be found on most other islands. Islands that produce cocoa, palm oil and copra are competing against much larger producers elsewhere in the tropics. Some manufacturing enterprises do exist but are small and generally serve limited domestic markets. Furthermore, imports of raw material tend to be costly because relatively small quantities have to be shipped over long distances.

Probably the greatest economic potential for many of the South Pacific islands, particularly those with limited natural resources, is tourism (Anon. 1991d). In some countries such as Fiji, Vanuatu, and parts of Micronesia, tourism is a major source of revenue and employment. Other countries in the region are trying to develop a better tourist industry infrastructure and increase earnings from this sector of the economy. The growth in the tourist trade may also offer greater potential for coastal fishermen as this will provide an additional market for their products and possibly a chance to demand a higher price than may be realized by domestic markets. However, the negative aspects of this growth are that quality fish and invertebrates may be channelled in increasing volumes away from domestic markets, and demand for specialist products may lead to large-scale stock depletion. A good example is Vanuatu, which receives about 45 000 tourist visitors per year. Among the attractions offered to visitors are gourmet dining on local produce such as flying-fox, deep-slope fishes and coconut crabs. The coconut crab, in particular, is one of the main items on the menus of restaurants catering for tourists. The downturn in other income-earning opportunities in rural areas, such as copra, has led to an increase in the harvesting of coconut crabs in Vanuatu, to the point where concern about localized extinctions led to an Australian funded research project to gather management information (Brown & Fielder 1991).

The other major influences on coastal fisheries resources and future fisheries development in the South Pacific are likely to come from neighbouring Southeast and Northeast Asia. Already, the majority of mother-of-pearl is sold to markets in Japan and Korea, while the Chinese have established a virtual monopoly on the buying of *bêche-de-mer*. While the coastal fisheries of Japan are highly regulated and managed, this is not entirely true of the countries of Southeast Asia, where combinations of high population growth and in some cases poverty, have created large artisanal fisheries that continue to cater for a growing demand for fish (Pauly 1989). Part of this demand is for high-quality reef fish and, as discussed previously, this has generated the development of live reef fish fisheries in a number of countries in the west of the South Pacific. Many of the countries of the region still have traditional systems of marine tenure and regulation of coastal fisheries, although this tends to break down where population pressure is very high and urbanization increases. However, Crocombe (1994) suggests that one of the major challenges to fisheries management and marine tenure will be the increasing influence of Northeast and Southeast Asia. If the pressure from Asia to share in the exploitation of the region's coastal resources increases, this is bound to cause conflict with traditional tenure

systems and may create serious political problems for the countries of the region.

Fisheries development initiatives in the South Pacific over the past 50 years have sought to improve fishermen's incomes by improving catch rates, identifying more lucrative markets and increasing the value of the landed catch through teaching better post-harvest techniques. Unfortunately, very few development initiatives for an export-oriented capture fisheries in the coastal zone have had any success. One typical example of this process was the establishment of fisheries on deep reef slope stocks, where success was very short-lived in most areas where it was tried. Hand-line catch rates of snappers and groupers of the deep-slope are on average two to three times greater than the equivalent effort spent in shallow reef fishing (Table 5, p. 418), and might be as high as ten times on virgin stocks. As the deep-slope fisheries developed, it was clear that domestic market alone would not support these fisheries. This led to the search for more lucrative markets overseas in Japan, Hawaii, Australia and New Zealand. Hawaii in particular was the marketing focus of the two biggest deep-slope fisheries in the region, Fiji and Tonga, and the opening of this market led in turn to better handling and preservation of fish to realize the best prices. Because this was an auction market, with a limited capacity, Fiji and Tonga exporters found themselves having to compete against each other.

The negative side of the development of deep-slope fisheries in the South Pacific was that they demonstrated most of the mistakes commonly associated with fisheries development in the region. The catch rates encountered on fishing virgin stocks were often used by fishermen to compute economic returns from fishing for deep-slope species although catch rates at MSY are likely to be one-third to one-half of those at the start. The products of deep-slope fishing, large snappers and groupers, are not the most favoured fish of Pacific islanders, who prefer the smaller more pungently flavoured shallow reef fishes to the more delicately flavoured species from the deep reef slope. The development of the deep-slope fisheries in locations like Tonga and American Samoa was also driven in part by easy credit and soft loans to fishermen for purchasing fishing dories (Itano 1991, Latu & Tulua 1991), with the intention of stimulating expansion of the fishery before the true limits of productivity were known. These fisheries then became over-capitalized, with excessive numbers of vessels competing for a shrinking resource, with the inevitable result that fishermen were forced to default on loan repayments and many vessels turned to other activities (such as, in Fiji, harvesting sea-cucumbers) or simply ceased operations. Similarities with patterns of fisheries development elsewhere are strong (Smith 1994).

As discussed earlier, the deep-slope fisheries have declined in favour of medium-scale fisheries for the larger tuna species caught and exported, usually fresh, to Japan and Hawaii for the lucrative sashimi trade. However, the experiences of developing the Overseas markets for unfrozen deep-slope fishes were valuable when establishing similar markets for unfrozen large pelagic species. Commercial finfishery development initiatives in the region, particularly export initiatives, are likely to continue to turn towards oceanic pelagic stocks rather than coastal fisheries because of the much larger unexploited resource base. The successful fisheries in Fiji, and elsewhere in the region, are proving the viability of adapting monofilament long-line gear to small and medium sized, locally based, fishing vessels and the high-quality fish produced by these South Pacific fisheries appears to be maintaining its market share in Japan and the USA in the face of competition from the large number of small Chinese long-liners now operating in the north of Micronesia. The main commercial limiting factor is transporting the catch by air from the Pacific islands to overseas markets. Some countries such as Palau, French Polynesia, New Caledonia, Fiji, Federated States of Micronesia and Tonga

have direct air links with Japan and Hawaii. Other countries where pelagic fisheries are developing will have to try to find some way of accessing these overseas markets and take advantage of the better returns on landings.

For the smaller resource-poor countries of the Pacific, *bêche-de-mer* and mother-of-pearl shell fisheries offer only reducing potential for generating income, given the lack of sustainability as a management objective in most areas. Shallow-water invertebrate fisheries are easily over-exploited and any income is generally considered to be “windfall” cash for village families rather than a basis for permanent investment. These fisheries are also strongly influenced by external market forces beyond the control of national economies and could easily go into price decline through decreased demand, as happened with *trochus* in the late 1950s, and again in 1991. Management of sessile invertebrate harvests, particularly in smaller countries, would have to be severely limited to maintain sustainable yields. Present management strategies for *trochus* in the former US Trust Territories of Micronesia and the Cook Islands are based on very short harvest seasons with quotas dictated by pre-season stock assessments. If a large part of the population expects to share in the revenues from resources such as *trochus* then limited seasons with short pulses of intensive effort may be the only way to effectively manage these stocks. It has also been suggested for *bêche-de-mer* (R. Richmond, University of Guam, pers. comm.) that producers form a cartel and rotate harvests between islands each year, giving depleted stocks the chance to recover in those islands not participating in an annual harvest, or even that *trochus* and *bêche-de-mer* harvest periods be opened alternately to provide a similar recovery period (P. Lokani, Department of Fisheries and Marine Resources, PNG, pers. comm.).

The estimates of fisheries production in Tables 26 and 27 are the most accurate that can be obtained at present and area “snap-shot” of fisheries production in the region towards the end of the 20th century, following 50 years of assisted development. Some countries, such as Fiji and the American territories, have very well developed monitoring and survey programmes for estimating commercial fish production. However, in almost all countries, the estimates of subsistence fisheries production must be computed empirically. This has been accomplished from dietary data where information has been recorded directly on *per capita* consumption of fish or, more commonly, on the frequency of fish and shellfish consumption.

Such information is collected during national nutritional surveys and epidemiological surveys periodically carried out by government health departments. Such approaches are likely to be the only practical and cost-effective method of determining subsistence catches. Advances have been made in the culture of commercial sessile invertebrates but other than the potential indicated by the successful deployment of spat collectors for pearl oysters in the Cook Islands and French Polynesia, there are no demonstrable examples of successful replenishment of depleted populations by maricultured stocks. This does not necessarily mean that all experiments have failed, but that the stock assessments used to date have not been sensitive enough to detect differences between natural and “enhanced” recruitment, and this was the main reason why Palau has discontinued *trochus* re-seeding experiments (N. Idechong, Marine Resources Division, Palau, pers. comm.). Further research and development is required to determine if re-seeding is feasible and cost-effective, especially for those species that do not have particularly low or erratic recruitment. It is generally accepted that recruitment is a major bottleneck in the rehabilitation of endangered giant clam populations, but resources like *trochus* are much less fragile, and replenishment is probably best accomplished through fishery management. Such pure research may be outside the financial and manpower resource priorities of most Pacific island fisheries departments and be more appropriately carried out by universities.

Hatchery reef re-seeding experiments may even contribute to unsustainable harvesting by suggesting that any current damage to stocks can be quickly repaired in the future. It should be recognized that, at present, there is no universal panacea for over-fishing (except the difficult decision to reduce either effort or catch). However, it has been noted (M. Amos, Fisheries Department, Vanuatu, pers. comm.) that an active hatchery-based re-seeding programme can have positive sociological benefits when persuading coastal communities to place controls on fishing, particularly if that control is in the form of a moratorium and the “re-seeded” organisms provide a reason for voluntarily avoiding fishing in a particular area.

Management and stock conservation research in the Pacific islands should continue to be focused on mechanisms of limiting total harvest volume in socially and economically feasible ways. The “traditional” approach to fisheries management that has evolved in the developed countries of the northern hemisphere involves a relatively large fisheries research and management administration containing scientists, technicians, mathematicians, fisheries managers plus all the administrative support staff that this entails. Sampling of landings at most ports is routinely conducted by the scientific staff, samples are taken from specimens for various studies, thousands of otoliths are collected for ageing and research cruises are conducted to collect unbiased estimates of CPUE and to collect further catch samples. Standing stock estimates are routinely computed from the biological data and the size of the catch for the following year or season is then estimated. The catch may then be divided up between different countries based on whether the stock straddles several international boundaries or on political agreements such as the European Union Fisheries Policy.

By contrast, most Pacific islands have small fisheries administrations, with little or no research capacity with which to gather information required for management. Every village in a Pacific island is a potential landing site although increasing urbanization does lead to greater centralization of commercial landings. The archipelagic nature of most countries, some stretching over hundreds of kilometres of ocean, and the relatively high costs of travel mean that those fisheries scientists and technical officers that are available are restricted in their ability to collect information, most often to the capital city and to other major urban centres. An increasing number of Pacific islanders are obtaining degrees in fisheries and marine sciences but there are still very few fisheries scientists in the region, particularly in the independent states, where graduates of all disciplines are sought for higher government administration posts, or where salary levels are far more attractive in Pacific rim than Pacific island countries. External funding is sometimes available to employ expatriate scientists and technical officers, but when they return to their home countries their experience, and in some cases the information, leaves with them. The budgets available to South Pacific islands fisheries administrations are often marginal and usually insufficient for necessary equipment. Even simple observations such as counting annuli in fish otoliths require some dissecting equipment and a low magnification compound microscope costing several hundred dollars. These shortages of qualified and experienced fisheries staff coupled with limited financial resources mean that management of coastal fisheries in much of the South Pacific is based on intuition rather than on collected observations and experience. Individuals can thus have enormous influence, for good or for ill, on the management of resources over large groups of islands.

Johannes (1994) has argued that this very problem is an opportunity to seek a new paradigm for fisheries management in the South Pacific — one that is not based on the conventional approach of intensive data gathering and analysis, but based on self-reinforcing feedback systems at the local level. Johannes argues that the very limitations evident in most island fisheries departments are sufficient to make the conventional approach invalid as it is usually impossibly cost-inefficient to collect sufficient data for the results to conform to the usual

tests of significance. Instead, another approach is required where less emphasis is placed on “hard” data and more on gathering information from the fishermen who prosecute the fishery. Johannes (1994) emphasizes that data-less management is not information-less management, but rather a mechanism that pays greater attention to the information provided by fishermen on their assessment of a stock, and of the ways in which traditional and community measures were brought into play to maintain stocks. Furthermore, such an approach would permit experimentation to assess the usefulness of given measures. For example, fishing on particular reefs is routinely proscribed for a year in a certain Pacific island when a high chief dies, both as a mark of respect and to let marine resources build up for the memorial feast. Such occasions permit observations on the effectiveness of reef closures. Johannes also notes that conventional fisheries research requires data collection over long time periods before it can generate significant answers, whereas management decisions are usually required immediately, and that a trial and error approach, where errors are part of the learning process, would be more suitable in the Pacific islands context.

It is likely that management of coastal fisheries in the South Pacific will develop into an amalgam of conventional approaches, including those where data are gathered according to sampling criteria to test hypotheses, and the less data intensive approach advocated by Johannes (1994). There also needs to be greater attention given to simply describing coastal fisheries to make better comparisons within and among countries that may, in turn, give greater insights into which management approaches may work with a given fishery. The task of assembling the information for this paper revealed that there is a great deal of documented information on Pacific island fisheries but much of this is in the informal or grey literature category and not readily available to fisheries scientists in the region. There are also a large number of complete unknowns, as might be expected from a group consisting of thousands of islands, using hundreds of languages, scattered over a significant proportion of the Earth's surface.

For the large archipelagos of Melanesia, management of coastal fisheries, other than those for commercial export invertebrates, is not likely to become a pressing issue in the near future. Management intervention on some of the smaller islands and atolls of Micronesia and polynesia, however, appears to be immediately necessary or will be required in the near future as populations continue to increase. Outright collapses of coastal fish stocks may be unlikely but, as stated earlier, some of the larger slower growing species can become very vulnerable to modern gears and can be fished to extinction. The challenge for coastal fisheries management into the next century will be to maintain production from the coastal zone as both human populations and the number of people turning to fishing as a livelihood increase.

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Appendix 1: Summary of annual nominal coastal fisheries production by volume and value.

<i>Fisheries statistics</i>	American Samoa	Cook Islands	Federated States of Micronesia	Fiji	French Polynesia	Guam	Kiribati	Marshall Islands	Nauru	New Caledonia	Niue
Nominal coastal fisheries production (t)	267	982	6880	23 253.04	6042.6	590.58	12314	2369	376.46	3480.5	115.4
Nominal value of coastal fisheries production (US\$)	993 000	3,362 444	12,720 944	64,107 438	28,840 189	2,392 045	18,143 667	3,817 717	848 205	12,968 650	526 224
Commercial fisheries production (t)	51.6	124	637	6653.04	2351.6	118.18	3240	369	278.6	980.5	12
Nominal value of commercial production (US\$)	178 762	314 761	1,483 544	18,340 043	14,371 469	456 413	4,770 000	714 504	628 605	3,968 650	54 720
Subsistence fisheries production (t)	215.4	858	6243	16 600	3691	4724	9084	2000	97.86	2500	103.4
Nominal value of subsistence fisheries production (US\$)	814 238	3,047 638	11,237 400	45,767 395	14,468 720	1,935 632	13,373 667	3,103 213	219 600	9,000 000	471 504
<i>Details of commercial fisheries production</i>											
<i>Finfish</i>											
Reef & deep-slope fish (t)	8.2	1	321	2917	909	9.5	1746	173	708	567.8	3.8
Reef & deep-slope fish (US\$)	32 800	3552	577 800	8,527 578	5,454 000	58 378	2,570 000	275 784	129 885	1,769 000	17 182
Pelagic species (t)	43.1	24	198.5	955	916.5	109	690	13	207.8	3030.7	8.2
Pelagic species (US\$)	144 200	85 526	357 300	2,654 335	5,787 718	397 515	1,015 833	34 836	498 720	255 800	37 538
Estuarine species (t)				708							
Estuarine species (US\$)				1,457 745							
<i>Invertebrates</i>											
Crustaceans (t)	0.3		205	436	3.1	0.08	13			34.1	
Crustaceans (US\$)	1 762		196 444	2,693 971	77 500	520	19 139			328 700	
Bêches-de-mer (t)				334						77.7	
Bêches-de-mer (US\$)				1,998 476						614 650	
Other echinoderms (t)				30.3							
Other echinoderms (US\$)				31 087							
Mother-of-pearl molluscs (t)		99	97	73	523			183		222.5	
Mother-of-pearl molluscs (US\$)		225 683	352 000	459 638	3,052 251			403 884		935 000	
Other molluscs (t)				1 199			791			13.7	
Other molluscs (US\$)			517 213			1,165 028			65 500		

COSTAL FISHERIES IN THE PACIFIC ISLANDS

Appendix 1 (continued)

<i>Fisheries statistics</i>	Northern Marianas	Palau	Papua New Guinea	Pitcairn	Solomon Islands	Tokelau	Tonga	Tuvalu	Vanuatu	Wallis & Futuna	Western Samoa
Nominal coastal fisheries production (t)	2966.2	1485.5	25554	8	11150	191	2362	927	2512	916.5	3488.5
Nominal value of coastal fisheries production (US\$)	12,894 231	4,215 251	63,272 908	16 000	12,749 471	104 509	4,707 849	755 592	3,467 724	5,422 089 5	389 140
Commercial fisheries production(t)	141.2	735.5	4966	0	1150	0	1429	120	467	295.5	207.5
Nominal value of commercial production (US\$)	613 804	2,410 059	22,096 908	0	4,343 811	0	2,806 641	97 811	1,514 364	2,316 729	319 066
Subsistence fisheries production (t)	2825.0	750	20,588	8	10000	191	933	807	2045	621	3281
Nominal value of subsistence fisheries production (US\$)	12,280 427	1,805 192	41,176 000	16 000	8,405 660	104 509	1,901 208	657 781	1,953 360	3,105 360 5	070 074
<i>Details of commercial fisheries production</i>											
<i>Finfish</i>											
Reef & deep-slope fish(t)	65.6	492.1	1,100		87		1254	77	274	165.6	171.7
Reef & deep-slope fish (US\$)	295 353	1,184 526	2,200 200		73 129		2,399 094	62 762	453 396	910 800	263 745
Pelagic species (t)	74.6		630				150	43		110.00	15.3
Pelagic species (US\$)	309 750		1,260 000				305 660	35 049		8,250 00	23 643
Estuarine species (t)			908								
Estuarine species (US\$)			1,960 000								
<i>Invertebrates</i>											
Crustaceans (t)	1	14.4	1,240		2		25		26	3.4	20.5
Crustaceans (US\$)	8701	125 533	10,500 000				101 887		127 358	37 400	31 678
Bêches-de-mer (t)			546	622					24		
Bêches-de-mer (US\$)											
Other echinoderms (t)											
Other echinoderms (US\$)											
Mother-of-pearl molluscs (t)	229.0	470		439					143	16.5	
Mother-of-pearl molluscs (US\$)	1,100 000	1,400 000		1,675 818					847 342	543 529	
Other molluscs (t)											
Other molluscs (US\$)											

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