

## CHAPTER 5

# Small Pelagic Fishes

*Paul J. Dalzell*

### I. INTRODUCTION

The small pelagic fishes of the South Pacific islands form an important part of the total fisheries production of the region. These fishes, which generally attain a maximum weight of less than 500g, have been fished by the indigenous populations of the region as a traditional food source and, more recently, by pole-and-line tuna fishing vessels as a source of live bait. Indeed, the exploitation of these fish stocks by tuna vessels probably constitutes the only industrial scale fishery to have operated in the coastal waters of the South Pacific islands.

Investigations into the biology, population ecology and fisheries dynamics of small pelagic fishes in the South Pacific have concentrated almost exclusively on the various populations of fish captured for live bait for tuna fishing. Most studies have focused principally on the smaller of these small pelagic resources, namely anchovies and sprats, because these are the most desired species for bait. Little work has been done on the biology of the larger small pelagic species, such as of mackerels and scads, although these are important in subsistence and small scale commercial fisheries in the region. Inferences on the biology of these species in the South Pacific must necessarily be made for the most part from studies in neighbouring South-east Asia and Hawaii.

This chapter follows on two recent reviews and syntheses of information of small pelagic fisheries resources in the South Pacific (Dalzell and Lewis, 1988; 1989). These reviews are updated in this paper, particularly with respect to recent work in Solomon Islands and Australia concerning small pelagic fish resources and their relation to other coastal fisheries (see contributions in Blaber and Copeland, 1989). The characteristics of tropical small pelagic fish stocks are described along with some estimates of potential yields from the South Pacific region. Alternatives to utilisation as live bait and the expansion and management of fisheries for small pelagics as food fishes are discussed.

### II. THE SOUTH PACIFIC REGION AND SMALL PELAGIC FISH FAUNA

For the purpose of this chapter, the 'South Pacific' includes the island groups of Melanesia, Micronesia and Polynesia and does not strictly refer to locations

south of the equator (Fig. 1). The nations and territories in the region range from the large land mass of Papua New Guinea (land area = 460,000 km<sup>2</sup>) through medium-sized island groups (land area 10 to 20,000 km<sup>2</sup>) such as Fiji, Vanuatu and the Solomon Islands, to small islands or atoll clusters (land area <5,000 km<sup>2</sup>) such as Tonga, Kiribati and French Polynesia. The region extends over  $29 \times 10^6$  km<sup>2</sup>, although total land mass covers only 550,000 km<sup>2</sup>, 85 percent of which is contained within Papua New Guinea.

The term 'small pelagic fishes' refers to a diverse group of mainly planktivorous fishes that share the same habitat, the surface layers of the water column, usually above the continental shelf and in waters not exceeding 200 m in depth. The definition of small pelagic fishes in the context of the South Pacific is given by the summary in Table I. The small pelagic fishes can be defined as the clupeoids (Engraulidae, Clupeidae), scads (Carangidae), mackerels (Scombridae), fusiliers (Caesionidae), flying fish (Exocoetidae), halfbeaks (Hemiramphidae) and silversides (Atherinidae). Fishes, such as the long toms (Belonidae), and some of the scombrids, e.g. bullet tunas (*Auxis* spp.) and shark mackerel (*Grammatorcynus bicarinatus*) fall between the large and small pelagic groupings. Others in this category include some of the smaller barracudas *Sphyræna* spp. and some other carangids (*Megalaspis cordyla*, *Carangoides* spp.). Given the diversity of the definitive small pelagic species, these marginal species are not included here other than noting their presence in landings from coastal areas in the South Pacific.

The taxonomy and identification of small pelagic fishes is problematic, given the close similarities between 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*. Further, as Lewis (1990) pointed out, other genera, such as *Herklotsichthys* and *Dussumieria*, contain separate morphs which are likely to prove to be sibling species and are suggestive of fine scale habitat partitioning.

The taxonomy of the clupeoids has been stabilised to some extent by the recent 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 and Bianchi, 1984), provide reasonable accounts of the descriptions 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.

Lewis *et al.* (1983) summarised the large body of data on the occurrence and distribution of small pelagic fishes encountered in the South Pacific region from the extensive surveys of the South Pacific Commission Tuna Programme (SPCTP) during the 1970s and 1980s. Dalzell and Lewis (1988; in press)

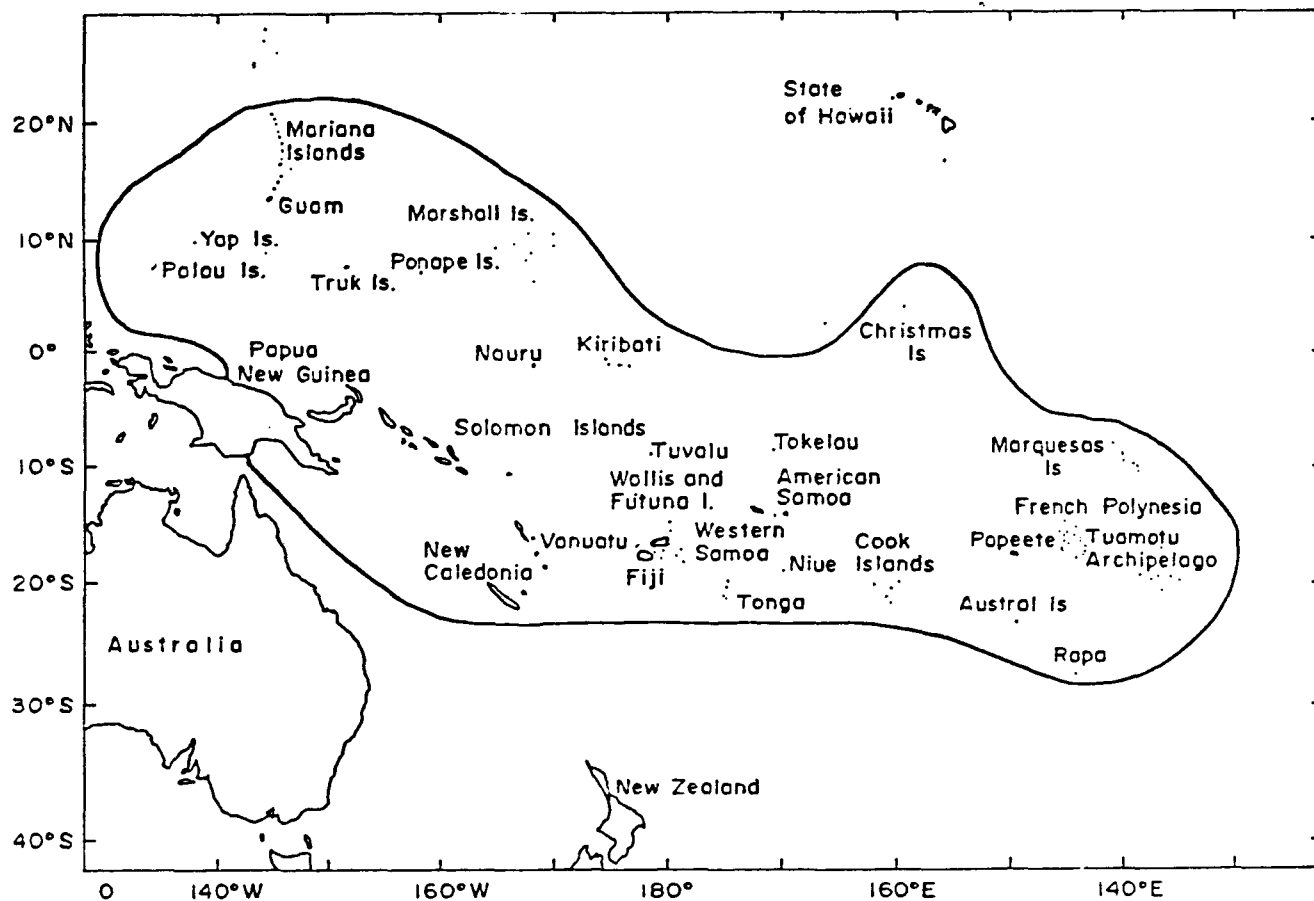


Figure 1. The South Pacific region as defined in the text.

**Table I. Definition of small pelagic fishes in the context of the South Pacific region.**

COMMON NAME	GENUS
Anchovies	<i>Encrasicholina</i> spp., <i>Stolephorus</i> spp., <i>Thryssa</i> spp., <i>Setipinna</i> spp., <i>Papuaengraulis</i> sp.
Sardines	<i>Sardinella</i> spp., <i>Amblygaster</i> spp.
Herrings	<i>Herklotsichthys</i> spp., <i>Pelona</i> spp.
Round herrings	<i>Dussumieria</i> spp.
Sprats	<i>Spratelloides</i> spp.
Mackerels	<i>Rastrelliger</i> spp.
Scads	<i>Decapterus</i> spp., <i>Selar</i> spp., <i>Selaroides</i> spp., <i>Atule</i> spp.
Fusiliers	<i>Caesio</i> spp., <i>Pterocaesio</i> spp., <i>Gymnocaesio</i> spp.
Flying-fish	<i>Hirundichthys</i> spp., <i>Cypselurus</i> spp., <i>Cheilopogon</i> spp., <i>Paraexocoetus</i> spp.
Half-beaks	<i>Hemiramphus</i> spp., <i>Hyporamphus</i> spp., <i>Oxyporamphus</i> spp.
Silversides	<i>Atherinomorus</i> spp., <i>Hypoatherina</i> spp., <i>Stenatherina</i> spp.

analysed this data and showed that there was a decline in small pelagic species abundance in a west to east direction across the South Pacific, from Palau to French Polynesia. This decline in species number is a characteristic of the region in general and has been noted by Springer (1982) to occur with other shorefishes. Allen (1975) has made a similar analysis for pomacentrid fishes in the South Pacific and has found that the level of decline was about the order of ten species per 1,000 km.

### III. LANDINGS FROM THE SOUTH PACIFIC REGION

Data on the landings of small pelagic fishes in the South Pacific region are sparse. Nominal production of small pelagic fishes for six different Pacific

islands nations are given in Table II. Information on subsistence catches, for example, is lacking thus not included. These data are not comprehensive. No information, for example, on the volume of catches of small pelagics in French Polynesia was found in the literature, although these fishes are known to be an important component of catches in this location (Bagnis *et al.*, 1974). The most accurate figures relating to small pelagic fish production concern the various live bait fisheries of the region of which three, Solomon Islands, Fiji and Kiribati, are still in operation. Another source of small pelagic production comes from the Gulf of Papua, in southern PNG, where a domestic trawl fishery for prawns catches about 14,000 tonnes (t) annually of fish including small pelagic species (see further below).

#### IV. FISHING METHODS AND GEARS

Baitfish for commercial pole-and-line tuna fishing are captured in the South Pacific by the use of a *bouke-ami* or stick-held lift net. The deployment and operation of the *bouke-ami* has been described in detail elsewhere (Dalzell, 1980; Muiyard, 1980; McCarthy, 1985). The *bouke-ami* net is mounted on the deck (Fig. 2) and can be dismantled and stowed when not in use. Tuna vessels normally employ two to three skiffs with a generator to power 1-1.5 kW submersible lamps for the purpose of aggregating the bait-fish at night. The net is hauled, leaving only a small portion immersed into which the bait mass is concentrated, prior to being loaded into the vessels bait wells manually by bucket.

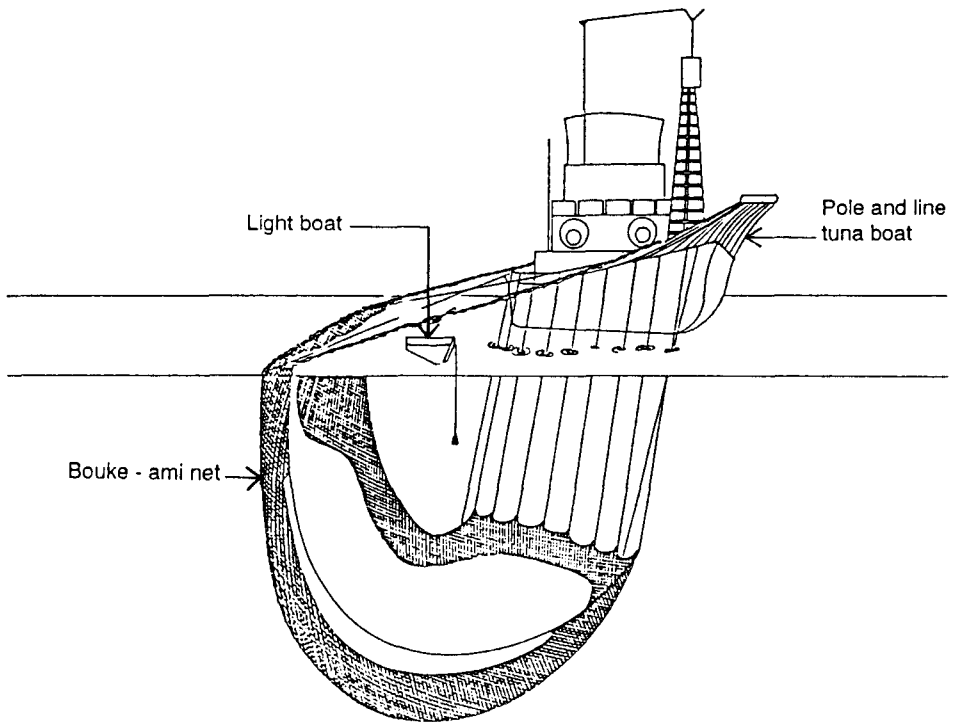
The incidental catches of sardines and anchovies in the Gulf of Papua prawn fishery are made mainly by 150 Gross Tonnage (GRT) trawlers operating two 12 fathom (foot-rope) nets. Trawling is carried out 24 hrs per day on voyages of 5-6 weeks duration. Most of the by-catch, including the sardines and anchovies, are discarded in favour of the more commercially valuable prawns.

In PNG, various small scale gears are used to capture small pelagic fishes. The gold spot herring, *Herklotsichthys quadrimaculatus*, and big eye scad, *S. crumenophthalmus*, are captured in the North Solomons Province by hand-held scoop nets (Hulo, 1985). A group of men will carefully surround a school in knee-deep water then scoop enclosed fish into baskets carried on their backs. Scoop nets are also used in the North Solomons to capture flying fishes (*ibid.*). The fishermen attract the flying fishes on a moonless night by a kerosene pressure lamp mounted on a canoe. This type of fishing is found also in the Micronesian islands of Palau (Johannes, 1983), Kiribati (Mees, 1985) and most of Polynesia where it is commonly practised. A danger of night fishing for flying fish in this manner is the risk of injury from long-toms (Belonidae) leaping from the water when they are startled or are pursuing prey. These fish have long bony beaks which can make fatal puncture wounds when they leap from the water and hit the human body (Barrs, 1982).

**Table II. Nominal annual small pelagic fisheries production (in tonnes) for various countries in the South Pacific region.**

Country	Half-beak	Flying fish	Scads	Sardines	Sprats	Herrings	Anchovies	Mackerel	Silver sides
Fiji <sup>a</sup>	99		2158	18	20	32	16	1349	98
Cooks <sup>a</sup>		43	59						
Kiribati <sup>a</sup>		964	1079						
N.Cale. <sup>b</sup>				3				86	
P.N.G. <sup>c</sup>				672			1400		
Solomons <sup>d</sup>				18	204	22	1356	55	7
Hawaii <sup>e</sup>			399						

- a. Average of nominal landings reported for the years 1985 to 1988 in FAO (1990).
- b. Average of landings reported for the years 1976 to 1986 in Anon (1988).
- c. Based on estimated volume and species composition of finfish by-catch from Gulf of Papua prawn trawl fishery (Kailola and Wilson, 1978; Watson, 1984; Dalzell, 1986).
- d. Based on species composition for Solomon Islands baitfish catch during 1982 and 1983 (Evans and Nichols, 1985) and average of total catch volume between 1979 to 1988 (Nichols and Rawlinson, 1990).
- e. From Shiota (1986).



**Figure 2. Operations of a Japanese style *bouke-ami* net used to catch small pelagic baitfish in the South Pacific. Based on FAO (1974) and Muyard (1980)**

Encircling seine nets, traditionally made from bush materials, are used in the Admiralty Islands of PNG to capture half beaks (Hemiramphidae) and other larger pelagics such as trevallies (Carangidae) and mullet (Mugilidae) (Kubohjam, 1985). In Palau, cast netting is used to capture *H. quadrimaculatus* when this species congregates in spawning aggregations, whilst the big eye scad (*S. crumenophthalmus*) is caught in gill nets (Johannes, 1981). In Guam, the congener of *S. boops*, *S. crumenophthalmus*, is captured inshore both by a variety of gill nets and by hook-and-line fishing (Amesbury *et al.*, 1986). In Guam, seasonal catches of big eye 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, the larger adult fish are caught further offshore in deeper water by using light attraction at night in conjunction with feather jigs. The big eye scad is highly prized in French Polynesia and is captured by drive-in seine netting, gill netting and jigging with feather lures on hand lines using light attraction (Bagnis *et al.*, 1974). In Hawaii, a rather more sophisticated fishery has developed for big eye scads using spotter planes to direct boats to schools for capturing the fish with surround nets (Shiota, 1986).

In Tahiti, the roundscad *Decapterus macarellus* is caught by hook-and-line using coconut pulp as bait (Bagnis *et al.*, 1974). These authors also report the capture of *D. macarellus* 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 handlines, surround seines and hoop nets. Gillett (1987) reports the successful adaptation of the Hawaiian hoop netting technique for roundscaids around the island of Niue. In the Cook Islands, roundscaids are chummed to the surface by divers who spit out clouds of chewed coconut flesh, then caught with small fishing poles (P. Cusack, South Pacific Commission, *pers. comm.*). Gill nets are used in Fiji both actively and passively to catch schools of the mackerels *Rastrelliger kanagurta* and *R. brachysoma*. Catches are highly seasonal but landings of up to 500 t/yr have been recorded (Lewis, 1985).

In Tonga and French Polynesia, structures similar in construction to Philippine fish corrals are used to capture both pelagic and demersal species. In the Philippines, such corrals are composed primarily of cane, whilst, according to Grand (1985), Polynesian fish corrals or 'parcs' are made from netting suspended from steel posts. The catches and economics of Polynesian parcs have been studied by both Grand (1985) and Morize (1985).

This survey of exploited species and fishing methods is far from exhaustive but does portray the two major features of small pelagic fishing in the South Pacific. Apart from the Hawaiian islands, small pelagic fisheries are small scale artisanal ventures. Second, 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* 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 were found in the literature.

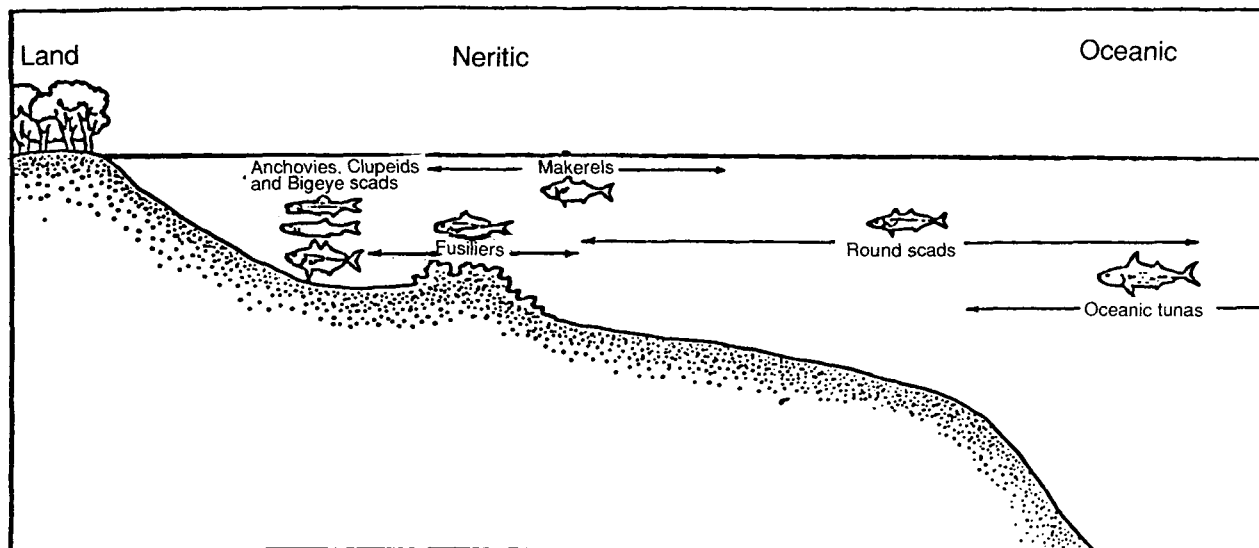
## V. BIOLOGY

### DISTRIBUTION

In the South Pacific, many of the small pelagic catches are associated with coralline areas and the waters immediately beyond the reef. The exceptions are the large high island groups of Melanesia which possess extensive river systems and estuarine areas. This is particularly true in mainland Papua New Guinea where the drainage of the central highland cordillera into the Gulf of Papua has created an extensive estuarine system along much of the South Papuan coast. The annual by-catch of the Gulf prawn fishery amounts to about 14,000 t of which 10.2 percent is comprised of anchovies (*Stolephorus* spp., *Thryssa* spp., *Setipinna* spp., and *Papuaengraulis* spp.) and a further 4.8 percent of sardines (*Sardinella* spp.). The estuarine nature of some of the sardines and other clupeids is also evident from the distribution of these species on the north Queensland coast. Williams and Capo (1990) reported that adults and juveniles of *Herklotsichthys castlenau*, *Sardinella albella* and *S. brachysoma* were present in both riverine and inshore estuarine areas of the coast. Adults of species such as *Herklotsichthys koningbergi*, *H. lippa* and *Sardinella gibbosa* are found further offshore but the juveniles are also present in inshore coastal waters.

Dalzell and Ganaden (1987) presented a generalised distribution of small pelagic fishes over the shelf area of South-east Asia (Fig. 3). Within the immediate coastal zone are found the big eye scads, anchovies, clupeids and half-beaks. The exception amongst the anchovies is *Encrasicholina punctifer*, a stenohaline species which prefers neritic and oceanic waters (Hida 1973). Dalzell (1984a) has shown that the catch per unit effort (CPUE) of *E. punctifer* in the coastal waters of PNG is inversely correlated with annual rainfall.

In the coastal lagoons of the coralline areas of the South Pacific are found the smaller gracile stolephorid anchovies, particularly *E. heteroloba* and *E. devisi*, and the sprats, *S. gracilis* and *S. delicatulus* (and *S. lewisi* in the waters of PNG and Solomon Islands). Mangrove stands often border lagoons and passages where habitats for the larger anchovies such as *Thryssa balaema*, *T. setirostris*, and larger stolephorids such as *Stolephorus indicus* and *S. waitei* are often found. These species can occasionally be taken in bait hauls, however, their appearance is usually seasonal and they do not form the basis of bait-



**Figure 3.** Schematic representation of principal small pelagic fish species in the South Pacific with respect to proximity to the coastal zone.

fisheries. The fusiliers may also be included with the small pelagic fishes of the coastal zone because their distribution is determined largely by the extent of coral cover which is generally associated with shallow (30m depth) coastal water. Studies of reef fish populations on the Australian Barrier Reef (Williams and Hatcher, 1983) and a small island fringing reef in the Philippines (Alcala and Gomez, 1985) have shown that fusiliers formed the largest component of the fish biomass in these habitats. Further, fusiliers form 75 percent of all fish captured by *muro-ami* or drive-in nets over Philippine coral reefs and account for 99 percent of all small pelagic fishes caught by this method (Dalzell *et al.*, 1990).

The mackerels (*Rastrelliger* spp.) are found further offshore although according to Druzhinin (1970), there appears to be a differential distribution between *R. brachysoma* and *R. kanagurta*, the latter being more common in offshore neritic waters. Ranging between the neritic and truly oceanic areas are the roundscads (*Decapterus* spp.). Although these species are generally caught above the shelf, they have been caught by purse seiners in the South Pacific operating large distances from land (Gillett, 1987). Similarly, flying fishes inhabit both inshore waters and the open ocean. In many of the South Pacific islands with steep shelves the separation between inshore, neritic and open ocean is much less distinct than South-east Asia. Thus although the distribution pattern shown in Fig. 3 is still applicable in the South Pacific, in many instances it is abbreviated such that species such as roundscads and flyingfish are found in waters immediately beyond the reef and within the range of small scale artisanal fishermen.

Besides the distribution patterns of small pelagic fish with proximity to the coast and the west-east decline in species, there are also marked differences between the species assemblages of small pelagics around high islands and atolls. This feature of small pelagic species distribution has been analysed in part by the SPC Skipjack Survey and Assessment Programme (SSAP) (1984). It was found that small pelagic species diversity was greater around high islands as opposed to atolls, and that the stolephorid anchovies were absent from atoll sites. These anchovies are also absent from high islands where there are neither embayments nor lagoon such as at Niue or Pitcairn Island. At Niue the only small pelagic fishes that appear to be present are *S. crumenophthalmus*, *Decapterus* spp. and flying fish. References made by Niueans to the 'Niue sardine' refer to seasonal schools of juvenile goatfish (*Mulloides flavolineatus*) that recruit onto the reefs between October to March (Dalzell *et al.*, 1990).

## LIFE HISTORIES

The importance of live bait for pole-and-line fishing prompted several studies of the small pelagic fishes comprising bait stocks. The dominant species in most of the South Pacific bait fisheries are or were anchovies, sprats and, to

a lesser degree, some other clupeids. Most studies of small pelagic fishes in the South Pacific have thus concentrated on these species. The biology of small mackerels, flying fishes, scads and halfbeaks has tended to be neglected in the region. The exception is the study by Conand (1986), who carried out biological studies on these larger small pelagic fishes as well as on the smaller gracile clupeoid species.

Conand (1986) 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 gram of fish. These include the stolephorid anchovies (*E. heteroloba*, *E. devisi*, *E. punctifer*), sprats (*S. gracilis*, *S. delicatulus*, *S. lewisi*) and a silverside (*Hypotherina ovalau*), all of which are important baitfish species.

**Type 2.** Species with an annual life cycle (but with some individuals surviving to two 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 gram of fish. These include the herrings and sardines (*Herklotsichthys* spp., *Amblygaster* spp., *Sardinella* spp.), the larger anchovies (*Thrissina* spp., *Stolephorus* spp.) and the sharp nosed sprats (*Dussumieria* spp.).

Useful though this differentiation is, a third category is required if all small pelagic species are to be considered.

**Type 3.** Species that have life spans of between 2 to 5 yrs 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 gram of fish, although flyingfish batch fecundities are much lower, (50 to 100 oocytes per gram of fish), in common with Type 2 species. Included in this group are the round scads (*Decapterus* spp.), the big eye scads (*Selar* spp.), the small mackerels (*Rastrelliger* spp) and the flying fish and half beaks (Exocoetidae and Hemiramphidae)

A summary of representative growth and mortality parameters for these different small pelagic fishes is given in Table III. Growth of these fishes is expressed using the von Bertalanffy growth equation which has (for growth in length), the form:

$$L_t = L_{\infty} [1 - e^{-K(t-t_0)}]$$

where  $L_t$  is length at time  $t$ ,  $L_{\infty}$  is the asymptotic size,  $K$  a growth constant

and  $t_0$  the curve origin. The natural mortality rates (M) in Table III were estimated using Pauly's (1980) empirical method that relates M to mean environmental temperature and growth parameters. More detailed compilations of the growth and mortality parameters for Indo-Pacific small pelagic fishes are given by Dalzell and Ganaden (1987) and Dalzell and Lewis (1988).

As might be expected from the foregoing, the short lifespans (0.4 to 4 yrs) 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 because many fish will die before completing much of their growth. That small pelagics

**Table III. Summary of growth, mortality and maturity parameters for a number of representative small pelagic fish species from the South Pacific and the Philippines.**

Species	Loc	$L_{\infty}$ (cm)	K yr <sup>-1</sup>	M yr <sup>-1</sup>	$t_{\max}$ (yr)	$L_m$ (cm)	$L_m/L_{\infty}$	Ref
<i>Encrasicholina heteroloba</i>	PNG	7.9	2.6	4.9	1.0	5.1	0.65	Dalzell (1984)
<i>Stolephorus waitei</i>	PNG	10.9	1.7	3.4	1.5	7.3	0.67	Dalzell (1987; 1989)
<i>Spratelloides delicatulus</i>	Fiji	7.3	4.6	6.9	0.4	4.0	0.55	Dalzell <i>et al.</i> (1987)
<i>Atherinomorus lacunosus</i>	New Cale.	11.4	2.5	4.1	1.2	8.5	0.75	Conand (1988)
<i>Herklotsichthys quadrimaculatus</i>	Fiji	12.6	2.0	3.5	1.6	9.5	0.75	Dalzell <i>et al.</i> (1987)
<i>Amblygaster sirm</i>	New Cale.	22.9	1.5	2.4	2.0	15.0	0.66	Conand (1988)
<i>Decapterus russelli</i>	New Cale.	24.9	1.3	2.1	3.0	18.0	0.72	Conand (1988)
<i>Selar crumenophthalmus</i>	Hawaii	27.0	2.57	3.4	2.0	23.0	0.85	Kawamoto (1973)
<i>Rastrelliger kanagurta</i>	New Cale.	23.7	3.0	3.7	1.0	20	0.87	Conand (1988)
<i>Cheilopogon nigricans</i>	Philip.	21.0	1.8	2.8	2.0	-	-	Dalzell <i>et al.</i> (unpublished data)

New Cale. = New Caledonia Philip. = Philippines

can withstand very high fishing mortalities is evident from the scale of harvests of these species from South-east Asia where small pelagic landings amount to about 1.3 million tonnes per annum (Dalzell and Ganaden, 1987). Further, on a much smaller scale Somerton (1989) has shown that the small baitfishery for Hawaiian nehū, *Encrasicholina purpurea*, in Pearl Harbour may remove up to 80 percent of the adult biomass in a given month.

There are possible adverse consequences, however, with constant heavy fishing pressure on multispecies small pelagic stocks. Dalzell and Pauly (1990) suggested that in the Philippines there has been a partial species replacement of more valuable small pelagics (mainly roundscads and sardines) by low value stolephorid anchovies, as a consequence of overfishing. The extreme example of small pelagic stock depletion through fishing pressure is the Peruvian anchovetta, *Engraulis ringens*, where sustained overfishing led to instability in recruitment and eventually, in conjunction with environmental effects, to a general recruitment failure (see contributions in Pauly and Tsukuyama, 1987; Pauly *et al.*, 1989).

## REPRODUCTION AND RECRUITMENT

The lengths at first maturity ( $L_m$ ) for some small pelagic fishes are given in Table III. The ratio of the mean size at maturity versus the asymptotic length from the von Bertalanffy growth equation ( $L_\infty$ ) is also included in Table III, and ranges from 0.65 to 0.88 with a mean of 0.72. These values are given here since the ratio  $L_m/L_\infty$  combined with the ratio of  $M/K$  can be used to compute simple equilibrium yield per recruit curves in the manner described by Beverton (1963). Such computations are normally made with the ratio of the length at first capture ( $L_c$ ) to the asymptotic size ( $L_c/L_\infty$ ). However, where the first capture length is unknown or cannot be approximated, the information in Table III still permits investigation of how the yield of a particular species is affected by changes in fishing mortality.

Given the relatively large number of small pelagic species studied in the South Pacific region and the diversity of species, it has been necessary to summarize information on spawning seasonality in tabular form (Table IV). Many of the examples cited come from the study of Conand (1988) on the small pelagic fishes of the New Caledonia lagoon. However, there are enough observations from other locations to permit some generalised observations on the seasonality of spawning in the South Pacific.

Many species, particularly the stolephorid anchovies and sprats have protracted or year-round spawning. For those species south of the equator, particularly at the higher tropical latitudes of New Caledonia, Fiji and northern Queensland, the major spawning season occurs in the latter half of the year, in the spring and summer months. Hoedt (1984) suggested that the rapid increase in temperature on the north Queensland coast after August acted as the trigger

for spawning activity of anchovies during the spring and summer months. Observations from the northern hemisphere are confined to the parts of Micronesia and Hawaii, but once again there is evidence to suggest spawning peaks during the spring and summer months for *E. purpurea*, *D. macarellus* and *S. crumenophthalmus*. Kovalevskaya (1982) notes that *Exocoetus volitans* in the tropical Pacific spawns all year in the equatorial latitudes but in the higher tropical latitudes spawning is restricted to the warmer spring and summer months.

Environmental influences on larval survival, particularly nutrient cycles in relatively poor coral reef environments, will be considerable, and successful spawning hence recruitment may only occur at particularly favourable times of the year. In northern PNG, the stolephorid anchovies spawn throughout the year but have distinct spawning peaks in the austral summer during November and during the austral winter between May to June. In such low latitudes temperature is unlikely to be such a critical factor and other influences may be important in determining the timing of spawning. Dalzell (1987) concluded that spawning peaks for the *E. heteroloba* and *E. devisi* in northern PNG were correlated with zooplankton production maxima which occurred with the change of the prevailing wind. Similarly the spawning peaks of several small pelagic fishes in New Caledonia are coincident with the annual peak in zooplankton abundance over the spring and summer months (Conand, 1988).

By contrast, Milton and Blaber (1990) found that the timing and intensity of spawning by *Encrasicholina* spp. (*E. heteroloba* and *E. devisi*) and *Sprattelloides* spp. (*S. gracilis*, *S. lewisi* and *S. delicatulus*) at three sites in Solomon Islands was highly variable. All species spawned throughout the year with periods of intense activity, although spawning peaks of the same species at the different sites did not coincide. No proximate stimuli correlated with spawning by any species at all sites although site specific spawning activity was partially correlated with moonphase, wind strength, rainfall and temperature.

The eggs of most of the small pelagics considered here are pelagic except for those of the sprats and some of the flying fishes. Observations on *S. gracilis* in Japan, both in captivity (Uchida *et al.*, 1958) and in the wild (Higo and Terada, 1985) confirm that this species, and probably the other members of the same genus, lay their eggs on a demersal substrate. Flying fishes eggs are sticky and possess filaments that aid in their attachment, either to a demersal substrate or to floating objects such as driftwood or bird feathers (Longhurst and Pauly, 1987). According to Kovalevskaya (1982), the filaments of the eggs of some flying fishes such as *Cheilopogon* spp. and *Prognichthys* spp. have lost their attachment function and now serve to keep the eggs afloat.

The eggs of most of the small pelagics considered here have rapid incubation times, ranging from about 24 to 35 hrs, depending on the temperature of the water (Dhebtaranon and Chotiyaputa, 1974; Bal and Rao, 1984; Clarke, 1989). The

**Table IV. Spawning seasons of small pelagic fishes from the South Pacific and Hawaii. Months where spawning was observed are marked with + and peak months with X.**

Species	Location	J	F	M	A	M	J	J	A	S	O	N	D	Ref
<i>Encrasicholina heteroloba</i>	PNG			+	+	X	X	+	+	+	+	X	+	Dalzell (1987)
	Palau	+	+	X	X	+	X	X	+	+	+	+	+	Muller (1976)
	Solomons	+	+	X	+	+	X	+	X	X	X	X	+	Milton & Blaber (1990b)
	N.C.	+	+	+	+	+					X	X	X	Conand (1988)
<i>E. devisi</i>	PNG			+	+	X	X	+	+	+	+	X	+	Dalzell (1987)
	Solomons	+	+	X	X	X	X	+	+	X	+	X	X	Milton & Blaber (1990)
	N.C.	X	+	+	+	+	+		+	X	X	X	X	Conand (1988)
<i>E. purpurea</i>	Hawaii	+	+	+	+	X	X	X	X	X	+	+	+	Tester (1955)
<i>S. indicus</i>	N.C.		+	+		+	+		+	+	X	X		Conand (1988)
<i>S. waitei</i>	N.C.		+	+	+	+	+		+	+	X	X	X	Conand (1988)
<i>S. nelsoni</i>	NE Qld								X	X				Hoedt (1984)
<i>S. carpentariae</i>	NE Qld								X	X				Hoedt (1984)
<i>Thryssa hamiltoni</i>	NE Qld								X	X				Hoedt (1984)
<i>T. setirostris</i>	NE Qld								X	X				Hoedt (1984)
<i>T. balaema</i>	N.C.			+					X	X	X			Conand (1988)
<i>Spratelloides gracilis</i>	PNG	+	+	+	+	+	+	+	+	+	+	+	+	Dalzell (1985)
	Solomons	+	+	+	+	+	+	+	+	+	+	+	+	Milton & Blaber (1990b)
	N.C.	X	+	+	+			X			+	+	+	Conand (1988)



Species	Location	J	F	M	A	M	J	J	A	S	O	N	D	Ref
<i>S.lewisi</i>	PNG		+	+	+	+	+	+	+	+	+	+	+	Dalzell (1987)
<i>S.lewisi</i>	Solomons	+	+	X	X	+	X	X	X	+	+	X	X	Milton & Blaber (1990)
<i>S.delicatulus</i>	Solomons	+	+	+	X	X	+	X	X	+	X	+	+	Milton & Blaber (1990)
	N.C.	+	+	X	+	+	+	+	+	X	X	X	X	Conand (1988)
	Fiji	X	X	X								X	X	Lewis <i>et al.</i> (1983)
	Kiribati	+	+	+	+	+	+	+	+	+	+	+	+	McCarthy (1985)
<i>H. quadri-maculatus</i>	N.C.	+		+					+	+		X	X	Conand (1988)
	Fiji											X	X	Lewis <i>et al.</i> (1983)
	Marshalls				X	X								Hida and Uchiyama (1987)
	Hawaii			+	+	X	X	X	+	+	+			Williams & Clarke (1983)
<i>Amblygaster sirm</i>	N.C.										X	X	X	Conand (1987)
	N.C.						+	+			+	X	X	Conand (1987)
<i>Sardinella marquesensis</i>	Fr. Poly	+	+	+	+	+	+	+	+	+	+	X	X	Nakamura & Wilson (1966)
<i>Dussumieria spp</i>	N.C.	X					+		+		X	X	X	Conand (1988)
<i>Atherinomorus lacunosus</i>	N.C.							+	+	X	X	X	X	Conand (1988)
<i>Rastrelliger kanagurta</i>	N.C.									+				Conand (1988)
<i>Decapterus macrosoma</i>	N.C.	X	X	X						+	+	X		Conand (1988)
<i>Decapterus macarellus</i>	Hawaii			+	+	X	X	X	+					Shiota (1986)
<i>Selar crumenophthalmus</i>	Hawaii		+	+	+	+	X	X	+					Shiota (1986)

N.C. = New Caledonia NE Qld = North-east Queensland, Australia

Fr Poly = French Polynesia

incubation time of the sprat *S. gracilis* in waters of about 20°C was between 7 to 9 days (Uchida *et al.*, 1958). The incubation period of the flying fishes is typically between one to two weeks and such a long period of development is a characteristic of beloniform fish in general (Kovalevskya, 1982 and contributions cited therein). Incubation times of pelagic flying fish eggs do not differ from those laid on demersal substrates (Kovalevskya, 1982).

Recruitment of tropical small pelagic fishes is poorly understood, as it is for most tropical teleost species. Muller (1976) fitted a Ricker type stock recruitment function to data for *E. heteroloba* from Palau. The fit of the model was considerably improved by the inclusion of a term for rainfall in the equation. Muller argued that recruitment strength was not simply a function of parental stock size but was also related to annual rainfall and enrichment of the Palau lagoon by allochthonous nutrient input from runoff.

Dalzell (1984b) followed the method of Pauly (1980; 1982), based on the earlier work of Hempel and Sarhage (1959) to generate estimates of recruit numbers and parental stock size for *E. heteroloba*, *E. devisi* and *S. gracilis*. The resultant stock recruitment relationships were nearly linear, which, according to Cushing (1971) is characteristic of relatively primitive species such as the clupeoids. The methods to generate the stock-recruitment data have, however, been criticised by Garcia (1983) for possibly producing a strong positive correlation, purely as a statistical artefact. Longhurst and Pauly (1987) suggested that the relationship between the production and rainfall for the same species and stocks in northern PNG presented by Dalzell (1984a) (see below) was in fact a recruitment model, where recruitment strength as measured by CPUE, is dependant on annual rainfall.

## FOOD AND FEEDING HABITS

The small pelagic fishes discussed in this paper are mostly considered planktivores, although some species such as the scads, mackerels and the larger anchovies will feed on small fishes. Detailed studies of the food and feeding of small pelagic clupeids in the South Pacific area, include those of Nakamura and Wilson (1970) on the Marquesan sardine (*S. marquesensis*), Chapau (1983) on stolephorid anchovies and sprats from northern PNG, Hoedt (1984) on a range of different anchovies from the north Queensland coast and Milton *et al.* (1990) on stolephorid anchovies, sprats and an apogonid from Solomon Islands. Further, the feeding habits of the Hawaiian anchovy or nehu, *E. purpurea* have been described by Hiatt (1951) and summarised by Nakamura (1970).

Chapau (1983) studied the food and feeding habits of *E. heteroloba*, *E. devisi* and *S. gracilis* from northern PNG, where these species formed the basis of a tuna baitfishery. Although the three species inhabited the same coastal waters, the anchovies mainly selected copepods, molluscs, decapods, ostracods and hydroids as opposed to the sprat which consumed mainly fish eggs and

larvae. Milton *et al.* (1990) included *E. heteroloba*, *E. devisi* and *S. gracilis* in their study of Solomon Islands tuna baitfish, as well as two other sprats, *S. lewisi* and *S. delicatulus*, and the apogonid *Archamia zosterophora*. All species were zooplanktivores, consuming copepods and other crustaceans. Copepods were the most important prey of all species except *A. zosterophora*, which consumed a greater biomass of larval fish. Milton *et al.* (*ibid.*) were unable to find any correlation between zooplankton abundance and fishing success as expressed as catch per unit of effort.

Hoedt (1984) studied the food of six anchovies (*T. hamiltoni*, *T. setirostris*, *Stolephorus insularis*, *S. carpentariae*, *S. nelsoni*, *S. devisi*) from the coastal waters of north Queensland and found that planktonic crustacea were the main food items taken by all six species. Some species such as *T. hamiltoni* and *T. setirostris* fed on zoobenthos and on small fish and fish larvae. Zoobenthos were found in the guts of all the anchovies studied by Hoedt, particularly *T. hamiltoni* which included penaeid and aceteid shrimps in its diet. Hoedt (*ibid.*) suggested that feeding on benthos by *Stolephorus* spp. may be a behavioral response that has reduced their vulnerability to attack by larger predators. Hiatt (1951) found that the nehu, *E. purpurea*, around Oahu, fed selectively on planktonic crustaceans. The predominant items in the diet were copepods, barnacle nauplii, ghost shrimps (*Leucifer* spp.) and crab megalopa.

The stomach contents of *S. marquesensis* were found by Nakamura and Wilson (1970) to be similar to those of the plankton from the surrounding waters. The predominant food items were planktonic crustaceans such as copepods, mysids and amphipods. They stated that *S. marquesensis* was both an active particulate feeder but that the presence of extremely small organisms in the guts, such as barnacle nauplii and diatoms, indicated that this species is also a filter feeder. A large amount of information on the feeding habits of various sardines and related species from Indian waters has been summarised by Bal and Rao (1984), including *Sardinella* spp., *Amblygaster* spp. and *Dussumieria* spp. The accounts given of food and feeding habits of these various sardines and round herrings suggest that they feed both on zooplankton and phytoplankton, obtaining food by particulate and filter feeding. Filter feeding appears to be more characteristic of adult fishes as the gill rakers of the juveniles are not sufficiently developed to strain very small organisms, such as diatoms, from the water.

Williams and Clarke (1983) observed that the herring, *H. quadrimaculatus*, in Hawaiian waters fed on small zooplankton (such as copepods), as juveniles, but took considerably larger prey (chaetognaths, polychaetes, shrimp and fish) as adults. There was no evidence of feeding by *H. quadrimaculatus* on phytoplankton, nor was phytoplankton observed in the diet of *Herklotsichthys punctatus* in the Andaman Sea (Marichamy, 1970) or of *H. dispilonotus* from around Singapore (Tham, 1950).

Bal and Rao (1984) have also summarised the literature on the food and feeding habits of the Indian mackerel, *R. kanagurta*, based on observations from Indian waters. Like the sardines, this species feed on both phytoplankton and zooplankton, strained from the surrounding waters by the well-developed feathery gill rakers borne by the gill arches. The feeding habits of the Indian mackerel appear to change with size from a purely herbivorous diet in juveniles to a combination of zooplankton and phytoplankton in adults. The diet of the short mackerel (*R. brachysoma*), from the Gulf of Thailand was also found to consist of both zooplankton and phytoplankton (Dhebtaranon and Chotiyaputa, 1974). As with *R. kanagurta* off the Indian coast (Bal and Rao, 1984), the distribution and abundance of *R. brachysoma* in the Gulf of Thailand was strongly correlated to the seasonal patterns of plankton distribution.

Tiews *et al.* (1970) described roundscad, *Decapterus macrosoma*, from the Philippines as a typical plankton feeder, with about 60 per cent of the diet of this species consisting of crustacean zooplankton. Crustaceans were also important in the diet of *D. russelli* from the same location but fish and fish eggs comprised over half the diet of this species. The presence of zoobenthos in the diet of roundscads was noted by Tiews (1962) and feeding on benthos was thought to become more important with the roundscads as they increased in size. Off Mozambique both *D. macrosoma* and *D. russelli* become increasingly vulnerable to demersal trawling as they increase in size and move to a demersal habitat (Souza and Gjesater, 1987; Souza, 1988).

Few observations have been made on the food and feeding habits of big eye scads (*Selar* spp.) in the South Pacific, and no accounts of feeding biology were apparent in the literature from elsewhere. Examination of stomach contents of *S. crumenophthalmus* showed that this small carangid fed on small fishes such as anchovies and juvenile holocentrids, together with copepods, crab megalops, stomatopods, shrimps and other free swimming crustacea (Kawamoto, 1973). Observations on the same species from the Marshall Islands reported by Hiatt and Strasburg (1960), showed that at this location the diet consisted of foramaniferans, gastropod molluscs, fish, and planktonic crustacea.

The silverside, *Pranesus insularum*, from Hawaii was found by Hobson (1974), to be a nocturnal planktivorous feeder that takes mostly crustaceans and foraminiferans. According to Longhurst and Pauly (1987), flying fish are generalised pelagic predators and their diet comprises plankton such as copepods, larval decapods, salps and molluscs as well as small fish and fish larvae. (Parin, 1970; Gorelova, 1980; Mahon *et al.*, 1986). Similarly, the diets of the closely related halfbeaks and shortwing flyingfishes consist mainly of zooplankton and small fish (Hiatt and Strasburg, 1960; Gorelova, 1980). Hiatt and Strasburg (1960) speculated that the elongated lower jaw of the halfbeaks might be used to stun small fish by a slashing action.

## VI. PRODUCTION AND YIELD

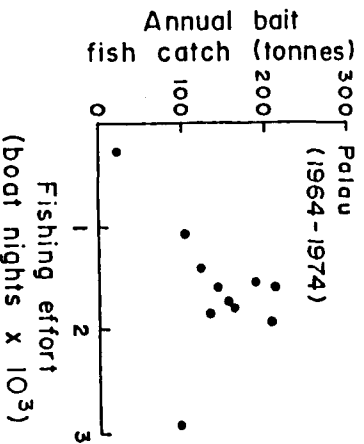
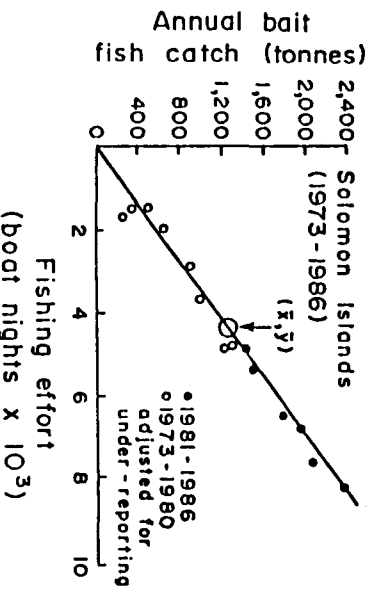
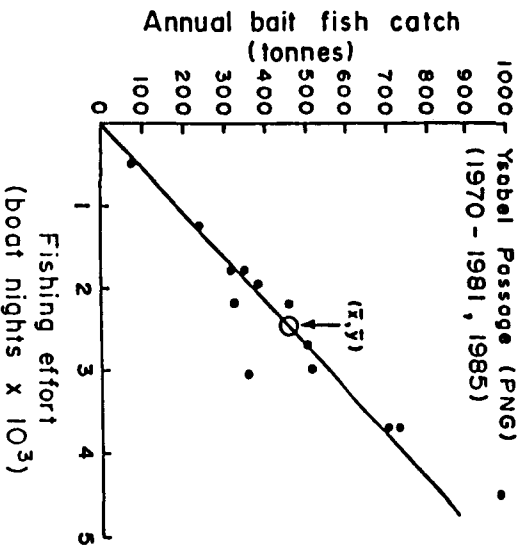
### PRODUCTION TRENDS

As with many fisheries in the South Pacific region, there is little information on catch and fishing effort for small pelagics. The most consistent sources of data concern the pole-and-line tuna fishery bait catches in PNG, Solomon Islands, Palau and Fiji (Fig. 4). In each instance, the total annual bait catch in tonnes has been plotted against annual fishing effort. For the PNG, Fijian and Solomon Islands bait fisheries, there was little evidence of curvature in the scatters of catch versus effort. Apart from the Fijian fishery, catches of live bait from these fisheries consist primarily of stolephorid anchovies. Similar 'linear' catch-effort relationships have also been found for small pelagic fisheries which catch mainly stolephorid anchovies in the Philippines (SCSP, 1976; 1977; 1978). Rather than fit a simple linear regression to the points, a line forced between the mean and the origin was used as the most realistic interpretation of the relationship. Attempts to fit a surplus production model to the baitfish catch and effort data from Fiji have been made (JICA, 1987), but the fit of the model was poor and the results spurious.

The lack of pronounced curvature in the catch-effort relationship for the PNG, Solomons 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 localised overfishing or through environmental effects, then the pole-and-line fleet will usually locate to another bait ground. Further, 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 this. An example of this is given in Fig. 5 which shows the antagonistic oscillations of the biomass of sprats and anchovies over a 14 year period at the Ysabel Passage, northern PNG.

Muller (1976) fitted surplus production curves (Schaefer, 1954; Fox, 1970) to catch and effort data from the Palau bait fishery and obtained estimates of the maximum sustainable yield (MSY) and optimal fishing effort ( $f_{opt}$ ). Muller's analysis used the average monthly catch and fishing effort between February to July for the years 1965 to 1974. When the annual values are plotted (Fig. 3), the scatter of points still suggests a possible curvilinear relationship but the fit of the curve is entirely dependant on the 1971 data point. Whether the decline in CPUE at Palau in 1971 was due in fact to overfishing or to some environmental parameter(s) is unknown.

Unlike the PNG, Solomon Islands and Palau baitfisheries, where catches tend to be dominated by *Encrasicholina* spp., the Fijian baitfish catches are composed of about seven species or species groupings including relatively high



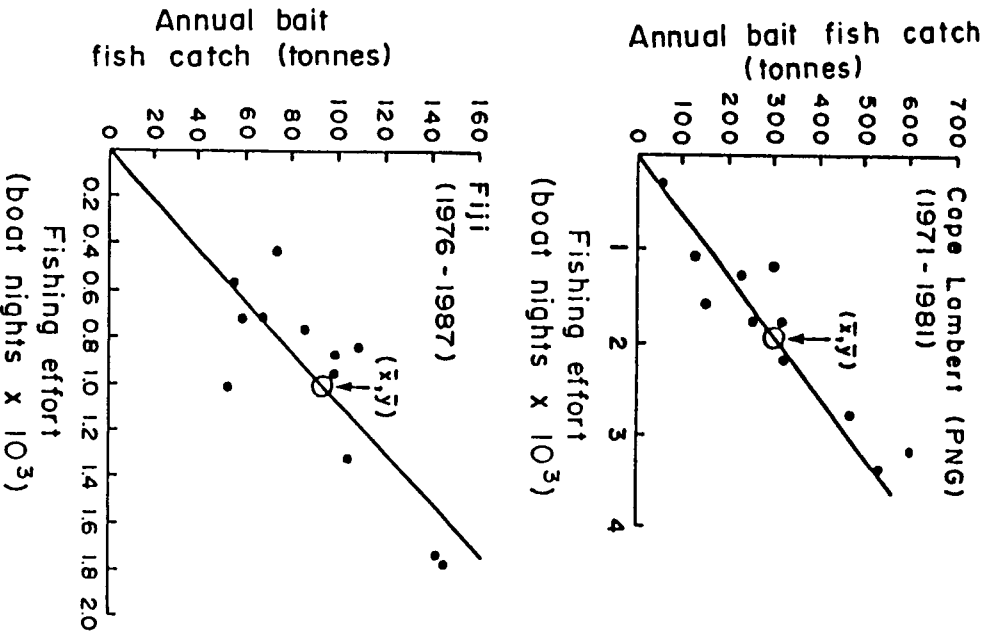


Figure 4. Catch versus fishing effort for South Pacific islands baitfisheries.

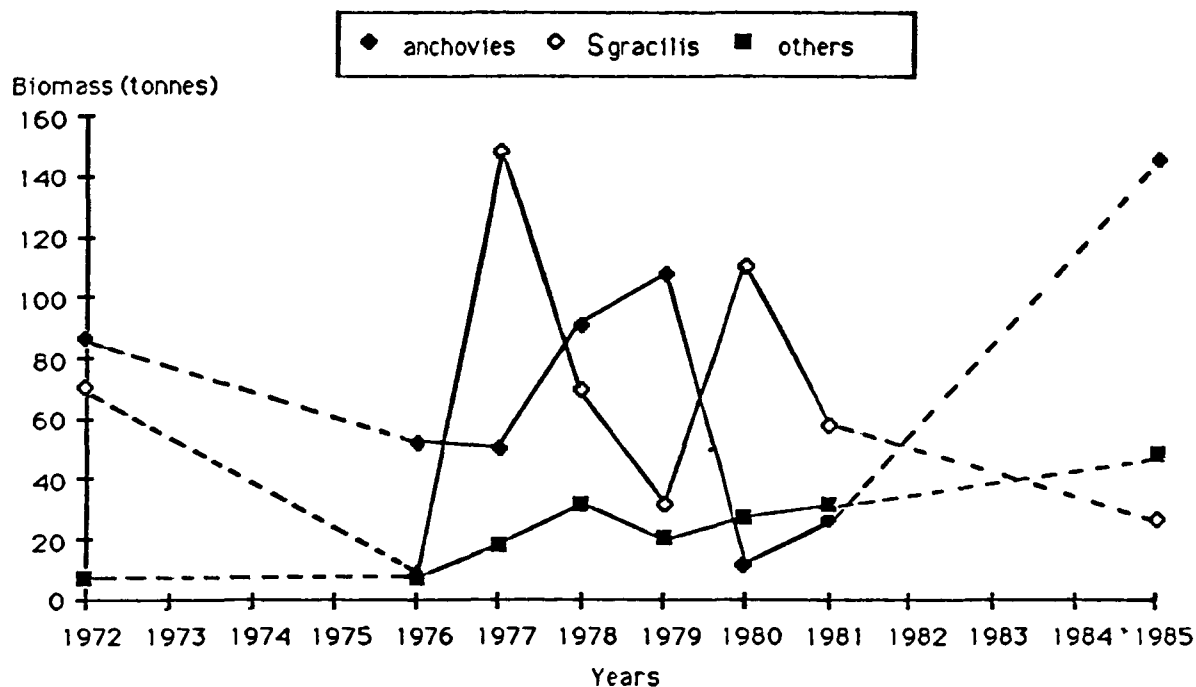


Figure 5. Changes in biomass of component stocks at Ysabel Passage from 1972 to 1985, taken from Dalzell (1989).



concentrations of demersal species such as the cardinal fish *Rhabdamia gracilis*. This is a consequence of using *bouke-ami* nets that hang deep enough to catch demersal fishes. Catch rates of baitfish in Fiji declined appreciably in 1979 and this prompted a study by SPC (Ellway and Kearney, 1981). The conclusions of the study were that there indeed appeared to have been a decline in the catch per effort of baitfish during 1979 but this may have been depressed further by deliberate under-reporting of the catch by the fishermen. The logic for this was to discourage competition among boats if good catches were encountered.

Dalzell (1984b; 1990) showed that the relationship between catch and fishing effort for stolephorid anchovies from the Ysabel Passage and Cape Lambert did not conform to the linear model for total bait catch. Dalzell (1984b) fitted simple Schaefer surplus production models to the data for catches of *E. heteroloba* and *E. devisi*. Initial estimates of MSY were made solely with catch data from the Ysabel Passage then were expanded to incorporate the smaller data set from Cape Lambert. Catch and fishing effort from each bait ground were standardised between the two baitgrounds by expressing them on a per unit area basis. An analysis of the *E. heteroloba* data alone gave a predicted MSY of 0.44 t.km<sup>-2</sup>.yr<sup>-1</sup>, similar to 0.48 t.km<sup>-2</sup>.yr<sup>-1</sup> for the same species in Palau (Muller, 1976). Actual yields ranged from 0.29 to 0.67 t.km<sup>-2</sup>.yr<sup>-1</sup> (mean = 0.44 t.km<sup>-2</sup>.yr<sup>-1</sup>) in Palau and 0.2 to 1.2 t.km<sup>-2</sup>.yr<sup>-1</sup> (mean = 0.49 t.km<sup>-2</sup>.yr<sup>-1</sup>) in PNG. The MSY for combined catches of *E. heteroloba* and *E. devisi* from the Ysabel Passage and Cape Lambert was about 0.65 t.km<sup>-2</sup>.yr<sup>-1</sup>. The actual yields of both anchovies combined ranged from 0.25 to 1.60 t.km<sup>-2</sup>.yr<sup>-1</sup> with a mean of 0.75 t.km<sup>-2</sup>.yr<sup>-1</sup>.

The analyses in the previous section 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 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. Several authors have demonstrated that there is a relationship between rainfall (and resultant fresh-water influx) and production of a number of tropical clupeoid fisheries (Tham, 1953; Ben Tuvia, 1972; Antony Raja, 1972; Wetherall, 1977; Ianelli, 1988). Dalzell (1984a) investigated the effects of rainfall on catches of stolephorid anchovies at the Ysabel Passage (mean annual rainfall = 3,300 mm.yr<sup>-1</sup>) and Cape Lambert (mean annual rainfall = 2160 mm.yr<sup>-1</sup>). Catches at Cape Lambert contain *E. punctifer* which, being a stenohaline species, declined in abundance (as expressed by CPUE) with increasing rainfall. For both *E. devisi* and *E. heteroloba* Dalzell (1984a) concluded that catch rates of these species might be modelled by a simple parabolic function of the form:  $y = a + bx + cx^2$ . In both species, the optimum rainfall for maximum CPUE is about 3000 mm.yr<sup>-1</sup> (Fig. 6).

Muller (1976) has indicated that rainfall enhances recruitment of *E. heteroloba* in Palau. Thus during the years that are drier than average, recruitment hence catch rates of *E. heteroloba* might be expected to decline. However, when rainfall is particularly heavy at the Ysabel Passage, catches of *E. heteroloba* and *E. devisi* decline appreciably. Tham (1953) has suggested that such declines may be due to the difficulties plankton feeders have in catching their prey in turbid waters or to the effect that a heavy particulate suspension has on the effective functioning of their respiratory systems. However, the effects of increased turbidity from rainfall on the attractive power of submersible lights must also be considered.

Other investigations of the effects of rainfall on small pelagics used as baitfish have been made in Fiji (Ellway and Kearney, 1981) and Kiribati (Ianelli, 1988). Ellway and Kearney (1981) suggested that rainfall did not markedly effect baitfish catches in Fijian waters. The authors did not, however, 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 baitfishery, although the scatter of points of catch rate versus rainfall presented by Ianelli (1988) suggests an initial increase in catch rates as rainfall increases, but with declining catch rates at the highest levels of precipitation. Ianelli (1988) did find, however, a significant positive correlation between catch rate of *S. delicatulus* and rainfall. Dalzell (1984a) found no correlation between rainfall and catch rates of the congener *S. gracilis* from the northern PNG baitfisheries.

## POTENTIAL YIELDS

The analyses of small pelagic catches presented here are concerned mainly with baitfisheries that catch *Encrasicholina* spp. and *Sprattelloides* spp. No equivalent data exist for other small pelagics such as scads, mackerels, flyingfish and halfbeaks. Unfortunately, the data for making these assessments are presently not available for most locations. The standing stock biomass per km<sup>2</sup> of small pelagics has been estimated by Petit and de Philippe (1983) for bays and lagoons around New Caledonia to be between 0.04 to 1.84 t.km<sup>-2</sup>, with a weighted mean of 0.465 t.km<sup>-2</sup>, consisting primarily of sardines, anchovies and sprats. Estimates of mean standing stock of small pelagics, primarily anchovies and sprats, for the Ysabel Passage and Cape Lambert bait grounds of PNG (Dalzell 1984, 1986) were 0.59 and 0.29 t.km<sup>-2</sup>, with an overall weighted mean of 0.42 t.km<sup>-2</sup>. 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.

Marten and Polovina (1982) showed that there was an empirical relationship between estimated potential yield ( $P_y$ ) in (t.km<sup>-2</sup>.yr<sup>-1</sup>) for tropical pelagic fisheries and primary productivity (gC.m<sup>-2</sup>.yr<sup>-1</sup>) over the continental shelf. Dalzell

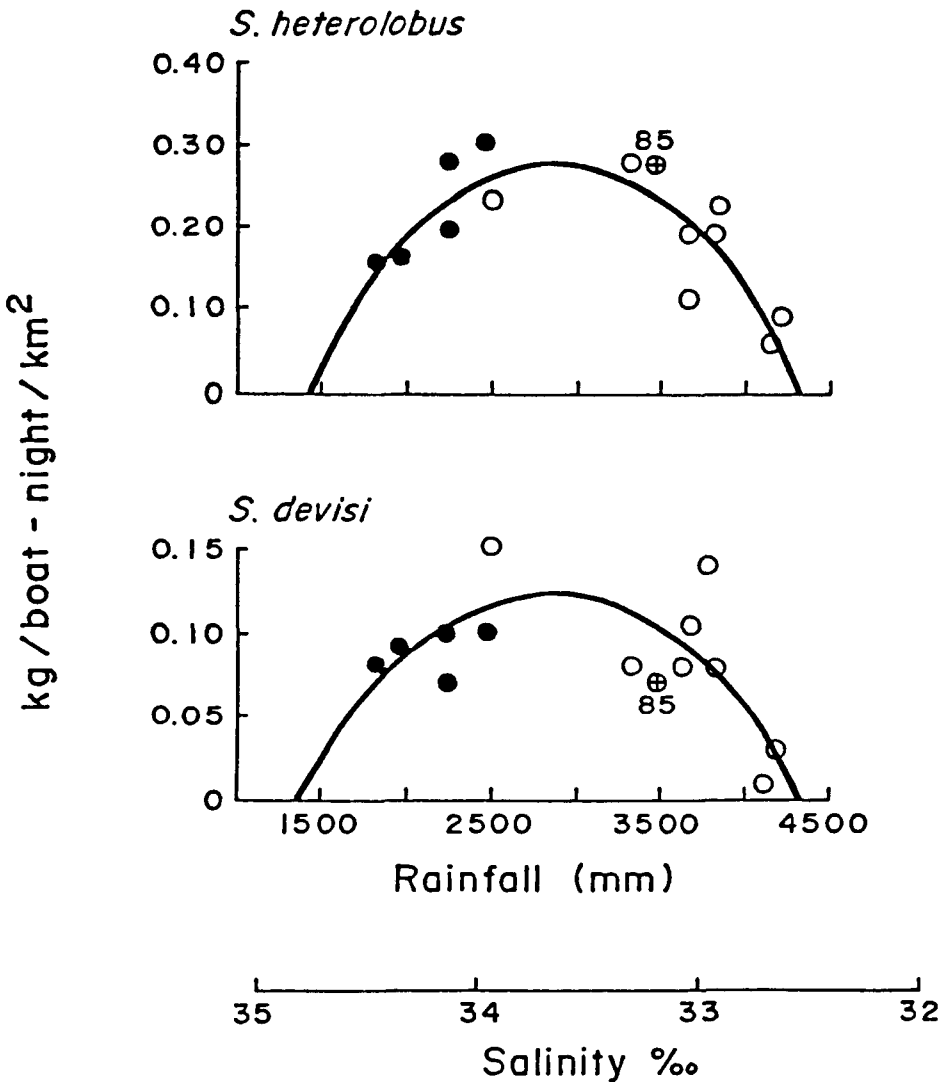


Figure 6. Mean annual yield of *E.heteroloba* and *E.devisi* versus rainfall for two Papua New Guinea baitfisheries. Open circles = Ysabel Passage, closed circles = Cape Lambert. Open circles with crosses are the 1985 data points for catches of *E.heteroloba* and *E.devisi* at Ysabel Passage that were added without recalculating the regressions.

and Pauly (1987) updated this information with respect to the Philippines and derived the empirical equation:

$$\text{Log}_{10}P_y = 0.0046\text{Prim.Prod.} - 0.23 \quad (r = 0.661; n = 13; p < 0.02; df = 11)$$

All the examples used by Marten and Polovina (1982) are adjacent to major land masses or extensive archipelagos such as Indonesia and the Philippines, thus the relationship may not be strictly applicable for the South Pacific islands. However, the usefulness of such an approach can be demonstrated with data from PNG, which has a shelf area of about 140,000 km<sup>2</sup> (Dalzell and Wright, 1986). Estimates of mean daily primary productivity in the waters around PNG were taken from FAO (1971). For the estuarine Gulf of Papua region this amounts to about 135 gC.m<sup>-2</sup>.yr<sup>-1</sup>. Substituting this into the above formula gives an estimated  $P_y$  of 2.443 t.km<sup>-2</sup>.yr<sup>-1</sup> or for a continental shelf area of 46,000 km<sup>2</sup>, a total yield of 112,400 t.yr<sup>-1</sup>. For the remaining coralline shelf the estimated annual primary productivity is 46 gC.m<sup>-2</sup>.yr<sup>-1</sup>, which gives a predicted  $P_y$  of 0.951 t.km<sup>-2</sup>.yr<sup>-1</sup> or 89,500 t.yr<sup>-1</sup> for a total remaining shelf area of 94,000 km<sup>2</sup>. This would give a total pelagic  $P_y$  in PNG of about 202,000 t.yr<sup>-1</sup>. Assuming ecological similarity with the Philippines and the Indonesian archipelagos, then about 60 to 70 percent of this or about 130,000 t would consist of small pelagic fishes.

Estimates of primary productivity for South Pacific waters range from 18 to 46 gC.m<sup>-2</sup>.yr<sup>-1</sup> (FAO, 1971). Applying the relationship derived from Marten and Polovina (1982) gives estimated yields of 0.71 to 0.95 t.km<sup>-2</sup>.yr<sup>-1</sup> or 0.50 to 0.66 t.km<sup>-2</sup>.yr<sup>-1</sup> of pelagic fish. The total size of the small pelagic resource depends on the shelf area of the different islands. By comparison, this is about one seventh of the yields of 3 to 5 t.km<sup>-2</sup>.yr<sup>-1</sup> that Munro and Williams (1985) state as a generalised figure for total neritic fish production from coralline shelf. Although such empirical methods may not be strictly applicable for the narrow shelves of most South Pacific islands, the absence of yield data other than from baitfisheries preclude the use of most other methods.

A possible alternative, however, is the extrapolation of sustained catches from one island group to another, where catch rates are expressed as tonnes per nautical mile (t.nmi<sup>-1</sup>) of 200 m isobath. Polovina *et al.* (1985) used this technique to make an empirical estimate of the potential yield of the big eye scad, *S. crumenophthalmus*, in the Mariana Islands. These authors quoted catch rates of 0.4 to 0.9 t.nmi<sup>-1</sup> of 200 m contour from the Hawaiian Islands and used these in conjunction with the length of the 200 m contour in the Marianas (490 nmi) to suggest possible sustainable harvests of 200 to 440 t.yr<sup>-1</sup> for these islands.

Dalzell and Preston (in press) have computed the extent of the 200 m isobath for each of the states within the South Pacific region, which totals 22,000 nmi. Following the method of Polovina *et al.* (1985) the region-wide sustain-

able yield of big eye scads may lie between 8,800 to 19,800 t.yr<sup>-1</sup>. Similarly catches of the roundscad, *D. macarellus*, around the main Hawaiian Islands amount to about 122.3 t.yr<sup>-1</sup> (Shiota, 1986) or a yield of 0.13 t.nmi<sup>-1</sup> of 200 m isobath. This translates to a figure of 2,753.9 t for the entire South Pacific. The estimates for both scads, however, are likely to represent the lower limits of the sustainable yields (J. Polovina, *pers. comm.*), given that the habitat area of 977 nmi is the extent of the 200 m isobath for all the main Hawaiian islands and that not all catches are reported.

## VI. FUTURE RESEARCH

The most important small pelagic fishes in terms of subsistence and commercial exploitation in the South Pacific region are the larger Type 3 species, principally the big eye scads, round scads and flying fishes. Despite this, the smaller clupeoid fishes have received greater attention from fisheries workers in the region because of their importance for tuna baitfisheries. Thus a considerable amount of information has been generated on the biology and population dynamics of species which tend not to be targeted for food, whilst the biology and fisheries of the socially and economically important small pelagics have largely been ignored. This trend is not atypical in the region where the impetus for research on exploited fisheries has mostly been devoted to those that generate cash incomes, either at the regional level, such as the high seas tuna stocks or at the local level, such as bêche-de-mer, trochus and black lip pearl shell.

Although little is known about the biology of the non-clupeoid small pelagic fishes in the South Pacific, a considerable amount of research has been conducted on these species in South and South-east Asia, where they are staple foods. Of more pressing concern is the almost complete lack of information on the size of the resource of small pelagics in the region other than the Type 1 baitfish species and the levels of exploitation. Some empirical approaches for biomass estimation and yields have been discussed here, but these are no substitute for properly conducted investigations for estimation of stock size. Initial approaches for this might be to obtain good time series of catch and fishing effort for small pelagic fisheries, both to determine the scale of resource exploitation, and to look at year-to-year variation in CPUE. Collection of length frequency data stratified by gear type and location should also be made in conjunction with information on catch and fishing effort. Where fishing mortality can be estimated or approximated then this may be used in conjunction with catch data to generate estimates of standing stocks.

Present levels of exploitation of small pelagic fishes in the South Pacific appear sustainable in the long term but there is no information on which to base this assessment objectively. Most reports on possible overfishing of small pelagic stocks are anecdotal without any supportive quantifiable evidence. For

example, Johannes (1981) reports that *H. quadrimaculatus* stocks in Palau have been reduced through a combination of legal and illegal dynamite fishing. The evidence for this, though convincing, is based on subjective reports of declines in seasonal abundance rather than accurate time series of catch and fishing effort records and supporting biological data.

The work of Petit and de Philppe (1983) in New Caledonia has shown some potential for estimating biomass from hydroacoustic methods. Hydroacoustics might also be a useful approach to determining whether seasonality of small pelagic fish is due to dispersement of schools along the coast or to the movement of schools offshore. This is of particular interest for the stocks of round scads and big eye scads found around atolls and small high islands. Further, in connection with this are the effects of fish aggregating devices (FADs) on the seasonal availability of small pelagic fishes. In Niue, schools of *S. crumenophthalmus* and *D. macarellus* are normally only available in the summer months (October to April); however, since the deployment of nearshore FADs, these fishes have been observed and caught in the proximity of these tethered rafts throughout the year (Dalzell *et al.*, 1990). Future research might also look in detail at the long-term effects of nearshore FAD deployment on the catchability of small pelagic fishes.

Some of the steps recommended above will improve the current state of knowledge on small pelagic resources, but other factors are important for the conservation and management of these stocks. Most of the small pelagics discussed here are limited to the shelf areas of the South Pacific islands, which in many instances are not extensive. Human population increase in the South Pacific is growing on average at 2.2 percent per year (Connell, 1984) or an effective doubling time of one generation (25 years). It is possible that in some areas human population growth may result in increasingly greater demand for fish of which small pelagics will need to play a part. Further, current interest in the exploitation of large oceanic tunas by artisanal fishermen for high priced export markets may stimulate a demand for a cheap local source of bait thus imposing additional pressure on small pelagic stocks. Such increases in demand are likely to lead to improvements in fishing methods for small pelagic fishes, displacing small scale traditional fishing with their inherent inefficiency. Such developments will require long-term management strategies that are part of a general regime for the conservation of the small pelagic and other fin fish resources discussed in this volume.

## REFERENCES

- Alcala, A. and Gomez E.D. (1985). Fish yields on coral reefs in the Central Philippines. *Proc. Fifth Coral Reef Cong.* Vol. 5, 521-524. Tahiti, French Polynesia.
- Allen, G.R. (1975). *Damselfishes of the South Seas*. T.F.H. Publications Inc., Ltd. Neptune City, New Jersey. 240 pp.
- Amesbury, S.S., Cushing, F.A. and Sakamota, R.K. (1986). *Guide to the Coastal Resources of Guam: Vol 3. Fishing on Guam*. University of Guam Press, 110 pp.
- Anon. (1988). Statistiques de pêches maritimes et de l'aquaculture (1976-1986). Territoire de Nouvelle Calédonie, Service territorial de la marine marchande et des pêches maritimes, Nouméa, 45 pp.
- Antony-Raja, B.T. (1972). Possible explanation for the fluctuation in abundance of the Indian oil sardine, *Sardinella longiceps* Valenciennes. *Proc. of the Indo-Pacific Fisheries Council*. 15(III), 242-252.
- Bagnis, R., Mazellier, P., Benet, J. and Christian, E. (1974). *Fishes of Polynesia*. Landsdown Press, Melbourne, 368 pp.
- Bal, D.V. and Rao, K.V. (1984). *Marine Fisheries*. Tata McGraw-Hill Publishing Company Ltd, New Delhi. 470 pp.
- Barrs, P.G. (1982). Injuries caused by garfish in Papua New Guinea. *British Medical Journal*, 284, 77-79.
- Ben-Tuvia, A. (1972). Possible explanation for the fluctuations in the stock of *Sardinella aurita* and its dependence on temperature and rain. In *Proceedings of the World Scientific Meeting on the Biology of Sardines and Related Species*. (H. Rosa and G. Murphy, eds.). pp. 1193-1203. Vol III. Food and Agriculture Organisation, Rome.
- Beverton, R. (1963). Maturation, growth, mortality of clupeid and engraulid stocks in relation to fishing. *Rapports et Proces Verbaux des Réunions de Conseil Permanent pour Exploration de la Mer*. 144, 44-61.
- Blaber, S.J.M. and Copland, J.W. (1989). Tuna baitfish in the Indo-Pacific region. *Proceedings of a Workshop, Honiara, Solomon Islands, 11-13 December 1989*. Australia Centre for International Agriculture Research (ACIAR) Workshop Proceedings 30, 211 pp.
- Chapau, M.R. (1983). Food and feeding behaviour of Ysabel Passage baitfish. *Fisheries Research and Survey Branch Research Report 83-08*. Department of Primary Industry. Port Moresby, Papua New Guinea. 24 pp.
- Clarke, T. (1989). Seasonal differences in spawning, egg size and early development time of the Hawaiian anchovy or nehu, *Encrasicholina purpurea*. *Fish. Bull.* 87, 593-600.
- Conand, F. (1988). Biologie et Ecologie des poissons pelagiques du lagon de Nouvelle Calédonie utilisables comme appât thonier. *Institut Français de Recherche Scientifique pour le Développement en Coopération (ORSTOM) Etudes et thèses*. Paris. 239 pp.
- Connell, J. (1984). Islands under pressure: population growth and urbanisation in the South Pacific. *Ambio* 13(526), 306-312.
- Cushing, D. (1971). The dependence of recruitment on parent stock in different groups of fishes. *J. Cons. Cons. Int. Explor. Mer.* 33(3), 109-116.
- Dalzell, P. (1980). Baitfish research in New Ireland Province. *Harvest* 6(3), 109-106.
- Dalzell, P. (1984a). The influence of rainfall on catches of stolephorid anchovies in Papua New Guinea waters. *Fisheries Research and Survey Branch Research Report 84-04*. Department of Primary Industry. Port Moresby, Papua New Guinea. 18 pp.

- Dalzell, P. (1984b). The population biology and management of baitfish in Papua New Guinea waters. *Fisheries Research and Survey Branch Research Report 84-05*, Port Department of Primary Industry. Port Moresby. 51 pp.
- Dalzell, P. (1985). Some aspects of the reproductive biology of *Spratelloides gracilis* in the Ysabel Passage, Papua New Guinea. *J. Fish Biol.* **27**, 229-237.
- Dalzell, P. (1987). Notes on the biology of *Spratelloides lewisi* (Wongratana 1983), a recently described species of sprat from Papua New Guinea waters. *J. Fish Biol.* **30**, 691-700.
- Dalzell, P. (1987). Some aspects of the reproductive biology of stolephorid anchovies from northern Papua New Guinea. *Asian Fish. Sci.* **1**, 86-91.
- Dalzell, P. (1990). Biology and population dynamics of small schooling pelagic fishes used for tuna baitfish in Papua New Guinea. In *Tuna Baitfish in the Indo-Pacific Region*. (S.J.M. Blaber and W. Copland, J., eds). pp. 100-113. Australian Centre for International Agricultural Research Workshop Proceedings No. 30. Canberra, Australia.
- Dalzell, P. and Wright, A. (1986). An assessment of coral reef fishery resources in Papua New Guinea. In *The First Asian Fisheries Forum*. (J.L. Maclean, L.B. Dizon, and L.V. Hosillos, eds.). pp. 477-481. Asian Fisheries Society. Manila, Philippines.
- Dalzell, P. and Ganaden, R. (1987). A review of the fisheries for small pelagic fishes in Philippine waters. *Technical Paper Series*. Vol X(1). Bureau of Fisheries and Aquatic Resources. Manila, Philippines. 58 pp.
- Dalzell, P. and Pauly, D. (1988). The fish resources of Southeast Asia with emphasis on the Banda and Arafura Seas. *Neth. J. Sea Res.* **25**(4), 641-650.
- Dalzell, P. and Lewis, A. D. (1988). Fisheries for small pelagics in the Pacific Islands and their potential yields. *Workshop on Pacific Inshore Fisheries Resources, Working Paper No. 9*. South Pacific Commission. Noumea, New Caledonia. 44 pp.
- Dalzell, P. and Penaflor, G. (1989). The fisheries biology of the big-eye scad, *Selar crumenophthalmus* (Bloch) in the Philippines. *Asian Fish. Sci.* **3**, 115-131.
- Dalzell, P. Corpuz, P., Ganaden, R. and Arce, F. (1990). Philippine small pelagic fisheries and their management. *Aqua. Fish. Manag.* **21**, 77-94.
- Dalzell, P. and Lewis, A. D. (1989). A review of the South Pacific tuna baitfisheries: small pelagic fisheries associated with coral reefs. *Mar. Fish. Rev.*, **51** (4), 1-10.
- Dalzell, P. Lindsay, S. and Patiale, H. (1990). Fisheries resource survey of the island of Niue. South Pacific Commission, Noumea, New Caledonia and Food and Agriculture Organisation South Pacific Aquaculture Project, Suva, Fiji. *mimeo. pag. var.*
- Dalzell, P. and Preston, G. (in press). Deep slope fishery resources of the South Pacific. *South Pacific Commission Inshore Fisheries Research Project Technical Report*. South Pacific Commission. Noumea, New Caledonia.
- Dhebtaranon, Y. and Chotiyaputta, K. (1974). Review of the mackerel fishery (*Rastrelliger* spp. in the Gulf of Thailand. *Proc. Indo-Pacific Fish. Council.* **15** (3), 265-286.
- Druzhinin, A. D. (1970). Indian mackerel, *Rastrelliger* spp., in Burma waters. *Proc. of the Indo-Pacific Fisheries Council.* **13**(II), 15-81.
- Ellway, C.P. and Kearney, R.E. (1981). Changes in the Fijian baitfishery, 1974-1980. *South Pacific Commission Skipjack Survey and Assessment Programme, Technical Report No. 5*. South Pacific Commission. Noumea, New Caledonia. 24 pp.
- Evans, D. and Nichols, P.V. (1985). The baitfishery of the Solomon Islands. Fisheries Department Report. Government of Solomon Islands. Honiara, Solomon Islands. 178 pp.



- FAO. (1971). Atlas of the living resources of the seas. *Fisheries Circular No 126*. Food and Agriculture Organisation. Rome, Italy. 92 pp.
- Fischer, W. and Bianchi, G. (1984). *FAO species identification sheets for fishery purposes. Western Indian Ocean; (Fishing Area 51)*. Food and Agricultural Organisation, Vol. 1-6. Rome, Italy. pag. var.
- Fox, W.W. (1970). An exponential yield model for optimizing exploited fish populations. *Trans. Am. Fish. Soc.* **99**, 80-88.
- Garcia, S. (1983). The stock recruitment relationship in shrimps, reality or artefacts and misinterpretations. *Oceanography Tropicale* **18**(1), 25-48.
- Gillet, R. (1987). Hawaiian-style *Decapterus* fishing trials in Niue. Document **87/4**. Food and Agriculture Organisation/United Nations Development Project Regional Fisheries Support Programme. Suva, Fiji. 24 pp.
- Gorelova, T.A. (1980). The feeding of young flyingfishes of the family Exocoetidae and of the smallwing flying fish, *Oxyphorampus micropterus*, of the family Hemiramphidae. *J. Ichthyol.* **20**(4), 60-71.
- Grand, S. (1985). The importance of the reef lagoon fishery in French Polynesia. *Proc. Fifth Coral Reef Cong.* Vol. **2**, 495-500. Tahiti, French Polynesia.
- Gulland, J.A. (1983). *Fish Stock Assessment: A manual of basic methods*. FAO/Wiley series on food and agriculture. Vol 1. Wiley and Sons, New York. 233 pp.
- Hempel, G. and Sarhage, D. (1959). Zur Berechnung des Anteils nicht angelandeter und unter massigen Fische im Gesamtfang. *Archiv für Fischereiwiss.* **10**, 58-67.
- Hiatt, R.W. (1951). Food and feeding habits of nehu, *Stolephorus purpureus* (Fowler). *Pac. Sci.* **5**, 347-358.
- Hiatt, R.W. and Strasburg, D.W. (1960). Ecological relationships of the fish fauna on coral reefs of the Marshall Islands. *Ecol. Monogr.* **30**, 65-127.
- Hida, T.S. (1973). Food of tunas and dolphins (Pisces: Scombridae and Coryphaenidae) with emphasis on the distribution and biology of their prey, *Stolephorus buccaneeri* (Engraulidae). *Fish. Bull.* **71**(1), 135-143.
- Hida, T.S. and Uchiyama, J.S. (1977). Biology of the baitfishes, *Herklotsichthys punctatus* and *Pranesus pingius* in Majuro, Marshall Islands. In *Collection of Tuna Baitfish Papers*. (R.R.S. Shomura, ed.). pp. 63-68. United States Department of Commerce, National Oceanographic and Atmospheric Administration, National Marine Fisheries Service Circular **408**.
- Higo, N. and Terada, K. (1985). A research on the blue sprat fishery at the around Sea of Koshiki Islands-I On the adhere to the substratum in the spawning ground at the off Sea of Arahito Saki. *Mem. Fac. Fish. Kagoshima Univ.* **34**(1), 97-109.
- Hobson, E. S. (1974). Feeding relationships of teleostean fishes on coral refs in Kona, Hawaii. *Fish. Bull.* **72**(4), 915-1031.
- Hoedt, F. (1984). Aspects of the biology of anchovies (Pisces: Engraulidae) from the waters of Cleveland Bay, Townsville. *unpubl. Honours Thesis*. James Cook University of North Queensland. Townsville, Australia. 77 pp.
- Hulo, J. (1984). Fishing practices in Buka Island, North Solomons Province. In *Subsistence Fishing Practices of Papua New Guinea*. (N. J. Quinn, B. Kojis and P. Warhepa. eds.). *Traditional Technology Development Institute Ser.* **2**, 28-33. Appropriate Technology Development Institute, University of Technology. Lae, Papua New Guinea.
- Ianelli, J. (1988). The status of the Kiribati live bait fishery. *Workshop on Pacific Inshore Fisheries Resources. Background Paper No. 59*. South Pacific Commission. Noumea, New Caledonia. 20 pp.

- JICA. (1987). *The fisheries resources of Fiji and Tuvalu*. Japanese International Cooperation Agency. Tokyo, Japan. 110 pp.
- Johannes, R.E. (1981). *Words of the Lagoon: Fishing and marine lore in Palau, District of Micronesia*. University of California, Berkeley, 245 pp.
- Kawamoto, P.Y. (1973). Management investigation of the Akule or big-eye scad, *Trachurus crumenophthalmus* (Bloch). *Hawaii Division of Fisheries and Game, Project Report No. H-4-R*. 28 pp.
- Kovalevskaya, N.V. (1981). Superfluous reproduction and development of flying fishes of the family Exocoetidae. *J. Ichthyol.* 22(4), 48-54.
- Kubohjam, G. (1984). The traditional fishing practices of Manus Island people. In *Subsistence Fishing Practices of Papua New Guinea*. (N. J. Quinn, B. Kojis and P. Warhepa. eds.). pp. 5-8. Appropriate Technology Development Institute, University of Technology. Lae, Papua New Guinea.
- Lewis, A.D. (1985). *Fishery Resource Profiles: Information for development planning*. Ministry of Primary Industry. Suva, Fiji. 90 pp.
- Lewis, A.D. (1990). Tropical South Pacific tuna baitfisheries. In *Tuna Baitfish in the Indo-Pacific Region*. (J.S.M. Blaber, and J.W. Copland, eds.). pp. 10-21. Australian Centre for International Agricultural Research Workshop Proceedings No. 30. Canberra, Australia.
- Lewis, A.D., Smith, B.R. and Ellway, C.P. (1983). A guide to the common tuna baitfishes of the South Pacific Commission area. *South Pacific Commission Handbook No. 23*. Noumea, New Caledonia. 82 pp.
- Longhurst, A.R. and Pauly, D. (1987). *The Ecology of Tropical Oceans*. Academic Press Inc., London, 407 pp.
- Mahon, R. Oxenford, H.A. and Hunte, W. (1986). Development strategies for flyingfish fisheries of the Eastern Caribbean. Proceedings of a Workshop at the University of the West Indies. *International Development and Research Council Manuscript Report 28e*. Canadian International Development Agency. Ottawa, Canada. 148 pp.
- Marichamy, R. (1970). Food and feeding of the spotted herring, *Herklotsichthys punctatus* (Ruppell) from the Andaman Sea. *Indian J. Fish.* 21, 582-584.
- Marten, G. and Polovina, J.J. (1982). A comparative study of fish yields from various tropical ecosystems. In *Theory and Management of Tropical Ecosystems*. (D. Pauly and G. I. Murphy, eds.). *Conference Proceedings* 9, 255-289. International Centre for Living Aquatic Resources Management. Manila, Philippines.
- McCarthy, D. (1985). Fishery dynamics of the major wild baitfish species, particularly *Spratelloides delicatulus*, from Tarawa, Kiribati. *Atoll Research and Development Unit Report*. University of the South Pacific. Suva, Fiji. 51 pp.
- Mees, C.C. (1985). The fisheries of Marakei Island. *Fisheries Division Report*. Ministry of Natural Resource Development. Tarawa, Kiribati. 23 pp.
- Milton, D.A., Blaber, S.J.M. and Rawlinson, N.J.F. (1990). Diet and prey selection of six species of tuna baitfish in three coral reef lagoons in the Solomon Islands. *J. Fish Biol.* 37(1), 205-224.
- Morize, R. 1985. Study on the small-scale fishery in atoll of Tikehau. *Proc. Fifth Coral Reef Cong.* Vol. 2, 501-506. Tahiti, French Polynesia.
- Muller, R.G. (1976). Population biology of *Stolephorus heterolobus* (Pisces: Engraulidae) in Palau, Western Caroline Islands. *Ph.D. thesis*. University of Hawaii. Honolulu, Hawaii. 174 pp.

- Munro, J.L. and Williams, D.M. (1985). Assessment and management of coral reef fisheries. *Proc. Fifth Coral Reef Cong.* Vol. 4, 545-581. Tahiti, French Polynesia.
- Muyard, J. (1980). Etat des connaissances sur l'appât vivant utilisable par les canneurs en Nouvelle Calédonie. Office de la Recherche Scientifique et Technique Outre-Mer Centre ORSTOM Noumea. *Rapp. Sci. Tech. No.* 6. 15 pp.
- Nakamura, E. (1970). Synopsis of biological data on the Hawaiian species of *Stolephorus*. In *The Kuroshio: a Symposium on the Japan Current*. East-West Center Press, Honolulu, 614p.
- Nakamura, E.L. and Wilson, R.C. (1970). The biology of the Marquesan sardine, *Sardinella marquesensis*. *Pac. Sci.* 24 (3): 359-376.
- Nichols, P.V. and Rawlinson, N.J.F. (1990). Development of the pole-and-line fishery in the Solomon Islands with reference to the bait fishery and its management. In *Tuna Baitfish in the Indo-Pacific Region* (J.S.M. Blaber and J.W. Copland, eds.) *ACIAR Proc.* No. 30, 30-44.
- Parin, N.V. (1977). *Ichthyofauna of the epipelagic zone*. Nauka, Moscow (Israeli Program of Scientific Translation). Jerusalem, Israel.
- Pauly, D. (1980). On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. *J. Cons. Cons. Int. Explor. Mer.* 39, 175-192.
- Pauly, D. (1982). A method to study the stock-recruitment relationship in shrimps. *Trans. Am. Fish. Soc.*, 111 (1), 13-20.
- Pauly, D. and Tsukuyama, I. (eds). (1987). The Peruvian anchovetta and its upwelling ecosystem: three decades of change. *Studies and Reviews* 15. International Centre for Living Aquatic Resources Management. Manila, Philippines. 351 pp.
- Pauly, D., Muck, P., Mendo, J. and Tsukuyama, I., eds (1989). The Peruvian upwelling ecosystem: dynamics and interactions. *Conference Proceedings*. 14. International Centre for Living Aquatic Resources Management. Manila, Philippines. 438 pp.
- Petit, D. and de Philippe, V. (1983). Estimation de stocks de petite pelagiques en Nouvelle Calédonie, results des campagnes echointégration. *Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM)*. Noumea, New Caledonia. 85 pp.
- Polovina, J.J., Moffit, R.B., Ralston, S., Shoita, P.M. and Williams, M.A. (1985). Fisheries resource assessment of the Mariana Archipelago, 1982 to 1985. *Mar. Fish. Rev.* 47(4), 19-25.
- Rapson, A.M. 1955. Survey of the fishing potential of the Coral Sea and Southern and Eastern Papua. *Papua New Guinea J. Agric.* 10(1), 1-12.
- Ricker, W.E. (1954) Stock and recruitment. *J. Fish. Res. Board Can.* 11, 559-623.
- Schaefer, M.B. (1954). Some aspects of the dynamics of populations important to the management of commercial marine fisheries. *Bull. I-ATTG/Bol. CIAT* 1(2), 27-56.
- SCSP. (1976). Report of the BFAR/SCSP Workshop on the fishery resources of the Visayan and Sibuyan Sea areas. *SCS/Gen/76/7*. South China Sea Fisheries Development and Coordinating Programme. Manila, Philippines. 26 pp.
- SCSP. (1977). Report of the BFAR/SCSP Workshop on the fishery resources of the Sulu Sea, Bohol Sea and Moro Gulf areas. *SCS/Gen/77/11*. South China Sea Fisheries Development and Coordinating Programme. Manila, Philippines. 35 pp.
- SCSP. (1978). Report of the BFAR/SCSP Workshop on the fishery resources of the Pacific coast of the Philippines. *SCS/Gen/78/19*. South China Sea Fisheries Development and Coordinating Programme. Manila, Philippines. 48 pp.

- Shiota, P.M. (1986). Carangidae. In *Fishery Atlas of the Northwest Hawaiian Islands*. (R. Uchida and J. Uchiyama, eds.). National Marine Fisheries Service Technical Report 38. pp. 98-99. United States Department of Commerce, National Oceanographic and Atmospheric Administration.
- Skipjack Survey and Assessment Programme. (1984). An assessment of the skipjack and baitfish resources of Northern Mariana Islands, Guam, Palau, Federated States of Micronesia and Marshall Islands. *Final Country Report No. 18*. Skipjack Survey and Assessment Programme, South Pacific Commission. Noumea, New Caledonia. 109 pp.
- Souza, M.I. (1988) Sources of bias in growth and mortality estimation of migratory pelagic fish stocks, with emphasis on *Decapterus russelli* (Carangidae) in Mozambique. In *Contributions to Tropical Fisheries Biology*. (S.C. Venema, J.M. Christensen and D. Pauly, eds.). Fisheries Report 389, 288-307. Food and Agricultural Organisation. Rome, Italy.
- Souza, M.I. and Gjøsæter, J.A. (1987). A revision of growth parameters of some commercially exploited fishes from Mozambique. *Rev. Invest. Pesqu. (Maputo) No. 16*, 19-40.
- Somerton, D.A. (1989). Baitfish stock assessment using the egg production method: an application on the Hawaiian anchovy or nehu (*Encrasicholina purpurea*). In *Tuna Baitfish in the Indo-Pacific Region*. (S.J.M. Blaber and J. W. Copland, eds.), pp. 152-158. Australian Centre for International Agricultural Research Workshop Proceedings No. 30. Canberra, Australia.
- Springer, V.G. (1982). Pacific plate biogeography with special reference to shorefishes. *Smithson. Contrib. Zool.* 367. 181 pp.
- Tester, A.L. (1955). Variation in egg and larval production of the anchovy, *Stolephorus purpureus* Fowler, in Kaneohe Bay Oahu. *Pac. Sci.* 9, 31-41.
- Than, A.K. (1950). The food and feeding relationships of the fishes of Singapore Straits. *Fisheries Publication* 1(1). Colonial Office. London. 35 pp.
- Than, A.K. (1953). A study of the physical, chemical and biological characteristics of Singapore Straits. *Fisheries Publication* 1(4), 1-65. Colonial Office. London.
- Tiews, K. (1962). Report to the Government of the Philippines on marine fishery resources. *Philipp J. Fish.* 6(2), 107-208.
- Tiews, K., Ronquillo, I.A. and Caces-Borja, I. (1970). On the biology of roundscads (*Decapterus* Bleeker) in Philippine waters. *Proc. Indo-Pacific Fish. Council.* 13(II), 82-106.
- Uchida, K., Imai, S., Mito, S., Fujita, S., Ueno, M., Shojima, Y., Senta, T., Tahuku, M. and Dotu, Y. (1958). *Studies on the eggs, larvae and juvenile Japanese fishes*. Fisheries Department, Faculty of Agriculture, Kyushu University. Series I, 7. Kyushu, Japan.
- Weatherall, J.A. (1977). Catch statistics and abundance of the nehu, *Stolephorus purpureus* in Kaneohe Bay. In *Collection of Tuna Baitfish Papers*. (R.S. Shomura, ed.). National Marine Fisheries Service Circular 408, 114-118. United States Department of Commerce, National Oceanographic and Atmospheric Administration.
- Whitehead, P.J.P. (1985). Clupeoid fishes of the world (sub order Clupeoidei). Part I. Chirocentridae, Clupeidae and Pristigasteridae. *Food and Agricultural Organisation Fisheries Synopsis No. 125*. Vol. 7, 1-303.
- Whitehead, P.J.P., Nelson, G. and Wongratana, T. (1988). Clupeoid fishes of the world (sub order Clupeoidei). Part 2. Engraulidae. *Food and Agricultural Organisation Fisheries Synopsis No 125*. Vol 7, 304-579.
- Williams, D.M. and Hatcher, A.T. (1983). Structure of fish communities on outer slopes of inshore, midshelf and outer shelf reef of the Great Barrier Reef. *Mar. Ecol.* 10, 239-250.

- Williams D.M. and Capo, M. (1990). Life histories of some clupeids in North-eastern Australia: preliminary data. In *Tuna Baitfish in the Indo-Pacific Region* (S.J.M. Blaber and J.W. Copland, eds.). pp. 70-74. Australian Centre for International Agricultural Research Workshop Proceedings No. 30. Canberra, Australia.
- Williams, V.R. and Clarke, T.A. (1983). Reproduction, growth and other aspects of the biology of the gold spot herring, *Herklotsichthys quadrimaculatus* (Clupeidae), a recent introduction to Hawaii. *Fish. Bull.* **81**(3), 587-597.