A Review of the South Pacific Tuna Baitfisheries: Small Pelagic Fisheries Associated with Coral Reefs

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ABSTRACT—A review is given of current information concerning small pelagic fishes exploited for tuna bait in the South Pacific. These fishes are usually caught over or near coral reefs using light attraction and lift nets. The most common and widespread species are anchovies (Engraulidae), sprats (Clupeidae), silversides (Atherinidae), and herrings (Clupeidae). Recorded yields ranged from 0.5 to 2.6 t/km², and methods are described to estimate potential yields empirically in the absence of catch data. Environmental effects on small pelagic fish prodution are discussed, and evidence is presented to suggest that rainfall markedly affects stolephorid anchovy production. Some species of small pelagic fish, such as Selar *spp.,* Decapterus *spp., and* Herklotsichthys *sp., have been fished traditionally by artisanal fishermen, but anchovy and sprat stocks were probably unexploited prior to pole-and-line tuna fishing in the South Pacific.*

Introduction

The small pelagic or mackerel-like and herring-like fishes of the South Pacific islands (Table 1) have been exploited both by artisanal fishermen as food fish and by pole-and-line tuna fishing vessels for live bait. Exploitation by tuna vessels is a relatively recent phenomenon and constitutes probably the only truly industrial-scale fisheries that have operated within the inshore coastal waters of the South Pacific islands. Not all these pole-and-line tuna fisheries have maintained operations. Examples of these are the fleets that were based at Palau in the Western Caroline Islands (Muller, 1976; Wilson, 1977) and in Papua New Guinea (PNG) (Lewis et al., 1974; Dalzell and Wankowski, 1980). Pole-and-line tuna fishing (and hence, baitfishing) continues to be pursued in the Solomon Islands (Evans and Nichols, 1985; Tiroba[1]), Fiji (Lewis et al., 1983; Sharma[2]), and Kiribati (McCarthy, 1985; Ianelli, 1988).

Investigations into the biology, population dynamics, and fisheries dynamics of past and present tuna baitfisheries represent the major studies of small pelagic resources in the South Pacific region, although some investigations of small pelagic resources have also been made around New Caledonia in the absence of an established pole-and-line fishery (Conand, 1988). The short-term survey fishing of the South Pacific Commission Skipjack Survey and Assessment Programme (SSAP) survey resulted in a wide ranging set of samples of small pelagic fishes taken in most of the states and territories within the South Pacific (Kearney, 1982). Artisanal fisheries which certainly exploit small pelagic resources remain for the most part unstudied.

All of the baitfisheries detailed above and many of the artisanal fisheries that catch small pelagics are adjacent to coral reefs. These fisheries are not, however, normally perceived as reef fisheries per se. Assessment of the inshore coral reef fishery resources of the South Pacific islands including the small pelagic fishes is timely, given the small agricultural land area of much of the region and the high rates of population increase currently estimated overall at 2.5 percent (Connell, 1984). In this paper, we review the available data on inshore reef-associated small pelagic resources. The characteristics of the resources and the fisheries are described and attempts are made to give some estimate of potential yields.

Table 1.—Species considered as small pelagics in the context of the South Pacific Region.

Common name	Genus
Anchovies	*Stolephorus*[1] spp., *Thryssa* spp.
Sardines	*Sardinella* spp., *Amblygaster* spp.
Round herrings	*Dussumieria* spp.
Herrings	*Herklotsichthys* spp., *Pelona* spp.
Sprats	*Spratelloides* spp.
Mackerels	*Rastrelliger* spp.
Scads	*Decapterus* spp., *Selar* spp., *Selaroides* spp., *Atule* spp.
Fusiliers	*Pterocaesio* spp., *Caesio* spp., *Gymnocaesio* spp.
Flying fish	Exocoetidae
Half beaks	*Hemiramphus* spp., *Hyporhamphus* spp.

[1]Nelson (1983) has placed the smaller stolephorids such as *Stolephorus heterolobus*, *S. devisi*, *S. punctifer* and *S. purpureus* in a separate genus, *Encrasicholina*. We have maintained the previous reference to avoid confusion.

Fishing Methods

The pole-and-line fishing vessels operating in the South Pacific region also serve as platforms for catching small pelagic baitfish. These are caught by the use of a stick-held dip net, or bouke-ami, assembled and mounted on the pole-and-line vessel (Fig. 1). The baitfish are aggre-

[1]Tiroba, G. K. 1986. Biological studies of exploited baitfish species, *Stolephorus heterolobus* and *Stolephorus devisi* in Western Province, Solomon Islands. Minist. Nat. Resour., Fish. Dep., Honiara, Solomon Isl. Unpubl. rep., 64 p.

[2]Sharma, S. 1988. The Fijian baitfishery. Presented at South Pacific Commission Inshore Fisheries Resources Workshop, Noumea, New Caledonia, March 1988, SPC/Inshore Fish. Res./BP 14. Unpubl. rep., 19 p.

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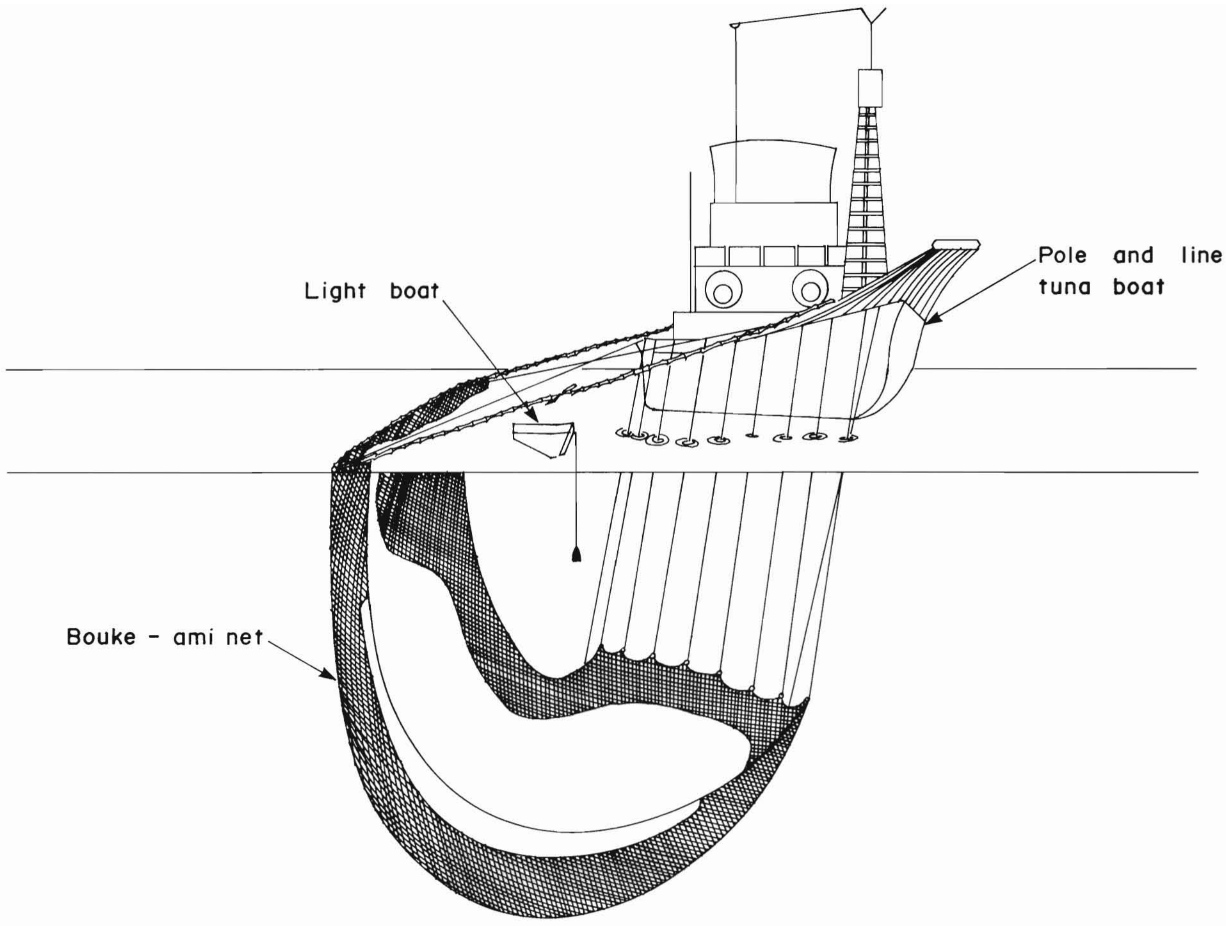

Figure 1.—Operation of a bouke-ami fishing net used to catch small pelagic baitfish; based on FAO (1974) and Muyard (1980).

gated at night around submersible lamps of 1–1.5 kW that are used after dusk. Besides lamps suspended from the vessel itself, other catching stations may be established by using lamps powered by a generator mounted on a small skiff.

During the setting and hauling of the net, the lights are raised to near the surface and dimmed to compact the baitfish schools. Surface illumination may also be employed to draw the fish nearer to the surface. After the net is hauled, the mass of baitfish is concentrated in one section of the net to be brailed into buckets and then emptied into baitwells set in the hull of the pole-and-line vessel.

Distribution and Biogeography of South Pacific Small Pelagics

The term "South Pacific," as defined here, includes the island groups of Micronesia, Melanesia, and Polynesia and does not strictly refer to locations south of the equator (Fig. 2). The nations and territories in the region range from the large land mass of PNG (land area = 460,000 km^2) through medium sized island groups (land area = 10–20,000 km^2) such as Fiji, Vanuatu, and the Solomon Islands, to small islands or atoll clusters (land area = $<5{,}000$ km^2) such as Tonga, Kiribati, and French Polynesia. The region extends over 29×10^6 km^2, although total land mass covers only 550,000 km^2, 85 percent of which is contained within PNG (Dahl, 1984).

Springer (1982) has proposed that the South Pacific belongs to a major subunit of the Indo-Pacific biogeographic region. This is because the Pacific Plate, largest of the earth's lithospheric plates, occupies most of the area referred to as the Pacific Basin. The faunal characteristics of the Pacific Plate are a cline of decreasing species diversity in an easterly direction across the Plate and a high degree of endemism within the Plate boundaries. The island groups of Melanesia (PNG, Solomon Islands Vanuatu, and Fiji) and the islands of Tonga are all situated on the Plate margin as are the Western Caroline and Marianas Islands. The remaining island groups of the South Pacific are all located on the Pacific Plate.

Besides "mackerel-like" and "herring-like", the term "small pelagic" here refers to fish which have a maximum weight of 500 g and inhabit the upper surface layer of the water column. The definition of small pelagic fishes in the context of the

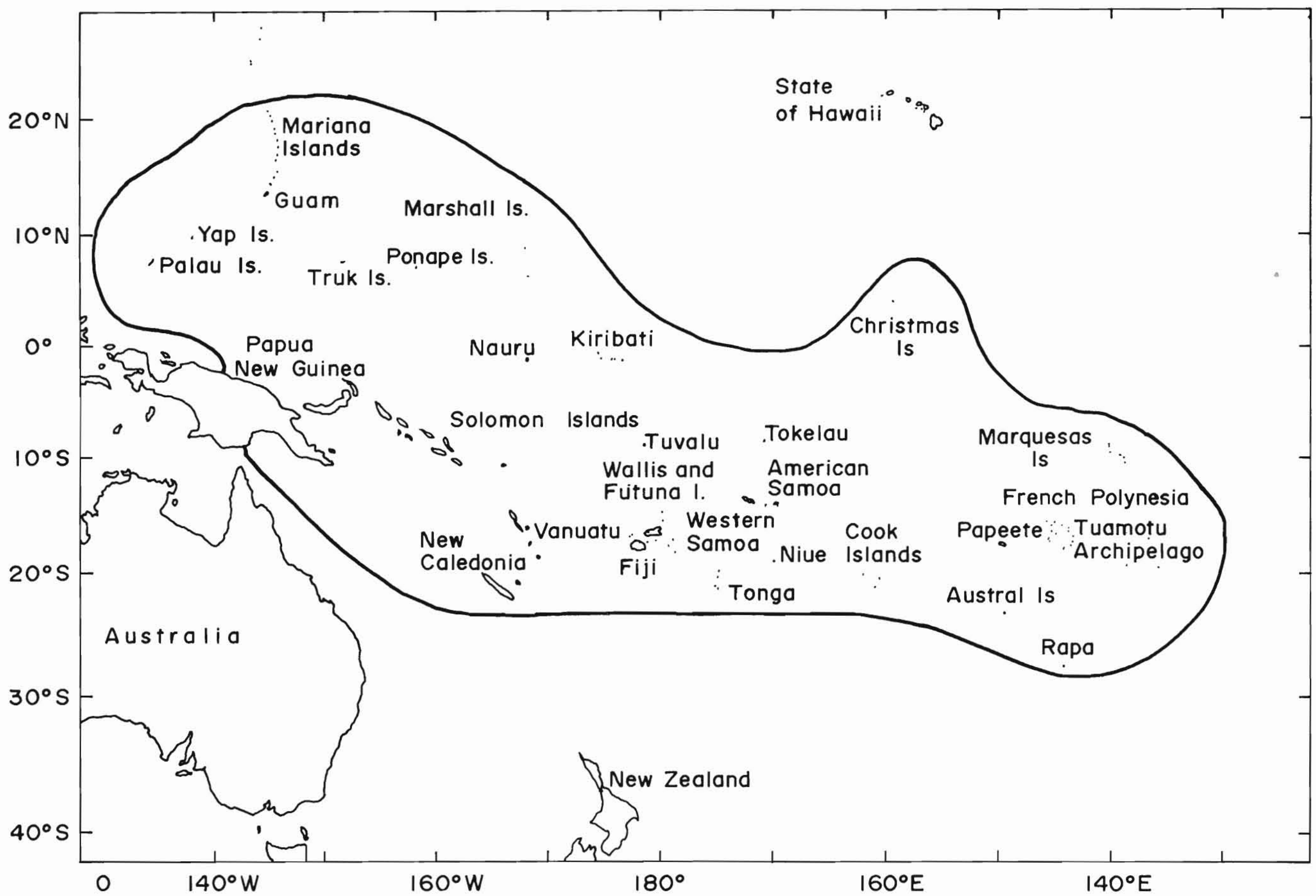

Figure 2.—The South Pacific Region as defined in the text.

Table 2.—Number of principal small pelagic baitfishes at different locations within the South Pacific region. Source: Lewis et al. (1983)

Country/ Territory	Anchovies	Sardines & sprats	Silver-sides	Scads	Fusiliers	Mackerel	Total	Distance from 130°E (km)	$L_n N$
PNG	8	14	7	7	6	4	46	2.070	3.83
Solomon Islands	5	9	6	6	6	3	35	3.106	3.56
Vanuatu	3	6	2	4	2		17	4.659	2.83
New Caledonia	5	8	4	5	6	1	29	4.400	3.37
Fiji	7	10	5	5	7	3	37	3.694	3.61
Tonga	2	6	2	4	0	1	15	6.730	2.71
Wallis/Futuna	1	4	3	2	1	1	12	5.954	2.48
Western Samoa	6	7	2	2	2	2	21	6.885	3.04
American Samoa	7	5	1	0	0	1	14	7.248	2.64
Palau	5	6	3	3	3		20	.518	3.00
Yap	3	2	2	0	1		8	.984	2.08
Truk	0	4	2	1	0		7	2.589	1.95
Ponape	4	5	5	4	2	1	21	3.365	3.04
Kosrae	5	3	4	2	0		14	3.883	2.64
Marshall Islands	0	3	2	1	0	1	7	4.400	1.95
Kiribati	0	5	2	3	4	1	15	5.436	2.71
Tuvalu	0	1	2	3	1		7	5.798	1.95
Tokelau	1	1	1	0			1	7.041	1.10
Cook Islands	0	1	3	2			6	8.542	1.79
Society Islands	3	2		3			8	9.319	2.08
Marquesa Isl.	0	1		4			5	10.923	1.61
Tuamotu Islands	0	1		2			3	10.613	1.10
N.E. Qld (Aust.)	6	5		1			12	2.330	2.48

South Pacific is given by the summary in Table 1. The occurrence of different small pelagic baitfish species in SPCTP baitfish hauls in the South Pacific region is documented in Lewis et al. (1983). This has been summarized by family in Table 2. The long. 130°E line was taken as a convenient western boundary of the South Pacific region. A functional regression of the logarithm of the number of small pelagic species vs. distance in an easterly direction from long. 130°E had a highly significant negative slope (Fig. 3). This analysis supports the suggestion of Springer (1982) that species diversity declines in an easterly direction across the Pacific Plate. Allen (1975) found a similar relationship for pomacentrid fishes in the South Pacific region.

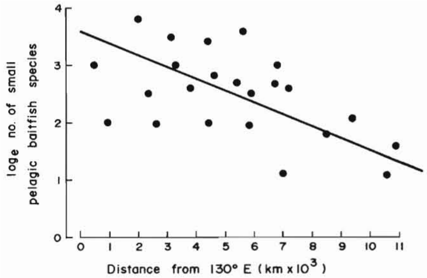

Figure 3.—Logarithms of number of small pelagic baitfish species vs. distance east of the long. 130°E line.

The generalized distribution of small pelagic fishes on both coralline and noncoralline shelf areas has been reviewed by Dalzell and Ganaden (1987). (This scheme is somewhat compressed in most Pacific Island situations with their very narrow continental shelves.) Within the coastal zone are found the big-eye scads, anchovies, clupeoids, and half-beaks. The exception amongst the anchovies is *Stolephorus punctifer*, a stenohaline species which prefers neritic and oceanic waters (Hida, 1973). Dalzell (1984a) has shown that the catch per effort and abundance of *S. punctifer* in PNG is inversely correlated with annual rainfall (see further below). The fusiliers (i.e., *Caesio* and related genera) are included since their distribution is determined largely by the extent of coral cover which is generally associated with shallow (<30 m depth) coastal water. Studies of lightly exploited reef-fish populations on the Australian Barrier Reef (Williams and Hatcher, 1983) and a heavily exploited small island fringing reef in the Philippines (Alcala and Gomez, 1985) have shown that fusiliers formed the largest component of the fish biomass. Further, fusiliers form 75 percent of all fish captured by muro-ami or drive-in nets on Philippine coral reefs and account for 99 percent of the small pelagic fishes caught by this method (Dalzell, unpubl. data).

Further offshore are found the mackerels (*Rastrelliger* spp.), although according to Druzhinin (1970), there appears to be a differential distribution between *R. brachysoma* and *R. kanagurta*, the former being more common in nearshore waters. Ranging between the neritic and truly oceanic areas are the roundscads (*Decapterus* spp.). Although these species are generally caught around shelf areas, they have also been captured around fish aggregating devices in the Celebes Sea in >5,000 m of water, well away from the shelf zone (K. L. Yamanaka, Univ. Brit. Col., personal commun., 1987) and are often caught by purse seiners in the South Pacific operating at great distances from land (Gillett, 1987). Similarly, flying fishes inhabit both inshore coastal waters and the open ocean.

Species Composition of Small Pelagic Baitfish Catches

The SSAP surveys for small pelagic tuna baitfish in the South Pacific region were carried out between 1977 and 1980. These surveys suggested that five species, *Spratelloides delicatulus*, *Stolephorus devisi*, *S. heterolobus*, *Herklotsichthys quadrimaculatus*, and *Atherinomorus lacunosa*, were both widespread and abundant. Other common species were *Hypoatherina ovalaua*, *Selar crumenophthalmus*, *Amblygaster sirm*, *Spratelloides gracilis*, and *Stolephorus punctifer*.

Long-term sampling of baitfish catches at Palau, PNG, Solomon Islands, Kiribati, and Fiji has resulted in more detailed information on the composition of these small pelagics at specific sites. A summary of the results of these studies is given in Table 3. At Palau, PNG, and the Solomon Islands, the dominant species caught are stolephorid anchovies at 50–90 percent of the landings. The sprats form another important species grouping, particularly at the Ysabel Passage, PNG, where *S. gracilis* averages 36 percent of catches.

Unlike the sites listed above, baitfish catches in Fijian waters are dominated by seven species or species groupings, with stolephorid anchovies comprising only 13 percent of the catch. At Kiribati, the dominant baitfish species are *Spratelloides delicatulus*, *Amblygaster sirm*, and *Herklotsichthys quadrimaculatus* which together contribute up to 86 percent of the catch. The herring, *H. quadrimaculatus*, which comprises about 7 percent of the catch, is also an important component of artisanal beach seine catches in Kiribati (Kleiber and Kearney, 1983; Ianelli, 1988).

In neighboring Southeast Asia, roundscads and sardines make major contributions to small pelagic fish catches. The only sardines of any significance in South Pacific small pelagic catches are *Amblygaster sirm* and *Sardinella marquesensis*. Interestingly, *A. sirm* is the most important sardine caught by fishermen in the Philippines and accounts for 8.5 percent of all small pelagic landings (Dalzell et al., In press). Nearshore artisanal gears in the Philippines and Indonesia take predominantly stolephorid anchovies and sardines (Dudley and Tampubolan, 1986; Corpuz and Dalzell[3]). Sardines and anchovies are also major components of large liftnet fisheries using light attraction in the Philippines, although roundscads also make significant contribution to catches (Corpuz and Dalzell[3]).

Some mention should also be made to the Hawaiian live baitfishery for the nehu, *Stolephorus purpureus*. Unlike the South Pacific baitfisheries, nehu are caught in Hawaii both by day and, rarely, by night (night fishing has not occurred in about the last 5 years. Day fishing is done with a seine in turbid inshore waters). South Pacific baitfisheries rely entirely on night baitfishing, although attempts at daylight fishing were made in PNG in the initial year of operations during 1970 (Lewis, 1977); daylight fishing operations were also carried out by the SSAP. In Hawaii, roughly 97 percent of the total bait catch

Table 3.—Species composition of sustained baitfish catches in the South Pacific region as determined by catch sampling.

Species	Fiji	PNG	Solomon Isl.	Palau[1]	Kiribati	New Caledonia
Sprats	23.4	18.1	11.1		40.5	3.7
Sardines	15.8	5.4	1.0		27.8	15.1
Herring	14.6		1.2		17.7	
Silversides	4.3	1.2	0.3		5.3	0.3
Mackerels	6.4	1.1	0.3			
Cardinals[2]	16.6	1.6	0.2		0.8	
Anchovies	10.4	62.6	72.7	91.0		62.5
Fusiliers		7.7	0.5			
Scands		1.4				
Others	9.1	0.9	13.0	9.9	8.0	18.4

[1]No details of other species in catch given by Muller (1976).
[2]Demersal fishes; consist mainly of *Rhabdamis* spp.

[3]Corpuz, P., and P. Dalzell. 1988. A summary of the catch, fishing effort data and species composition collection by the DA/BFAR-ICLARM Small Pelagics Management Project. Dep. Agric., Bur. Fish. Aquat. Resour., Int. Cent. Living Aquat. Resour. Manage. Unpubl. rep., 114 p.

comprises *S. purpureus*. Also caught in the baitfishery are *S. delicatulus* and *A. lacunosa* (Uchida, 1977). A relatively large literature exists on *S. purpureus* biology and fisheries; key references include Nakamura (1970), Struhsaker and Uchiyama (1976), and contributions in Shomura (1977) and Clarke (1987; In press).

Catches, Yields, and Biomass of South Pacific Small Pelagic Baitfishes

Time series of catch and fishing effort data are available for the PNG, Solomon Islands, Fiji, and Palau baitfisheries. At all locations, effort can be expressed as boatnights or number of nightly fishing operations by the pole-and-line vessels on an annual basis. A better index of catch per effort (C/f) would be catch per haul. However, effort data (haul numbers) have not been collected consistently at all locations throughout the history of the fisheries. Plots of the relationships of catch vs. effort are shown for the different baitfisheries in Figure 4. Apart for the Palau fishery, the data are best fitted with a straight line forced through the mean of the scatters and the origin.

One interpretation of the apparent linearity of the catch-effort relationship of the baitfisheries is that effort and yields could be increased appreciably. However, the various scatters of points refer to total catch and not individual component species. In the case of the Palau fishery which was comprised almost entirely of a single species, *S. heterolobus*, C/f was markedly reduced at the highest levels of fishing effort (Fig. 4). Further, the catch rates of stolephorid anchovies in northern PNG also appeared to be inversely correlated with fishing effort. Surplus production models of the Schaefer and Fox type could be fitted to the PNG and Palau data (Muller, 1976; Dalzell, 1984b); however, as shown later, environmental effects may be more closely linked to fluctuations of C/f than changes in fishing effort.

In the Ysabel Passage baitfishery of northern PNG, sampling records extend over 14 years, from 1972 to 1973, 1976 to 1981 (Dalzell, 1984b), and again during 1985 (Dalzell, 1986). In the early years of the fishery, species other than *S. heterolobus*, *S. devisi*, and *S. gracilis* comprised about 5 percent of the total catch. By 1976, these other species, comprising mainly Clupeidae, Caesionidae, Atherinidae, and Carangidae, had risen to 10 percent of the catch and continued rising to 30 percent by 1981 (Table 4). Between 1982 and 1984, there was a cessation of fishing activities, which resumed in 1985. Other species comprised 25 percent of the catch during 1985. Such changes are not apparent from simple catch and effort data and may indicate that levels of fishing effort are such that they induce major fluctuations in the biomass and hence, catch rates of the principal species, *S. heterolobus*, *S. devisi*, and *S. gracilis*.

Table 4.—Annual percentage species composition for the Ysabel Passage baitfishery, 1972-1973, 1976-1981, and 1985.

Year	*S. heterolobus*	*S. devisi*	*S. gracilis*	Subtotal	Other spp.
1972	41.9	25.9	26.2	94.0	6.0
1973	41.4	14.6	40.2	96.2	3.8
1976	53.0	30.1	7.0	90.1	9.9
1977	18.9	14.0	56.8	89.7	10.3
1978	41.1	12.8	29.7	83.6	16.4
1979	37.1	28.4	22.2	87.7	12.3
1980	10.2	1.8	65.3	77.3	22.7
1981	20.7	7.7	41.4	69.8	30.2
1985	42.8	11.8	20.7	75.3	24.7

Such large changes in catch composition over the history of a fishery appear to be a characteristic of small pelagic clupeoid fisheries where declines in abundance of one species are offset by partial replacement by other species. Examples of these are the increase of the northern anchovy *Engraulis mordax* with the decline of the California sardine *Sardinops caerulea*; increase of the sardine *Sardinops sagax* with decline of the Peruvian anchoveta *Engraulis ringens*; and the decline of the South African pilchard *Sardinops ocellata* and increase of the anchovy *Engraulis japonicus*. All the examples quoted here are or were major fisheries on upwelling eastern boundary currents (Parrish et al., 1983) whereas the Ysabel Passage baitfishery was a localised small pelagic fishery influenced more by monsoon seasonality (Dalzell, 1984a). Although small pelagic fish populations may demonstrate large natural fluctuations, it is apparent that major changes in species composition and abundance in both instances are possibly induced by fishing pressure. Daan (1980) has reviewed the mechanism responsible for partial species replacement in the above examples and other fisheries.

Table 5.—Average annual yields of small pelagic baitfish at three locations in the South Pacific region.

Location	Area fished (km^2)	Yield (t/km^2 per year)	Sources
PNG[1]	743	1.06	Dalzell (1984b)
Solomon Isl.[2]	806	2.64	Nichols[3]
Palau[4]	300	0.52	Muller (1976)

[1]Based on catches at two baitgrounds, the Ysabel Passage (336 km^2) and Cape Lambert (407 km^2) between 1970 and 1981.
[2]From 120 baitground locations in the Solomon Islands monitored between 1984 and 1986.
[3]Paul Nichols, Fisheries Department, Ministry of Natural Resources, personal commun.
[4]Based on catches at Palau between 1965 and 1974.

Information on yields from the small pelagic baitfisheries is concerned mainly with anchovies, sprats, sardines, and herrings. In only three instances are data suitable to estimate yields directly from observed catches and areas of fishing ground. These are shown in Table 5 and range from about 0.5 to 2.5 t/km^2/year of fishing ground. Munro and Williams (1985) suggest that a figure or 3–5 t/km^2/year is a reasonable estimate of multi-species sustainable yield from coralline shelves.

Muller (1976) analyzed the catch and effort data for the Palau baitfishery and estimated a maximum sustainable yield (MSY) at about 0.48 t/km^2/year for *S. heterolobus*. Dalzell (1984b, 1986) performed similar analyses for the Ysabel Passage and Cape Lambert baitfisheries; the MSY of exploited stocks of *S. heterolobus* and *S. devisi* was about 0.6 t/km^2/year. An analysis of the *S. heterolobus* data alone gave predicted yields of 0.44 t/km^2/year, similar to Muller's (1976) estimate for the Palau stock of the same species. Actual yields of *S. heterolobus* ranged from 0.29 to 0.67 t/km^2/year ($\bar{x} = 0.44$ t/km^2/year) in Palau and 0.20 to 1.20 t/km^2/year ($\bar{x} = 0.49$ t/km^2/year) in PNG.

Little is known about the size of standing stocks of small pelagic baitfishes in the South Pacific region. Petits and de

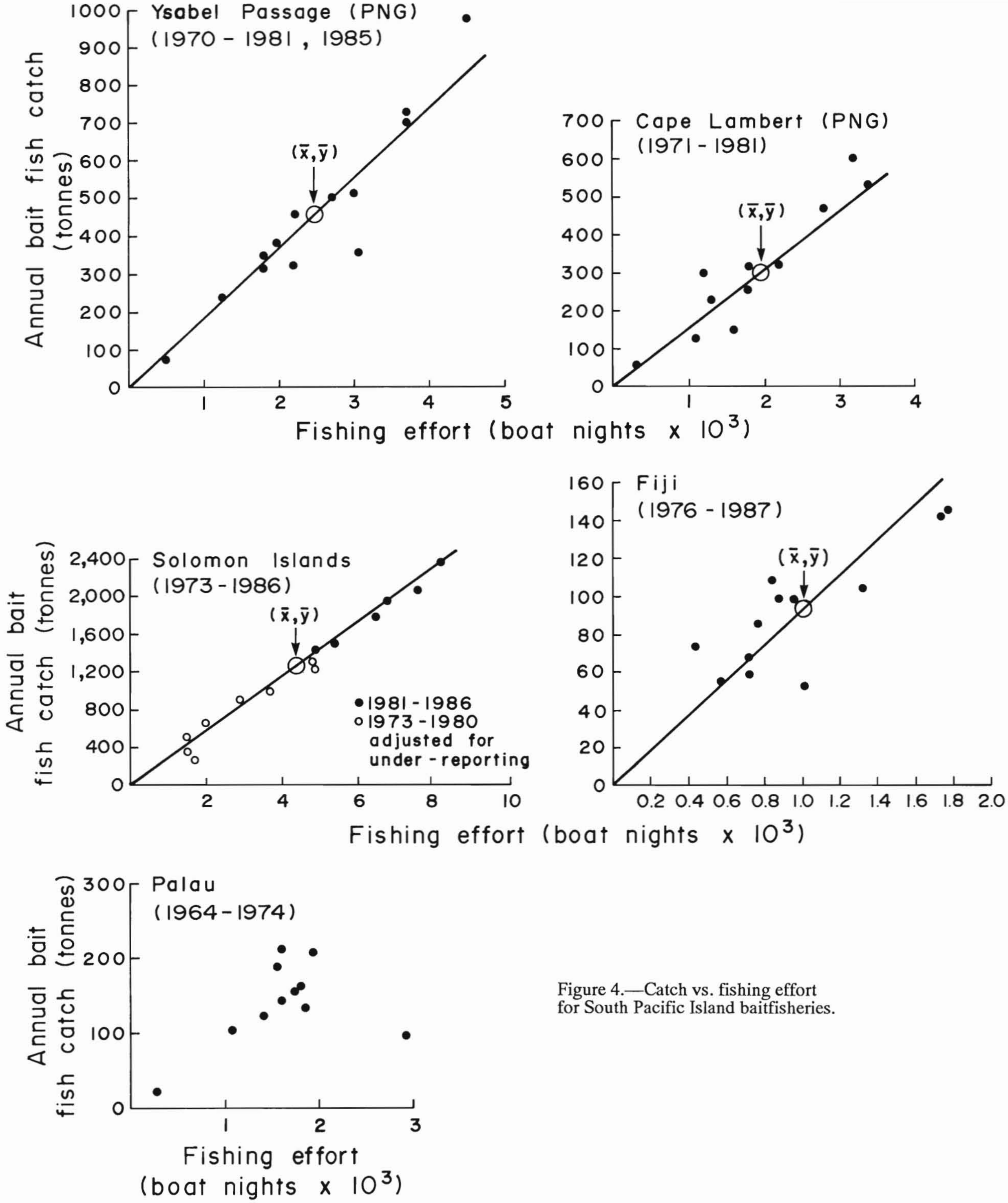

Figure 4.—Catch vs. fishing effort for South Pacific Island baitfisheries.

Philippe[4] estimated the biomass of small pelagic fishes in the lagoons and bays around New Caledonia to range between 0.04 and 1.84 t/km^2 with a weighted mean of 0.46 t/km^2, consisting primarily of anchovies, sprats, and sardines.

[4]Petits, D., and V. de Philippe. 1983. Estimation des stocks de petits pelagiques en Nouvelle-Caledonie, resultats des campagnes d'echointegration. ORSTOM, Noumea, New Caledonia, 85 p.

Estimates of average standing stocks of small pelagics, primarily anchovies and sprats for the Ysabel Passage and Cape Lambert bait grounds in PNG, were 0.59 t/km^2 and 0.29 t/km^2, respectively, with a weighted mean of 0.43 t/km^2 (Dalzell, 1984b). These very limited data suggest that at least around high islands in the South Pacific region, the biomass densities of small pelagic fishes may be relatively similar.

An empirical approach to estimating potential yields (P_y) of pelagic fishes is that described by Marten and Polovina (1982) who showed that there was a relationship between estimated P_y (in t/km^2/year) for tropical pelagic fisheries and primary production (in gC/m^2/year). Dalzell and Pauly[5] updated their compilation with respect to pelagic yields from the Philippines and derived the empircal equation:

$$\log_{10} P_y = 0.0046 \text{ Prime Prod. } -0.233$$
$$(r = 0.661, n = 13, P<0.02).$$

Estimates of primary productivity for the South Pacific region range from 18 to 46 gC/m^2/year (FAO, 1971). Substituting these into the above equation gives potential pelagic yields of 0.71 to 0.95 t/km^2/year. The heavily fished pelagic fisheries of Indonesia and the Philippines comprise between 60 and 70 percent small pelagic species (FAO, 1986). Assuming ecological similarity, this suggests a small pelagic MSY of 0.46 to 0.62 t/km^2/year in the South Pacific region.

A possible alternative approach to estimating yields is the use of sustainable catch rates expressd in tons/n.mi. of 200 m isobath. Polovina et al. (1985) used this technique to make an empirical estimate of the potential yield of *Selar crumenophthalmus* in the Mariana Islands. These authors quoted catch rates of 0.4 to 0.9 tons/n.mi. 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 n.mi.) to suggest harvests of 200 to 440 t/year for these islands.

Comparative data on baitfish catches are given by Gillett and Kearney (1983) summarised from the SSAP. These data refer to catches made at different locations in the South Pacific with a stick-held lift net of 700 m^2. Catch rates ranged from 39 to 291 kg/haul with a mean of 98.2 kg/haul. An analysis of catch, effort, and species composition was made for data collected in Micronesia to assess differences between high islands and atoll lagoons (SPC, 1984). The results suggested that catch per effort at high island sites ($\bar{x}$ = 104 kg/haul) was much higher than at atoll lagoons ($\bar{x}$ = 54 kg/haul). Further, the species composition of bait catches at high island sites was more varied and contained species of stolephorid anchovies.

Other analyses by the SSAP in the same report (SPC, 1984) indicate that there is a greater degree of variability of catch per effort at atoll bait sites than at high island bait sites. It was concluded that atolls in general offer much less potential for commercial baitfishing than high islands, and this may also be the case for small pelagic fish production in total. The productivity potential for small pelagic fishes at atolls is expectedly lower due to relative lack of terrestial input. This has been discussed for coral reef fisheries in general in the Caribbean by Ogden (1982) and the Indo-Pacific by Munro and Williams (1985).

Environmental Effects on Production

Since small pelagic fishes live near the air-water interface, it is likely that climatically induced environmental effects will markedly affect production. Tham (1953) demonstrated that the abundance of catches of stolephorid anchovies (principally *S. heterolobus*) in the Singapore Straits were partially correlated with copepod abundance which, in turn, was correlated with rainfall, phosphate content of the sea water, and standing crop of phytoplankton. A positive correlation has been demonstrated between the recruitment of *Sardinella aurita* in the Mediterranean with sea temperature and rainfall (Ben-Tuvia, 1960). Similarly, Antony Raja (1972) showed that recruitment and catch rates of *Sardinella longiceps* were positively correlated with rainfall off the west coast of India. In Hawaii, Wetherall (1977) demonstrated an inverse relationship between stream outflow into Kaneohe Bay and catch per effort of *Stolephorus purpureus*.

In the South Pacific region, the generally nutrient-poor waters around coral reefs will be enriched by runoff as the result of precipitation. However, rainfall through runoff and stream discharge will also lower salinity and increase turbidity which may have adverse effects on pelagic species. Dalzell (1984a) investigated the effects of rainfall on catches of *Stolephorus* anchovies at two baitfishing locations in northern PNG, Cape Lambert, and Ysabel Passage. The annual rainfall at Cape Lambert ($\bar{x}$ = 2,160 mm/year) is about two-thirds of that at Ysabel Passage ($\bar{x}$ = 3,300 mm/year). Catches of baitfish at Cape Lambert include *S. punctifer*, a stenohaline species. Not surprisingly, the annual abundance of this species as expressed by mean catch per effort declines with increasing rainfall (Fig. 5).

For both *S. devisi* and *S. heterolobus*, Dalzell (1984a) concluded that the catch rates of these species might be modeled with a simple parabolic function of the type $y = a + bx + cx^2$ (Fig. 5). The catch rates at each baitfishing ground were standardized on a per-area basis since the areas fished by the pole-and-line vessels could be accurately defined from the fishing vessel catch data. In both species, the optimum rainfall for maximum catch per effort is about 3,000 mm per year. Note that the additional points for 1985 for Ysabel Passage, which fit rather well, were added without recalculating the curves (Fig. 5).

Muller (1976) has indicated that rainfall enhances recruitment of *S. heterolobus* at Palau. Thus, during years that are drier than average, recruitment and, hence, catch rates of *S. heterolobus* might be expected to decline. However, when rainfall is particularly heavy at Ysabel Passage, catches of *S. heterolobus* and *S. devisi* decline appreciably. Tham (1953) has suggested that such declines with heavy rainfall 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. The effects of increased turbidity from rainfall on the attractive

[5]Dalzell, P., and D. Pauly. 1987. The fish resource of Southeast Asia with emphasis on the Banda and Arafura Seas. Pap. Pres. at Snellius II Symposium, Jakarta, Nov. 1982. Mimeogr., pagin. var.

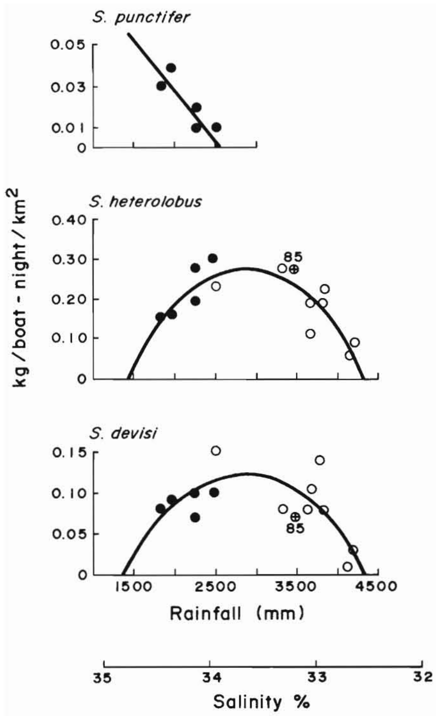

Figure 5.—Mean annual yield of *S. punctifer*, *S. heterolobus*, and *S. devisi* vs. rainfall for two Papua New Guinea baitfisheries. Circles = Ysabel Passage; dots = Cape Lambert. Circles with crosses are the 1985 data points for *S. hetelobus* and *S. devisi* at Ysabel Passage.

power of lights must also be considered, however.

Other investigations of the effect of rainfall on baitfish catches have been made for the Fiji (Ellway and Kearney, 1981) and Kiribati (Ianelli, 1988) baitfisheries. Ellway and Kearney (1981) suggested that rainfall did not markedly affect baitfish catches in Fijian waters. These authors did not, however, investigate the effect of rainfall on individual catch components; rather, they used the catch data for all species. There was also no significant correlation between rainfall and total catch in the Kiribati baitfishery, although the scatter of points of catch rate vs. 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 *Spratelloides delicatulus* and rainfall. Dalzell (1984a) found no correlation between rainfall and catch rates of the congener *Spratelloides gracilis* from the northern PNG baitfisheries.

Catches of small pelagic baitfishes in PNG, New Caledonia, and Fiji are all highly seasonal with peaks in production during the Austral winter when the winds blow predominantly from the southeast. The combined effects of an overlying seasonal pattern with random environmental effects further compound the management problems for these fisheries. Their prime function is a regular and constant supply of live bait for pole-and-line fishing. This means that they can be a serious limiting factor to the tuna fisheries, as has been documented for the PNG pole-and-line fishery by Doulman and Wright (1983).

Despite the extensive nature of the PNG coast, baitfishing was ultimately confined to the two sites, Ysabel Passage and Cape Lambert. Much of the PNG coast is not greatly indented and lacks large harbors. Small ones are common, but the fleet style of operation (i.e., with a mother vessel) could only really utilize areas capable of supporting 10 vessels or more such as Ysabel Passage and Cape Lambert. This was further compounded by sociopolitical problems which confined the PNG pole-and-line fishery to these two sites. The lack of alternative sites during times of low baitfish abundance at Cape Lambert and Ysabel Passage was a serious impediment to the PNG pole-and-line fishery.

The Future of Small Pelagic Fisheries in the South Pacific

The persistence of baitfisheries in the South Pacific is dependent on the pole-and-line tuna fisheries maintaining operations in the region. During the late 1970's and early 1980's, Japanese and U.S. purse-seine fleets began to exploit successfully the skipjack and yellowfin tuna stocks of the South Pacific region. The advent of purse seining has meant that pole-and-line fishing may ultimately be made redundant. Nevertheless, pole-and-line fishing persists in the Solomon Islands, Kiribati, and Fiji. Both Fiji and the Solomon Islands have canneries served by domestic pole-and-line fleets and by purse seine catches. Pole-and-line fishing is politically attractive since it offers employment opportunities to Pacific Islanders.

However, small pelagic fishes are clearly a resource in their own right and are exploited by artisanal fishermen throughout the South Pacific. Accounts in the literature suggest that the commonly exploited species are scads (*Selar* spp., *Decapterus* spp.), herrings (*Herklotsichthys* spp.), mackerels (*Rastrelliger* spp.), halfbeaks (Hemiramphidae), and flying fishes (Exocoetidae and Hemiramphidae). No accounts were found of artisanal fisheries that regularly catch stolephorid anchovies or *Spratelloides* spp., although these species constitute significant resources in the western South Pacific. Passive gears that catch these fishes in the Southeast Asia such as fish corrals do not appear to be traditionally used in Micronesia and Melanesia, although similar structures known as "parcs" are recorded from French Polynesia (Grand, 1985; Morize, 1985). The principal small pelagic species captured by parcs is *S. crumenophthalmus*.

Anecdotal information and personal communications to the authors from PNG would suggest that prior to inception of the baitfisheries, the anchovy and sprat resources of the coralline shelf of PNG were unexploited. Given the size of this area, Dalzell (1986) has suggested that the potential sustainable yields of stolephorid anchovies from PNG may range from 5–10,000 t/year to 40,000 t/year based on comparisons with similar Southeast Asia fisheries. Whether local fisheries for stolephorid anchovies could prosper in PNG is another matter, however, given the small population (about 3 million people) and lack of markets.

There has been considerable speculation about the effects of the capture of small pelagic baitfish on other reef fisheries. Concern stems from the removal of baitfish species as food for reef-associated piscivorous fishes and the capture of juveniles of reef and lagoon species. Little work has been done to address these questions, although, presently, investigations are being made on this subject in the Solomon Islands (Nichols[6]). Lewis[7] has suggested that the scale of baitfishing operations are such that the effects of removal of reef and lagoon species may be minimal. Despite the industrial nature of the fishery, the average catch per night by a pole-and-line vessel is small and rarely exceeds 100-150 kg. However, as shown here, long-term fishing may have effects on species composition of bait catches.

Floating fish aggregation devices, or payaos, are commonly used in Indonesia and the Philippines to concentrate small pelagic fishes and tunas (Floyd and Pauly, 1984). Payaos have been used in the South Pacific (Boy and Smith, 1984), but their purpose is to concentrate tunas and large pelagics for trolling or pole-and-line fishing. The exploitation of small pelagic species around payaos appears not to have been considered. This, like the neglected anchovy resources in the region, will probably not change until population levels and economics dictate otherwise. The larger small pelagic species, because of their desirability, will remain exploited at the artisanal level, e.g., by beach seines, handlines, and gill nets, while the smaller clupeoids may continue to be largely unexploited other than for tuna baitfish.

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