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Tuna Baitfish in the Indo-Pacific Region

Proceedings of a workshop, Honiara, Solomon Islands, 11–13 December, 1989

Editors: **S.J.M. Blaber and J.W. Copland**

Contents

Foreword

Tuna fishing is a vital source of food, employment and export in both Solomon Islands and Maldives. Most of the tuna is caught using the traditional pole-and-line method, a technique that relies on baitfish — small fish which are thrown live into the sea to attract tuna schools within range of the boat.

The harvesting of baitfish is therefore an integral part of the fishing operation and it is critical that the stock not be overexploited.

To assist in the development of appropriate management strategies ACIAR has supported a collaborative research project between CSIRO Division of Fisheries Research, Cleveland, Australia; Fisheries Division, Ministry of Natural Resources, Honiara, Solomon Islands; Marine Research Section, Ministry of Fisheries, Male, Maldives, and the Fisheries Division, Department of Primary Industry, Port Moresby, Papua New Guinea.

Research personnel from each of these institutions together with a number of other people with a research interest in baitfish met in Honiara in December 1989 to discuss the results of the project to date and issues pertinent to baitfish management in the Indian and Pacific Oceans.

These proceedings contain the papers presented at the workshop. Although many of these papers were directed primarily at understanding the biology of tuna baitfish, they also have a wider relevance. Most of the species used as baitfish in the tropical Indian and Pacific Oceans, particularly the anchovies and sprats, are important food fishes in the countries of south east Asia, the Indian sub-continent and the African coast. Hence much of the data contained in this volume will be of interest to tropical fisheries scientists throughout the world.

ACIAR acknowledges the valuable contribution of all those involved in this project. We would like to record our thanks to the project leaders Dr Steve Blaber, CSIRO Division of Fisheries, Mr Paul Nichols, Fisheries Department, Solomon Islands and Mr Hassan Maniku, Ministry of Fisheries, Maldives. In addition appreciation is extended to the Hon. Allan Paul, Minister for Natural Resources, Solomon Islands, who welcomed the workshop delegates and opened the meeting.

G.H.L. Rothschild
Director

Summary

Overviews of tuna baitfisheries were presented in the first session of the workshop. These were followed by aspects of the general biology of the species making up the fisheries. The small fishes that form the basis of tuna baitfisheries in the Indo-Pacific region comprise Engraulidae and Clupeidae (particularly *Stolephorus* and *Spratelloides*) and to a lesser extent Apogonidae, Atherinidae and Caesionidae.

There are three main active pole-and-line tuna fisheries in the Pacific that require a continuous supply of suitable live baitfish. The largest of these in Solomon Islands took about 2000 tonnes of baitfish in 1988. The baitfisheries of Fiji and Kiribati are smaller but no less vital to the industry in each country. A small-scale pole-and-line fishery exits in Hawaii and relies on a regular supply of the estuarine dependent *Stolephorus purpureus*. In the Indian Ocean Maldives has an artisanal pole-and-line fishery that is vital to the nation's economy and likewise needs an assured supply of baitfish. In other tuna fishing countries of both oceans there has been a move away from pole-and-line fishing to purse-seining, largely for economic reasons. The large Papua New Guinea pole-and-line fleet ceased operation in 1984. However, it is unlikely that the countries presently pole-and-line fishing will cease such fishing in the near future. The pole-and-line method is labour intensive, hence providing more jobs, produces higher quality fish, and involves technologies more suited to certain developing countries.

Papers in the second session indicated that baitfish are also important for the lucrative game-fishing industry in north eastern Australia. Anchovies of the genus *Stolephorus*, the mainstay of Pacific tuna baitfisheries, form very important coastal fisheries in India and Indonesia where they are used for human consumption.

The third session dealt with population dynamics and aging. Most baitfish species live for less than a year. Historically, much of the research was conducted on the now extinct Papua New Guinea fishery, with more recent work in Solomon Islands, Maldives and Kiribati. *Stolephorus* and *Spratelloides* species have received the most attention. Additional information on *Stolephorus* not used as baitfish was given in papers from research in north eastern Australia, India and Indonesia. Growth patterns based on length-frequency analyses using ELEFAN showed broad agreement between areas, with K values of 2.0 to 2.4 for *Stolephorus* and 4.0 to 5.0 for *Spratelloides*. Growth curves were also generated from analyses of daily growth rings in otoliths. The rings have been validated as daily in *Spratelloides* but experiments on *Stolephorus* have so far been inconclusive. Otolithic aging of *Spratelloides* species produced curves with K values of 4.0 to 5.0, similar to those generated by ELEFAN. Otolith data from *Stolephorus* from Solomon Islands indicates a K value of 4.0 to 5.0, and hence a much more rapid growth rate than that generated by ELEFAN results. However, modal progression analysis of length-frequency data from *Stolephorus* in India gave results closer to those from the otolith analysis. Work is currently in progress to confirm the growth rate of *Stolephorus* as this vitally affects interpretation of the population dynamics of this most important baitfish.

The session on reproductive biology that followed showed that *Stolephorus* and *Spratelloides* are continuous batch spawners in the tropics, with several spawning peaks per year that vary according to site, time and geographical area. Such continuous spawning, with often ill-defined modes, may hamper length-frequency analyses as following single cohorts is difficult. The spawning of both genera appears to be driven by food availability and an array of environmental factors (eg. moon phase, tidal phase, wind, rainfall and temperature), the influence of

each of which varies according to local conditions. The fish apparently maximise spawning success by varying the intervals between spawnings to coincide with favourable local conditions. Hence there is often no correlation between spawning times, even at sites close to one another. Therefore, high local fishing effort should not adversely affect the overall stock: fecundity, egg abundance in plankton and commercial catch data indicate that commercial catches in a baitground are supported by immigration of baitfish from other grounds.

It is significant that in both sessions three and four that no direct evidence of overexploitation was presented. Neither were there significant differences in the biology and ecology of baitfish between fished and unfished sites that could be attributed to fishing pressure.

Stock assessments of the Papua New Guinea baitfishery during its period of operation indicated that it was at about MSY. Catch and effort data from Solomon Islands suggested the occurrence of short-term overfishing at one site during a period of high effort in 1987. In Hawaii the spawning stock biomass was directly related to levels of exploitation.

Tuna baitfisheries do not exist in isolation. The pelagic target species form part of the reef fish community and hence fishing effects on baitfish may alter such communities, and possibly affect other fisheries. In the last session such interactions were discussed. In Solomon Islands a major concern was whether baitfishing reduced numbers of baitfish sufficiently to impact on their natural predators which form the basis of subsistence reef fisheries. In Solomon Islands, baitfish comprised about 25% of the diet of 28 predatory species. In Maldives only 10 species ate baitfish. To simulate the subsistence fishery in Solomon Islands, fishing competitions (using droplining, spearfishing and trolling) were held. Droplining was the predominant technique and contributed most to overall catch. Baitfish predators are primarily pelagic piscivores caught by trolling. A household survey was carried out in Solomon Islands using a purpose-designed questionnaire in order to obtain information relating to the subsistence fishing activities of rural communities. Results indicated that the lagoon areas near rural communities are most commonly used as fishing grounds and hand/droplinings is the dominant technique. A close correlation was found between the results of the survey and catch and effort data from the fishing competitions; the latter appear to be an excellent means of rapidly assessing subsistence fisheries. Most fish caught by the subsistence fishery in Solomon Islands do not eat baitfish. Unless there is a marked increase in trolling, there is little evidence that the commercial baitfishery in Solomon Islands has a direct trophic effect on the subsistence reef fishery. Conversely in Maldives at least four major baitfish predators are important in the developing reef fishery. Baitfish predators may become a significant proportion of artisanal catches in Maldives in the future.

Another possible effect of baitfishing relates to the by-catch of non-target species during baitfishing operations. These are primarily juveniles of reef species. The problem only exists with night light fishing as practised in the Pacific. Daylight baitfishing as used in Maldives catches few non-target species. In the final paper an attempt is made to quantify the numbers of juvenile reef fish caught in commercial catches in Solomon Islands. There was a seasonal pattern in the numbers and species taken. However, the relative importance of the mortality of juvenile reef fish caused by baitfishing remains unknown and requires further investigation.

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I Baitfish Resources

Tropical South Pacific Tuna Baitfisheries

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Abstract

Features of the tuna baitfisheries of the tropical South Pacific, which are based on nightly dipnet catches of primarily small clupeoid species (anchovies, sprats, herrings), are described. The three remaining fisheries (Solomon Islands, Fiji, Kiribati) provide strong contrasts in terms of size and species compositions. Biological characteristics of the important bait species are reviewed and two distinct life cycle strategies recognised. Recruitment appears to be environmentally influenced and fisheries are probably based on exploitation of numerous genetically distinct stocks. Several approaches to estimating yields are described, and are consistent in predicting sustainable yields (total catch of all species) of the order 1–2 t/km^2/yr. Tuna baitfisheries in the region tend to be self-regulating. It is concluded that there are, however, sufficient data currently available on which to base preliminary management plans should they be required, in particular circumstances.

POLE-AND-LINE fisheries for skipjack tuna (*Katsuwonus pelamis*) continue to be important to the economic livelihood of several South Pacific island nations, despite a global trend during the last decade, away from this labour-intensive method, towards the use of purse seine for reasons of economic efficiency. Pole-and-line fisheries are totally dependent for their success on the initial capture of live bait, typically small clupeoid fishes schooling in coastal coral reef waters. They have no intrinsic value in this context but the bait is used to induce an enhanced feeding response by tuna schools, enabling their capture by pole-and-line gear (feather lure with barbless hook and bamboo/fibre glass pole) (Ben Yami, 1980.) Production ratios (weight of tuna captured to weight of bait used) in the range 20 to 40:1 are typical in the region (Conand, 1988).

Tuna baitfisheries in the tropical South Pacific are multi-specific, and use gears designed to maximise the survival of target species. The species most commonly taken, anchovies (*Stolephorus*: Engraulidae) and sprats (*Spratelloides*: Clupeidae) are characteristically less robust in terms of post-capture survival following handling (netting, crowding, transfer to baitwells) than their temperate water (e.g. *Engraulis*) and eastern Pacific (e.g. *Cetengraulis*) equivalents (Yoshida et al., 1977), due to their very deciduous scalation (Smith, 1977).

The use in sheltered coastal waters of the stick held dipnet (Japanese: bouke-ami), a small mesh lift net which facilitates careful handling of the bait, has become almost universal in South Pacific baitfisheries, in association with underwater lights to attract the bait. Other gears which are widely used in small pelagic fisheries elsewhere, such as encircling nets (ring, lampara and purse seine nets), drive-in nets (oikomi-ami), beach seines and fish corrals have all been tried in various locations. They have in some cases supported commercial fisheries in the past e.g. oikomi-ami (PNG — Kikawa, 1977; Truk-Wilson, 1971) or in other cases used as supplementary bait sources (e.g. beach seine — Kiribati (Ianelli, 1988); coral head lift net — Tuvalu (Gillett, 1984)). Other than the continuing use of surround nets in Hawaii for day baiting, (Uchida, 1977), only bouke-ami gear is presently used in South Pacific live bait fisheries.

* Tuna and Billfish Assessment Programme, South Pacific Commission, P.O. Box D5, Noumea Cedex, New Caledonia.

Table 1. Baitfish catch by the SPC Skipjack Programme in Tropical South Pacific countries, grouped by predominant habitat type. (Habitats are: HI, high islands dominant; CO, high islands and atolls; AT, atolls; IS, exposed islands with limited or no fringing reefs; LL, limited lagoon area. Catches are kg per bouke-ami haul.)

Territories and countries	Habitat	Avg. catch/ haul	No. of hauls	Percentage composition by weight				
				Anchovies	Sprats	Sardines	Hardyheads	Other
Wallis and Futuna	HI	291	36	82.3	1.1	15.1	0.1	1.4
Fiji	HI	180	71	22.0	20.0	42.4	4.7	10.9
Solomon Islands	HI	148	60	43.0	11.1	22.2	0.8	22.8
New Caledonia	HI	130	40	62.5	3.7	15.1	0.3	18.4
Fed. Sts of Micronesia	CO	121	56	64.0	5.4	12.6	15.7	2.1
Papua New Guinea	HI	120	57	71.5	7.7	13.7	0.9	6.7
Average		165		54.4	9.3	22.7	3.6	10.1
Tuvalu	AT	100	15	0.0	90.3	0.0	4.6	5.1
Palau	AT	97	34	56.2	31.1	1.3	7.6	3.7
Western Samoa	HI/LL	80	14	69.5	1.3	1.3	0.0	22.9
French Polynesia	CO	78	98	0.7	17.4	64.6	0.0	17.3
Marshall Islands	AT	76	8	0.0	7.4	67.5	25.0	0.0
Kiribati	AT	57	21	0.0	29.3	8.9	25.0	36.7
Average		81		17.4	26.8	35.9	5.0	14.8
Cook Islands	CO	39	15	0.0	96.3	0.0	3.4	0.3
American Samoa	HI/LL	36	5	89.4	10.6	0.0	0.0	0.0
Vanuatu	HI/LL	35	5	29.4	34.6	10.4	17.6	7.8
Tonga	CO	34	32	23.8	16.3	15.5	19.2	25.3
Average		36		23.2	40.5	9.2	12.8	14.3
Pitcairn Islands	IS	0	0	0.0	0.0	0.0	0.0	0.0
Niue	IS	0	0	0.0	0.0	0.0	0.0	0.0
Nauru	IS	0	0	0.0	0.0	0.0	0.0	0.0
Tokelau	AT	0	0	0.0	0.0	0.0	0.0	0.0
Norfolk Island	IS	0	0	0.0	0.0	0.0	0.0	0.0

Tuna Baitfisheries

Potential for development

The availability of adequate quantities of suitable live bait species to support industrial level pole-and-line fisheries cannot be assumed (Kearney, 1975) and varies widely amongst the island countries of the tropical South Pacific, according to their size and physical configuration. Surveys by the SPC's Skipjack Survey and Assessment Programme, using standard bouke-ami gear and techniques (Hallier et al., 1982) have provided a yardstick for the realistic assessment of baitfishery potential.

Countries most likely to support baitfisheries are those with large high islands, numerous sheltered anchorages of moderate depth (20–40 m) inside the seaward coral barrier, extensive productive inshore habitat (mangroves, estuaries) and nutrient input from freshwater runoff (Argue, 1988). These include Papua New Guinea, Solomon Islands, New Caledonia, Fiji, Wallis Islands, and parts of the Federated States of Micronesia. Atolls and low islands provide smaller average catches, which over time are more liable to fluctuations in abundance e.g. Tuvalu, Palau, Marshall Islands, Kiribati. Some high islands e.g. Western Samoa, Vanuatu, American Samoa, Cook Islands (Rarotonga) lack extensive inshore lagoons and suitable anchorages, whilst other (mostly small) islands e.g. Nauru, Niue, Norfolk, Pitcairn are totally exposed without any shelter. Baitfishery potential in these cases is low or negligible.

Table 1, based on Argue (1988), summarises these findings, which clearly confirm the large high Melanesian islands as having the greatest potential for baitfishery development.

Species taken

Although a large number of teleost species show a positive phototactic response and are taken in dipnet hauls (over 300 species were identified in PNG waters — Lewis, 1977); less than 50 species are taken regularly enough to contribute significantly to catches.

The diverse baitfish species assemblage varies with habitat and geographic location. Within New Caledonian waters Conand (1988) distinguished species groups associated with coral reef, estuarine, and deepwater habitats, as well as ubiquitous species and one oceanic anchovy. Lewis (1977) and Kikawa (1977) recorded similar habitat associations. Stolephorid anchovies dominate high island catches, with contributions from sprats, herrings and sardines (Clupeidae), whilst sprats and sardines (*Amblygaster*) dominate atoll catches (Table 1). Minor contributions to overall catches in most locations are made by silversides (Atherinidae), cardinal fish (Apogonidae), fusiliers (Caesionidae) and chub mackerels (Scombridae). Table 2 lists the important bait species by family in the region. The species assemblage also contains numerous cogeneric pairs of co-occurring species with apparently very similar ecology e.g. *Stolephorus devisi* and *S. heterolobus*; *Spratelloides gracilis* and *S. lewisi*; *Amblygaster sirm* and *A. clupeoides*; *Selar crumerophthalmus* and *S. boops*. Additionally other genera (*Herklotsichthys, Dussumieria*) contain clearly separate morphs which are likely to prove to be sibling species with further study. The existence of these pairs is suggestive of fine scale habitat partitioning.

There is, in parallel with most coastal teleosts, a steady decline in species diversity eastwards from Papua New Guinea (Dalzell and Lewis, 1988).

Table 2. Baitfish species important to tropical South Pacific bouke-ami fisheries (Nomenclature from Lewis et al., 1983a and Whitehead et al., 1988)

ENGRAULIDAE (anchovies)	CLUPEIDAE (herrings, sardines, sprats)
*Stolephorus heterolobus**	*Spratelloides gracilis*
*S. devisi**	*S. lewisi*
*S. punctifer**	*S. delicatulus*
S. insularis	*Herklotsichthys quadrimaculatus*
S. indicus	*Amblygaster sirm*
Thrissina baelama	*A. clupeoides*
	Sardinella melanura
SCOMBRIDAE	*Dussumieria* spp
Rastrelliger kanagurta	
	ATHERINIDAE
APOGONIDAE	*Hypoatherina ovalaua*
Rhabdamia gracilis	*Atherinomorus lacunosus*
R. cypselurus	
	CAESIONIDAE
CARANGIDAE	*Gymnocaesio gymnopterus*
Selar crumenophthalmus	*Pterocaesio pisang*

* These species now referred to the genus *Encrasicholina* (Whitehead et al., 1988).

The taxonomy of baitfishes has proved difficult in the past, rendering much early biological work of doubtful value, but these difficulties have now largely been resolved (Lewis et al., 1983a; Baldwin, 1984, Whitehead, 1985, Whitehead et al., 1988[1]).

Bait species vary considerably in their attractiveness as live bait (Smith, 1977; Baldwin, 1977) with stolephorid anchovies probably the most attractive under a variety of conditions (Argue, 1988.) Sizes of 4–7 cm are preferred for skipjack fishing, but larger fish are frequently taken, with some of the commonly captured species groups (*Amblygaster, Rastrelliger, Decapterus*) attaining sizes in excess of 20 cm. The concept of tails per bucket comes into play, when assessing the fishing value of a given quantity of bait.

Existing baitfisheries

Economic factors have seen the cessation of domestic pole-and-line fisheries in several countries during the decade, including Papua New Guinea, New Caledonia and Palau. In addition, the large Japanese-based distant water pole-and-line fleet has been much reduced in size, but the efficiency of the remaining units, as reflected in average daily catch per unit effort (CPUE) has increased (Hampton, 1988). The bait fisheries of Solomon Islands and Fiji, with a smaller Kiribati fishery, are now the only active domestic ones in the region.

All bouke-ami baitfisheries in the region, past and present, share features in common. By the standards of small pelagic fisheries, nightly catches are relatively small (100–200 kg). Combined with the poor survival rates, this means that baiting operations are normally required each night. Fishing vessels invariably capture their own bait and have the flexibility to move freely between baiting areas, according to tuna and/or baitfish availability.

Distribution of baitfishing effort is related to the proximity of productive tuna fishing grounds, proximity of tuna unloading points, weather conditions relative to baiting ground aspect and, more recently, the location of deployed fish aggregation devices. As baiting occurs in most countries within areas subject to customary fishing right claims, access arrangements may also need to be negotiated, and can influence effort distribution.

The unit of catch in live bait fisheries is the bucket, used to transfer fish to bait wells. Rated wet weight of fish per bucket varies from 1.8 kg (Fiji — Lewis et al., 1983b) to 6.4 kg (Hawaii day baiting — Hida and Wetherall, 1977), but 2 kg can be considered typical. Baitfish catches are thus approximations in all cases, probably ±25%.

The appropriate unit of effort is the individual set, rather than the nightly catch, as several sets (up to 9 — Evans and Nichols, 1984) may be made each night. Even when these data are available, use of catch per set as an index of abundance may still be subject to problems. When bait is abundant, available bait capacity may be filled and the surplus catch discarded, unrecorded. In periods of poor tuna fishing, baitfishing efficiency may drop (and vice versa during periods of good fishing). When bait indications are poor, vessels may opt not to set the net, rather than incur a poor catch.

Bait catchability itself is also influenced by a variety of factors including, most importantly, the lunar cycle (Kearney, 1977), weather conditions (wind, current, turbidity), power of the light source (and possibly its spectral composition) and other more subtle species-specific environmental factors.

The three existing baitfisheries in the region provide marked contrasts — a large high island fishery relying on two anchovy species (Solomon Is.), a medium size mixed habitat multi-species fishery (Fiji) and a small atoll fishery (Kiribati). These are briefly described here and in more detail elsewhere in this volume.

Solomon Islands (7–11°S, 156–162°E)

From its beginnings in 1971, this fishery, probably the most productive in the region, has grown steadily to its present level of 35 pole-and-line vessels which landed 33,052 tonnes of tuna in 1988, utilizing 1.1 million buckets of bait, reportedly equivalent to 2500 tonnes (Diake, 1989).

Bait catches are heavily dominated by stolephorid anchovies, especially *S. heterolobus*, with smaller amounts of sprats and herrings (Table 1; Argue and Kearney, 1982; Evans and Nichols, 1984). Baiting areas are widely distributed throughout the country, with some concentration of effort on areas near the unloading points of Noro and Tulagi. The Western Province accounted for 79% of the 1988 baitfish catch (Diake, 1989).

Access to baitfishing grounds is subject to approval by traditional custodians, and royalty payments pro-rated on vessel size. Solomon Is. Government maintains and administers a register of approved baitfishing areas (Evans and Nichols, 1984).

Average nightly catches of >120 buckets have been recorded since 1981 when reporting of catches was regularised. Seasonality in catch

[1] The authors however inexplicably and unnecessarily confuse the *heterolobus devisi* distinction.

levels is not marked at this latitude, although species composition may show considerable change. The overall abundance of baitfish and multiplicity of sites impose few constraints on tuna fishing activities, although at least one instance of a sharp decline in production, believed to be fishery induced at Tulagi (Nichols, pers. comm.) is recorded. Bait is used generously and, although production ratios are relatively low, tuna catches are high. Evans and Nichols (1984) provide historic details of the fishery and preliminary information on the biology of the major species.

Fiji (16–19°S, 177E–178°W)

The Fiji pole-and-line fishery commenced commercial operations in 1976. At this more southerly latitude, both tuna availability and bait catches show more seasonality, the latter being strongly correlated with sea surface temperature. This collectively reduces the length of the viable fishery season in most years to approximately eight months (December-July). Fleet size has fluctuated, partly as a result of this, and peaked at 14 vessels in 1981 (Sharma, 1988). In 1988, 4300 tonnes of skipjack and yellowfin were landed by 11 vessels (Anon, 1989). Data on bait catches is incomplete for recent years, but yearly totals have never exceeded 150 tonnes. Baitfishery effort is widely distributed utilising at least 70 sites throughout the group (Lewis et al., 1983b). For analytical purposes, 11 zones with some consistency in habitat type are recognised.

The Fiji baitfishery is a multi-species one, with the sprats (*Spratelloides delicatulus*), sardines (*Amblygaster sirm*), herrings (*H. quadrimaculatus*), anchovies (*Stolephorus* spp.) and cardinal fish (*Rhabdamia gracilis*) all contributing significantly to catches. This species composition is subject to spatial, temporal and seasonal variation (Lewis et al., 1983b), but there does appear to be relative consistency in species composition by zone between years.

The importance of cardinal fish is partly due to targeting with deeper nets in specific areas, particularly when the catch of clupeoid species is poor. The biology of this species, as well as blue sprat and gold spot herring (Dalzell et al., 1987; Lewis et al., 1983b; Munch-Petersen, 1983), has been partly documented.

Northern Vanua Levu and Lomaiviti zones are the most important fishing zones. Nightly catches are considerably lower than Solomon Islands (average 50 buckets/night since 1980, and relatively stable), and tuna production ratios considerably higher, through more cautious use of available bait.

Kiribati (0–3°N, 172–174°E)

Following earlier survey work, the commercial baitfishery commenced in 1979 with a single vessel, growing to four by March 1983. Four atolls have been subject to baitfishing activity (Tarawa, Abemama, Butaritari and Abaiang), with the first named accounting for 70% of bouke-ami effort between 1977 and 1986 (Ianelli, 1988). Catches are dominated by blue sprats (*Spratelloides delicatulus*) with smaller amounts of sardines (*Amblygaster*) and herrings (*Herklotsichthys*). The biology of the blue sprat has been studied by McCarthy (1985). As to be expected in an atoll situation, average catches are low (39 buckets/night, 1977 to 1986) and variable. Two of the remaining three vessels shifted operations to Fiji at the end of 1987, as a result of difficulties in obtaining regular supplies of bait combined with a very poor fishing season. Bait fishing now occurs only intermittently.

Analysis of available data on this vulnerable fishery through 1983–1986 shows increasing prominence of herrings in the catch, seemingly at the expense of sardines. This was tentatively attributed to variable recruitment rather than the effects of the bait fishery (Ianelli, 1988).

The Kiribati fishery is unique in the region in that catches of wild bait, often inadequate, have been supplemented by quantities of pond cultured milkfish (*Chanos chanos*). Supplies to date have either been insufficient or not regular enough to entirely support commercial activity.

Previously active baitfisheries

Brief mention needs to be made of other baitfisheries previously active in the region.

Papua New Guinea (2–11°S, 142–156°E)

Throughout the 1970s and early 1980s, the Papua New Guinea baitfishery was the largest in the region, with a maximum tuna catch of 48 900 tonnes taken in 1978, utilising 1900 tonnes of bait (Tuna Programme 1984a). The fishery closed for economic reasons at the end of 1981 and, apart from a brief period of activity in 1984–85, has not resumed.

Without established shore bases fishing operations were centred on mother ships concentrating baitfishing effort in a few productive areas capable of supporting the activities of a fleet of vessels for extended periods. Four companies utilised six exclusive bait fishing areas around the Bismarck Sea, with others utilised seasonally in the Solomon Sea and Coral Sea. Ysabel Pass and Cape Lambert were the most productive of these. A large number of smaller anchorages are not used.

Catches were dominated, as in the Solomons, by stolephorid anchovies, but with sprats (*S. gracilis*) of considerable importance in Ysabel Pass. Average nightly catches in the range of 70–100 buckets were typical. Severe declines in catches were experienced in 1978–80 in Ysabel Pass and Cape Lambert fisheries, following retraction of effort to these areas, and rotational vessel quotas were introduced for a time (Wankowski, 1980).

The biology and population dynamics of the major species have been documented in a series of papers which are updated and summarised by Dalzell (these Proceedings).

Palau (7°N, 134°E)

Live bait fisheries in Micronesia, (bouke-ami and drive-in) produced under Japanese occupation 33 000 tonnes of skipjack in 1937, with 13 800 tonnes of this coming from Palau (Rothschild and Uchida, 1968). These fisheries ceased at the start of World War II. The Palau fishery, alone of the various Micronesian fisheries, resumed in 1964 and catches built up to an average of 6600 tonnes annually before closing down in 1982 (Tuna Programme 1984b).

Bait catches were dominated by *S. heterolobus* (90%) and reached a maximum of 220 tonnes in 1969. Growth and mortality of *S. heterolobus* and the dynamics of the essentially single species fishery were documented by Muller (1977).

New Caledonia (20–23°S, 164–167°E)

Three long range pole-and-line vessels operated in New Caledonia from August 1981 to April 1983 (Hallier and Kulbicki, 1985; Conand, 1988), following extensive earlier baitfish and tuna surveys.

Bait catches were favourable (65–80 buckets/night on average) for eight months of the year (December to July) and marginal (<40 buckets) for the remainder. The parallels with the Fijian fishery at similar latitudes are evident. The closure of the fishery was related to prevailing tuna market conditions, the level of tuna catch achieved and socio-political factors related to baitfishing. A small bouke-ami (one vessel) fishery remains intermittently active, providing fish for local consumption.

The baitfishery was a multi-species one, with stolephorid anchovies, herrings (*Herklotsichthys*), sardines (*Amblygaster*) and mackerel scad (*Decapterus*) contributing to overall catches. The biology of 20 species regularly taken was studied in detail during ORSTOM surveys (Conand, 1988), as was their relation to the environment and potential yield.

Other Areas

No other regional countries have supported commercial baitfisheries in the recent past, although some have demonstrated potential (e.g. Wallis Is.).

Biological Characteristics

Life cycle strategies

Although much remains to be learned about the dynamics of exploited populations of baitfish, work in the region has elucidated details of the basic biology of the more important species, particularly the stolephorid anchovies and sprats (*Spratelloides* spp.) Other species of lesser overall importance have been little studied with the exception of work in New Caledonia (Conand, 1988), where 20 commonly captured species were examined in varying detail. Age and growth have been estimated from modal progression analysis and reading of daily otolith rings, mortalities from analysis of catch curves, and reproductive details from gonad examination. Recruitment and early life history have been less well studied.

On the basis of available information, Conand (1988) and Lewis et al. (1983b) recognised two basic life cycle strategies in the baitfish which contribute to these multi-species fisheries:

Type 1

Species with a short life cycle (less than one year), which are relatively small in size (7–10 cm maximum), 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 important stolephorid anchovies (*S. heterolobus*, *S. devisi*, *S. punctifer*), the sprats of the genus *Spratelloides* (3 species) and an atherinid (*Hypoatherina ovalaua*).

Within this group, which includes the primary bait species and has thus attracted more study, the stolephorid anchovies show some periodicity in spawning (Dalzell and Wankowski, 1980; Dalzell, 1987; Evans and Nichols, 1984) and a relatively small number of individuals may survive into the second year of life. The sprats, on the other hand, spawn year round and probably rarely live beyond six months (Dalzell, 1985).

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 maximum), attain sexual maturity towards the end of the first year,

Table 3. Life history parameters for selected tropical South Pacific baitfishes.

Species	Location	L_∞	K	L max	T max	M	Spawning season	References*
TYPE 1 SPECIES								
Stolephorus heterolobus	Palau	9.1	2.1	9.0	(2.2)	4.0	n.a	Muller, 1977
Stolephorus heterolobus	PNG-Y.P.	7.9	2.6	7.2	1.0	5.2	May-June-November	Dalzell, 1987
Stolephorus heterolobus	PNG-C.L.	8.7	2.4	8.2	1.2	6.2	Apr-July	Dalzell pers. comm.
Stolephorus devisi	PNG-Y.P.	7.4	2.1	7.2	1.5	5.7	May-June-November	Dalzell, 1987
Stolephorus devisi	PNG-C.L.	7.4	2.4	7.2	1.3	7.4	Apr-July	Dalzell pers. comm.
Stolephorus devisi	PNG-FH.	7.8	2.0	7.2	1.3	6.9	n.a.	
Spratelloides delicatulus	Fiji	7.3	4.6	6.2	0.4	6.9	All year?	Lewis et al., 1983
Spratelloides delicatulus	Fiji	7.5	4.4	7.3	n.a.		n.a.	Munch Petersen, 1983
Spratelloides gracilis	PNG-Y.P.	7.6	4.3	7.0	0.5	11.3	All year	Dalzell, 1985
Spratelloides lewisi	PNG-Y.P.	5.5	5.4	4.9	0.4	8.9	All year	Dalzell, 1987
Spratelloides lewisi	PNG-C.L.	7.0	5.4	6.2	0.4	8.4	All year	Dalzell, 1987
TYPE 2 SPECIES								
Herklotsichthys quadrimaculatus	New Cal	15.5	1.54	15.9	2.0	5.01	Nov-Dec	Conand, 1988
Herklotsichthys quadrimaculatus	Fiji	12.6	2.0	12.2	1.6	3.53	Nov-Dec	Lewis et al., 1983
Herklotsichthys quadrimaculatus	(Kiribati	13.5	1.83	10.1	0.8	3.31)	n.a.	
Amblygaster sirm.	New Cal	22.9	1.5	22.9	2.0	n.a.	Oct-Dec	Conand, 1988
Amblygaster clupeoides	New Cal	24.5	1.82	25.0	2.0	n.a.	Oct-Dec	Conand, 1988
Stolephorus insularis	New Cal	11.9	3.01	12.3	2.0	n.a.	Oct-Dec	Conand, 1988
Stolephorus insularis	PNG	10.9	1.7	9.9	1.5	3.35	n.a.	
Rastrelliger kanagurta	New Cal	23.6	2.97	28.5	2.0?	n.a.	Sept-Oct	Conand, 1988
Decapterus russelli	New Cal	24.9	1.31	27.4	2.0+	n.a.	Sept-Oct	Conand, 1988
OTHER								
Rhabdamia gracilis	Fiji	5.0	2.67		1.0+?	n.a.	n.a.	Dalzell et al., 1987

Key: C.L. = Cape Lambert; F.H. = Fairfax Harbour; Y.P. = Ysabel Pass. Lengths in centimetres; K,M values annual.
* References primarily for spawning season data

spawn on a restricted seasonal basis, (September-December in the Southern Hemisphere, although this remains to be verified for equatorial areas), and have batch fecundities of the order of 300–500 oocytes per gram of fish.

These include the herrings and sardines (*Herklotsichthys, Amblygaster*), the mackerel (*Rastrelliger*), the larger anchovies (*Thrissina, Stolephorus indicus, S. insularis*) and sharp-nosed sprats (*Dussumieria*).

In a separate category are the mouth-breeding cardinal fish (*Rhabdamia*) with an annual life cycle (Dalzell et al., 1987), unknown length of spawning season and probable low fecundity.

Table 3 lists available information on K, L_∞, L max, and spawning season for six species in each life cycle type.

These life cycle differences have clear implications for exploitation. Type 1 species, with their short life span, high fecundity, rapid growth, and high natural mortality (thus high M/K value), would clearly seem more amenable to exploitation. The Type 2 species, with their slower growth, lower natural mortality and lower fecundity would logically be more vulnerable to depletion through exploitation.

Recruitment

Recruitment processes in tropical baitfish species as in tropical teleosts generally, are not well understood, and little or no egg/larval work has been done, other than on the Hawaiian nehu (*Stolephorus purpureus*) (Somerton, these Proceedings). It is to be expected that environmental influences on survival, particularly nutrient cycles in relatively nutrient-poor coral reef environments, will be considerable, and successful recruitment may only occur at particularly favourable times (windows). Dalzell (1987) concluded that anchovy spawning peaks in northern PNG are correlated with zooplankton production maxima. The restricted spawning season of the larger Type 2 species presumably coincides with the onset of favourable conditions. On the other hand, the very fecund sprats appear to spawn year round (Lewis et al., 1983b; Dalzell, 1985, 1987), with recruitment possibly occurring on a much less predictable basis, the probability of success determined by stochastic processes.

Dalzell (1984) found that annual yields in PNG of two stolephorid anchovies relative to rainfall fitted a parabolic function, indicating that rainfall up to a certain point may enhance recruitment, before turbidity and lower salinity negatively impact on catch rates. Muller (1977) noted a positive effect of rainfall on recruitment of *S. heterolobus* in Palau. No such relationship was found for *Spratelloides gracilis* in PNG (Dalzell, 1984), but Ianelli (1988) found, in Tarawa atoll, a positive correlation between yield and rainfall for *S. delicatulus*.

The stock-recruitment relationship has been investigated and found to be near linear for PNG stolephorids and *S. gracilis* (Dalzell, 1984) although the methods used to generate the data have been criticised by Garcia (1983). By contrast, Muller (1977) was able to fit a Ricker function to the essentially single species *S. heterolobus* fishery in Palau, the fit being improved by including a rainfall factor in the equations.

It is likely that both environmental factors and parental stock size interact to determine levels of recruitment in tropical baitfishes. Muller (1977) believed that, in the Palau fishery, recruitment was more dependent on environmental factors than the number of eggs spawned.

Stock relationships

Because of discontinuities in habitat, and their presumed inshore mode of spawning, baitfish populations are predisposed to division into genetically-isolated populations. In the only test of this reasonable assumption, (Daly and Richardson, 1980), allozyme variation amongst populations of baitfish species (*S. heterolobus, S. devisi* and *Spratelloides gracilis*) was examined at three sites in Papua New Guinea, (Manus Is., Ysabel Pass, C. Lambert) separated by deep ocean water. Populations of both anchovy species were found to be genetically isolated. Furthermore, within populations at the same site, some evidence of local differentiation was found. Sprat numbers available for study were insufficient to investigate differentiation, since the two species *S. gracilis* and *S. lewisi*, not formally separated taxonomically at the time, were inadvertently grouped. They were easily separable genetically.

With the rapid population turnover of the main species, the existence of unfished buffer zones in most baitfisheries and the probable division of stocks into a number of generally discrete but spatially overlapping units, it is clear why the few available examples of recovery from periods of heavy exploitation are rapid. This stock differentiation and the large number of fishing sites in most fisheries may help to explain the absence in baitfisheries of order of magnitude fluctuations seen in large coastal/oceanic fisheries for small pelagics (Lewis, 1984).

Yield Estimates

The application of surplus production models to total catch and effort data in baitfisheries has been relatively unsuccessful, the relationship in most cases proving to be linear e.g. Evans and Nichols (1984); Dalzell and Wankowski (1980), Sharma (1988). Given the difficulties with effort measures and the tendency to relocate baitfishing effort when catches start declining, this is perhaps not surprising. Additionally, these analyses typically involve aggregate data whereas it may be more appropriate to examine discrete geographic, single species situations.

When the catch has been separated into species components, some curvature has been apparent, at least for stolephorid anchovies (Dalzell and Lewis, 1988). A first approximation MSY of 0.6 t/km^2 was suggested for the two anchovies, with 0.48 t/km^2 attributed to *S. heterolobus* (Dalzell, pers.comm.). As has been noted earlier, however, environmental effects on both recruitment and catch rates must also be considered. Dalzell (1984), translating these approximate yields for anchovies (sprats not included) into total yields and vessel nights per year, suggests the northern PNG grounds could support one vessel per 30 km^2 of baitfishing ground.

Another approach, given that accurate and complete catch effort may not be available, involves use of virgin standing stock biomass estimates to compute MSY, where natural mortality estimates are available (Gulland, 1983; $MSY = 0.5\,MB_{\infty}$). Petit and Le Philippe (1983), in an echo-integrator survey of New Caledonian lagoons, obtained biomass estimates for small pelagics, giving a weighted mean of 0.465 t/km^2. Dalzell and Lewis (1988) and Dalzell (these Proceedings) used this approach for PNG, where fishing mortalities (F) and annual catches were known, to calculate standing stock biomass estimates, obtaining an overall mean of 0.43 t/km^2, very similar to the above.

A third approach (Dalzell and Lewis, 1988, following Marten and Polovina, 1982) uses the empirical relationship between primary productivity and potential pelagic fish yield for tropical small pelagics. Given available primary productivity estimates in South Pacific waters are in the range 18–46 $gC/m^2/yr$, potential yields in the range of 0.71 to 0.95 $t/km^2/yr$ can be expected. Assuming that 60–70% of pelagic fish production is attributable to small (baitfish) pelagics, potential yields of 0.46–0.62 $t/km^2/yr$ are obtained. These estimates could be applied to the known lagoon area in individual baitfisheries to obtain first order yield estimates.

Species Interactions

In multi-species baitfisheries, there are many possible species interactions at many levels, as a response to exploitation, and in unexploited populations. These may have fishery implications particularly in terms of the species mix. Several possible examples are discussed.

On the basis of their similar yield/annual rainfall response (Dalzell, 1984) and their additive contributions to standing stock biomass estimates, the two stolephorid anchovies (*S. heterolobus, S. devisi*) in northern PNG appear to exhibit a response to exploitation independent of their relative abundance. Dalzell (1984 and these Proceedings) suggests however that anchovy abundance oscillated in an antagonistic manner to that of sprats and that some interaction may be occurring. A study of the feeding habitats of these species in the same area (Chapau, 1983) revealed that there was limited dietary overlap between the anchovies and the sprat, but that fish eggs and larvae accounted for 80% of the total *S. gracilis* diet in Ysabel Pass, providing a possible basis for the interaction.

Ianelli (1988) in Tarawa lagoon (Kiribati) noted a gradual decline in sardine abundance, coupled with a corresponding increase in herring abundance. This was attributed to variation in recruitment. In Fiji, a similar decline in sardine abundance concurrent with increasing herring abundance, from 1983–1987 at one location, was indicated (Sharma, 1988).

Baitfishery Management

Tropical South Pacific baitfisheries present some problems for conventional fisheries management. The fisheries themselves are support fisheries only and the magnitude and distribution of baitfishery effort will normally be determined by tuna fishery factors. Effort will normally relocate if catch rates decline, unless available baitfishery sites are limited, as in small islands and atolls, fishing vessels are aggregated on a fleet basis, proximity advantages [e.g. to landing ports and fish aggregation devices (FADs)] outweigh the disadvantages of reduced catch rates.

Yield estimates probably need to be derived on an individual species/individual site basis, to be reasonably precise. Given the large number of baitfish localities utilised in most fisheries, this will not be practicable in Pacific Island countries.

Fisheries based on type 1 species (anchovies and sprats) are likely to be resilient, quick to recover following depletion, and largely self-regulating. Where there is evidence of a need to regulate effort (see examples above), there should be sufficient data available to frame a preliminary basis for management e.g. one vessel for 30–40 km^2 of lagoon, or a yearly maximum number of baiting nights.

Two other factors may however influence management of baitfisheries. Provision or denial of access to baitfishery areas by traditional custodians obviously will influence the disposition of baitfishery effort and can be invoked as a conservation measure. Secondly, there may be calls for the restriction of baitfishery activity if it is perceived to negatively impact on artisanal fisheries exploiting the same stock e.g. herrings (*H. quadrimaculatus*) or impact indirectly in a variety of ways e.g. reducing forage availability for reef fishes. Some of these issues are addressed elsewhere in these Proceedings.

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Tuna Baitfishing in Maldives

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THE Maldives form the central and largest part of the Laccadive Chagos ridge which extends southwards from India to the centre of the Indian Ocean. The whole of Maldives is made up of atolls and associated coral structures. Although its territorial area is considerable (90 000 km^2), a relatively small proportion of the total area (approx. 300 km^2) is dry land. There are 1302 islands, the majority of which are small, only nine exceed 2 km^2 and only three of these exceed 4 km^2.

Like many developing countries, the population of Maldives is increasing rapidly. From 1974–78 it rose by 36% from 128 212 to 200 000. Fifteen years ago the pole-and-line based tuna fishery was the main revenue earner. In recent years tuna fish revenue has almost been equalled by that of a rapidly expanding tourist industry. Population growth, and increased wealth from tourism and the fishing industries, has created a steadily increasing demand for building materials in the form of coral nodules and sand. Of particular concern is not only the apparent failure of mined reef flats to recover but the consequent loss of both coral and associated reef fish resources to the economy (Brown et al. 1989).

At the moment the reef dependent food fishery is under-exploited and as such is a target for expansion, especially as the currently fished tuna stocks appear to be exploited at a rate close to the optimum level.

The only reef resource exploited on a comparatively large scale has been the baitfish used in the pole-and-line tuna fishery. Baitfish are composed of reef associated species which are dependent on a thriving reef environment; they are collected at the reef edge and include species which require the intricate habitat provided by the coral reef.

Tropical live fish exports started in the early 1980s. It is a very well managed fishery based on strict monitoring of species, number, space and time.

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As reef resource use has expanded in the past 15 years, there has been much concern for research in the area of reef use. A series of programs to study man's interaction with the reefs' resources has been initiated through the 1980s.

Some of the studies include:

- description of the reef associated fishery, together with the biology and behaviour of the major commercial species and their trophic base,
- a socio-economic survey of the artisanal fishery,
- a comparative description of variations in degradation of the environment and associated variations in the abundance and species composition of the reef fish populations and fish catch in the artisanal fishery,
- a reef fish research and stock survey to determine the present levels of exploitation,
- investigations into the biology of the main bait species,
- use of concrete structures to investigate recruitment in a mined reef.

This paper describes the Maldivian live bait fishery in this context.

The Tuna Industry

The Maldivian tuna fishery forms one of the main components of the national economy. It provides a major source of employment, food and export earnings. Most tuna caught are taken by pole-and-line. This requires copious supplies of small live fish which can be used as bait. Indeed something of the order of 5000 tonnes of live bait are used annually by Maldivian pole-and-line fishermen.

Knowledge about the status of the livebait fishery is important not only because fishermen rely directly on regular and plentiful supplies of bait for their fishing activities, but also because monitoring of the status of the tuna fishery depends on an understanding of the effects of variations in bait availability and use on tuna catches. For these reasons the Ministry of Fisheries in the Republic of Maldives is actively involved in research on baitfish resources. Some monitoring is carried out during the course of normal activities. In addition, a major investigation into the biology of the main bait species is being carried out by the Ministry's Marine Research Section in conjunction with the CSIRO Marine Laboratory, Cleveland, Australia. This project is funded by the Australian Centre for International Agricultural Research (ACIAR).

Information on the Maldivian livebait fishery is given by Jonklass (1967), Munch-Petersen (1978), Anderson (1983) and Anderson and Hafiz (1984). The livebait fishery at Minicoy in the Laccadives is very similar to that in the Maldives and has been described in some detail (e.g. Jones, 1958, 1964).

The Fishing Method

Maldivian pole-and-line vessels, or masdhonis, only do one-day fishing trips. They typically leave their islands for baitfishing on nearby reefs just before dawn; travel to the tuna fishing grounds outside the atolls once enough bait has been collected; and return with their catch in the late afternoon or early evening.

At any season fishermen will know which reefs near their islands are most likely to have baitfish. The boat will cruise along the side of the reef until a likely spot is located. The dhoni will then anchor alongside the reef using the wind and current to hold it off. At this point plugs in the hull are removed in order to flood the bottom of the boat. The baitfish, once caught, are kept in the flooded hull.

As soon as the dhoni is secured in position the bait net is prepared. The net is of fine mesh and roughly 7 m square. It is deployed as a simple lift net. To submerge and spread the net, its four corners may be tied to the ends of four long poles. One fisherman holds each pole. More often, the two outer corners of the net will be tied to lines weighted with coral rock. To help spread the net underwater two further lines, which run to the far side of the boat, may be used. An increasingly common practice used particularly in the capture of deeper schools, is to dispense with the poles altogether and use four weighted lines. The two outer ones are controlled by swimmers in the water. They may use the sailing spar or some other form of float for support, or they may be completely free swimming.

Once the net is in position the bait may be driven by swimmers or lured with fish paste. The net will then be hauled rapidly to the surface and the captured bait flipped into the flooded hull of the dhoni. The process will be repeated several times, perhaps with one or more changes of site, until enough bait has been caught. The dhoni will then leave for tuna fishing outside the atoll.

While the great majority of bait catches are made with a lift net, another method is occasionally used. At islands with large shallow lagoons bait may sometimes be caught by chasing into a large hand-held net. The bait may be driven by splashing, or herded by a longline with suspended coconut fronds.

If any bait is left at the end of the day or if baitfishing is carried out in the afternoon, for example on a Friday, the bait will be kept for use the next day. Since an adequate circulation cannot be maintained in a stationary dhoni the bait will be transferred to a floating bait box.

Recent developments

In recent years there have been several developments in the bait fishery. While not altering its overall character they have certainly made it a much easier operation. These include:

1. The use of bait nets made from nylon instead of cotton. The old nets required a considerable amount of maintenance and had a relatively short life. The new nets are almost maintenance free, long-lasting and relatively cheap. The introduction of the nylon nets started in the 1950s.

2. A related change has been in the keeping of bait overnight. This is now frequently done in the bait net itself. It is rigged over the side of the dhoni, its sides are supported by poles and its centre is weighted with coral rocks so that it dips into the sea. While bait boxes are still in wide use their wooden slatted sides are increasingly being replaced by netting.

3. Diving masks were introduced to Maldives on a large scale after the start of organised tourism in 1972. Their use spread rapidly throughout the country. Masks make it much easier for the fishermen to locate schools of baitfish on the reef, and to catch them once located. Prior to their introduction fishermen would flick coconut oil on to the water to improve through-surface visibility. The use of masks was also instrumental in the increasing use of swimmers to deploy the bait net, and the less frequent use of long poles from the dhoni.

4. The mechanisation of masdhonis, which started in 1974–5 not only revolutionised tuna catching because of increased speed and manoeuverability on the fishing grounds, but also improved the maintenance of bait within the boat. In sailing masdhonis water circulation had to be maintained by constant bailing. This full-time, back-breaking, job was normally rotated

between crew members. With an engine it became possible to pump water out in order to maintain circulation, thereby relieving the crew of this arduous duty.

5. A related development was the introduction of much larger holes in the vessel's hull for improved water circulation. An old vessel would have up to about 30 small holes, each little more than 1 cm in diameter, drilled through its hull. Many vessels now have a couple of larger holes, about 6 cm in diameter. When the boat is moving a plastic tube with an angled end inserted into one of these holes can be used to force water into or out of the hull, depending on which way the angled opening is facing. This development was apparently recommended by two Hawaiian masterfishermen who visited the Maldives in the early 1980s.

The Bait Species

A wide variety of fish species is available for use as livebait by Maldivian fishermen. In fact over 20 species are in regular use. However, there are three major categories that dominate the fishery: fusiliers (Caesionidae), sprats of the genus *Spratelloides* and cardinal fishes (Apogonidae).

Juvenile fusiliers, known locally as muguraan, are considered to be very good baitfish. They are relatively easy to catch, are good chummers, and fairly hardy. Several species are taken, most fishermen recognising between four and seven varieties. Following the recent revision of the Caesionidae by Carpenter (1987) the identification of fusiliers in Maldivian livebait catches is being re-examined. Of the 13 species listed by Carpenter as known from or likely to occur in the Maldives the following are definitely used as livebait: *Caesio caerulaurea*, *Pterocaesio tila*, *P. chrysozoma*, *P. pisang* and *Gymnocaesio gymnoptera*.

Two species of *Spratelloides* (F. Clupeidae) are important as live bait: the silver sprat *S. gracilis* known locally as rehi (*S. japonicus* is a synonym) and the blue sprat *S. delicatulus*, known as hondeli. Of the two, *S. gracilis* is the more common. It is easy to catch in large numbers when in season, and with its silver striped sides makes excellent chum. However, both this species and *S. delicatulus* suffer high mortality in captivity and cannot be kept overnight.

Several species of apogonids, including the genera *Apogon*, *Archamia* and *Rhabdamia*, are used as bait. Maldivian fishermen recognise two major varieties. Broadly speaking, red coloured species which live on reefs are called boadhi, while pale coloured ones which live in lagoons are called fathaa. Boadhi are more important. Schools of them tend to be found rather deep and sheltering close to corals so are difficult to catch. As a result boadhi have only been caught in substantial quantities in some areas since the introduction of diving masks. In other areas, such as Lhaviyani Atoll where fishermen have been adept at deep diving, boadhi have always formed a major part of the livebait catches.

These three categories account for most of the bait used in the Maldives (see below) but a number of other varieties are also used on a more or less regular basis. These include two Pomacentrids: *Lepidozygous tapeinsoma* (bureki) and *Chromis caerulea* (nilamehi). Although they live in shallow water both are rather difficult to catch because they hide among the corals. Nevertheless both are hardy and good chummers. Other varieties which can be caught in shallow lagoons, and which tend to be hardy but relatively poor chummers, include juvenile scads (Carangidae) such as *Selar crumenophthalmus* (mushimas) and *Decapterus macarellus* (rimmas); sardines (Clupeidae) of the genus *Sardinella* (gumbalha); hardyheads (Atherinidae) which are usually known as hikaa. Anchovies (Engraulidae: *Stolephorus*) known locally as miyaren do not form a major component of the livebait catch. This seems to be one of the main differences between the Maldivian livebait fishery and those of the Pacific (cf. Sakagawa, 1987). Miyaren occur infrequently, but when they are present they can usually be caught in large quantities. Miyaren do not survive well in captivity. Anecdotal evidence suggests that they may occur more often in the south of the Maldives than in the north.

Catch composition

Interviews with experienced chummers from more than 30 fishing islands suggested that muguraan (Caesionidae), rehi (*Spratelloides gracilis*) and boadhi (Apogonidae) are the most important bait varieties. This is borne out by two sets of quantitative data.

Since January 1986 the Ministry of Fisheries has been recording the main variety of bait used by each pole-and-line masdhoni landing its catch at Male market in the afternoon. The data for 1986 and 1987 are summarised in Table 1. (In cases where two bait varieties contributed significantly to a boat's catch each was given a value of 0.5 boat days utilisation).

Another source of information is a small survey of baitfishing activity conducted at a number of islands throughout the Maldives. Cooperative chummers were asked to maintain a baitfishing logbook for a number of weeks or months. Among the information requested were details of the main bait variety taken during each period of baitfishing. The results are given in Table 2.

Table 1. Summary of bait utilisation at Male in 1986 and 1987.

Family	Species	Local name	No. of boats 1986	No. of boats 1987	% of boats 1986	% of boats 1987
Caesionidae	—	Muguraan	3444	4378	48.85	63.51
		Kudhien	—	6	—	0.09
Clupeidae	*S. gracilis*	Rehi	2418	1401.5	34.3	20.33
	S. delicatulus	Hondeli	85	61	1.21	0.88
Apogonidae	—	Boadhi	613	762	8.7	11.05
		Fathaa	56.5	14	0.80	0.20
Pomacentridae	*L. tapeinosoma*	Bureki	384	120.5	5.45	1.75
	C. caerulea	Nilamehi	18.5	64	0.26	0.93
Carangidae	*S. crumenophthalmus*	Mushimas	6.5	36	0.09	0.52
	D. macarellus	Rimmas	5	6	0.07	0.09
Atherinidae	*Allahetta*	Thaavalha	10	15	0.14	0.22
	—	Keravalha	3	6	0.04	0.09
	—	Hithiboa	3	1	0.04	0.01
Engraulidae	*Stolephorus*	Miyaren	2.5	3	0.04	0.04
Labridae	—	Hikaa	1	—	0.01	—.
Unknown juveniles		Lhaen	—	19	—	0.28
Total			7050	6893	100.0	99.99

A summary of both data sets is given in Table 3. There is a small difference between the two: the Male data refer to numbers of days of use, the logbook data to numbers of baitfishing operations. The difference is that hardier species may be used for more than one day after being caught. This does not, however, alter the overall conclusions.

The most important group is clearly the Caesionidae, of which several species are used. The most important single species is undoubtedly *Spratelloides gracilis* which probably contributes something of the order of 25% to the total baitfish catch (in terms of number of boat-days of use). The three major groups (Caesionidae, *Spratelloides* and Apogonidae) together comprise over 90% of the total.

Beyond such generalisations too much reliance should not be placed on these data. Although the data from Male are comprehensive they only refer to one locality. On the other hand the logbook data, while coming from a number of widely spaced islands, is hardly comprehensive. Important regional and seasonal variations will probably have been overlooked. Major inter-annual variations also occur in the case of *Stolephorus*, which may exhibit major temporal as well as regional variations. A final point is that the method of recording the data (i.e. main bait variety contributing to day's catch) will tend to overrepresent the major varieties and underrepresent the minor ones.

Seasonal variation

A limited amount of information about seasonal variation in baitfish utilisation is available from Male sampling and from interviews with experienced chummers.

The monthly utilisation of major bait varieties at Male during 1986 and 1987 is summarised. In Male the use of *S. gracilis* (rehi) is greatest during the SW monsoon season. It appears to occur along the eastern side of the Maldives mainly in the NE monsoon season. (This statement and those following must be regarded as preliminary).

At Male in 1986 and 1987 the largest quantities of boadhi (Apogonidae) were taken at the end of the NE monsoon. There is no clear pattern of seasonal utilization in other atolls. Most chummers report that it is present in both seasons, utilisation perhaps depending to some extent on the availability of other varieties.

Muguraan (Caesionidae) are available year round in Male, and most other parts of the Maldives. They are, however, apparently taken most frequently during the NE monsoon season in the north of the Maldives, and during the SW monsoon season in Vaavu and Meemu Atolls to the south of Male.

Bureki (*Lepidozygous tapeinosoma*) is apparently present year round in many localities. In Male and atolls to the north it is taken mainly during the NE monsoon. To the south there is no clear seasonal pattern, although on many islands it is used during the intermonsoon period between the NE and SW seasons, presumably when other baits are scarce.

Thaavalha (Atherinidae) are used by fishermen on the east of the Maldives mainly during the NE monsoon if other varieties are not available. Although thaavalha is not a very attractive bait for tuna, much of the fishing during this season takes place around drifting flotsam.

Table 2. Summary of information on time spent baiting (i.e. time between leaving island and completing baiting operation) and on utilisation of bait varieties from bait fishing logbooks.

Island	Period	No. Days	Time spent baiting (minutes)			Bait varieties used				
			Mean	Min.	Max.	Caesionidae	Apogonidae	Spratelloides	*Stolephorus*	Others
R. Alifushi	1/87–1/88	136	222	45	355	90	32.5	10	—	3.5
Lh. Naifaru	7/84–9/84	42	237	148	380	10	13.5	8.5	—	—
K. Gaafaru	4/85	18	270	65	360	—	3	15	—	—
K. Male	8/83–9/83	23	192	125	270	13	—	10	—	—
A. Maalhos	3/86–4/86	24	217	175	267	24	—	—	—	—
Dh. Kudahuvadhoo	3/87–11/87	48	239	155	327	3	10	35	—	—
L. Hithadhoo	3/87–11/87	94	293	90	630	51	34.5	3	1.5	4
G.Dh. Thinadhoo	5/87–11/87	87	85	15	215	2	0.5	40	31	13.5
Total	—	472	214	15	630	193	94	131.5	32.5	21

Table 3. Percentage composition of bait catch, by major groups, from Male as recorded by Ministry of Fisheries, and from various islands as recorded on baitfishing logbooks.

	1. Male 1986–87	2. Various islands (see Table 2)
Caesionidae	56.1	40.9
Spratelloides	28.4	27.9
Apogonidae	10.4	19.9
Pomacentridae	4.2	1.3
Carangidae	0.4	1.1
Atherinidae	0.3	2.0
Engraulidae	0.04	6.9
Others	0.2	0.1

Baitfish biology

A considerable amount of information on the biology of the major bait species is being collected under the auspices of the Ministry of Fisheries/CSIRO Baitfish Research Project. This will be published in due course, and a brief summary is given here.

Length measurements of regular bait samples are being collected. Representative length frequency histograms of most of the bait are within the range 2–7 cm standard length, although caesionids of slightly larger size are sometimes used. This compares with an estimated optimum size range of 2–6 cm for fishing skipjack off Hawaii (Yuen, 1977).

Growth estimates from length frequency data are being supplemented by studies of daily growth rings in otoliths. Information is also collected on reproduction, feeding and predation.

Catch Estimates

Daily bait catch estimation

The only data available come from three fishing trips in March–May 1985, when the amounts of bait (Caesionids) caught by a masdhoni were weighed. The average from the three days was 25 kg, but this was felt by the crew to be less than the amount that would normally be taken for a day's fishing. As a first approximation it is roughly estimated that the amount of bait used per day is 30 kg.

This applies to hardy species such as caesionids, apogonids and pomacentrids but may be an underestimation for the more delicate *Spratelloides* and *Stolephorus*. These varieties are apparently taken in larger amounts, both because they are normally present in huge numbers when available, and to offset their high mortality in captivity. It is therefore roughly estimated that the amount of *Spratelloides* and *Stolephorus* used as bait in one day is 40 kg.

There are plans to refine these preliminary approximations, but they will be used here as working estimates in order to calculate annual bait catch.

Annual bait catch estimation

The annual fishing effort by the pole-and-line fleet, in numbers of boat days, is given in Table 4 (data from Anderson, 1986 and Ministry of Fisheries unpublished data). The average annual effort in 1985–87 was about 160 000 days.

Two estimates of the frequency of usage of different bait varieties are given in Table 2. These are subject to many inadequacies, but in order to roughly quantify total bait usage the following crude 'averages' are suggested:

Cacsionidae	49%	i.e. 78 400 days.
Spratelloides	28%	44 800 days.
Apogonidae	15%	24 000 days.
Stolephorus	3%	4 800 days.
Pomacentridae	2%	2 200 days.

From the above, the average amount of *Spratelloides* and *Stolephorus* is estimated at 30 kg. However, these species, if not used on one day, may be kept for the next. To roughly allow for this the estimated number of days on which they are fished is reduced by 5%. The following catches are estimated:

Caesionidae	2230 ± 560 t
Spratelloides	790 ± 450 t
Apogonidae	680 ± 170 t
Stolephorus	190 ± 50 t
Pomacentridae	140 ± 35 t
Others	90 ± 25 t
Total:	5120 ± 1290 t

A confidence interval of ±25% is arbitrarily assigned to these estimates. Given the uncertainties in estimating average weight by bait used per day, and the percentage species composition for the whole country, this may not be too large. Annual variations between groups may be considerable. The estimate for *Stolephorus* may be particularly inadequate.

Despite its uncertainties this estimate of about 5000 t of baitfish used per year is important because it is the first one made and it gives some idea of the magnitude of the fishery. In 1978–1981, a few years after the start of mechanisation in 1974, fishing effort had dropped to about 100 000 days per year (Table 4). Annual bait usage might have

Table 4. Number of days fished, total tuna catch, and average tuna catch rates of sailing and mechanised pole-and-line vessels in the Maldives.

Year	No. days fished		Total tuna catch (t)		Average tuna catch rate (kg/day)	
	Sail	Mech.	Sail	Mech.	Sail	Mech.
1960	151 218	—	20 364	—	135	—
1961	163 903	—	24 603	—	150	—
1962–65	...	—	...	—	...	—
1966	192 722	—	20.193	—	105	—
1967	185 952	—	21 553	—	116	—
1968	165 511	—	20 122	—	122	—
1969	...	—	22 182	—	...	—
1970	191 421	—	31 884	—	167	—
1971	169 237	—	32 351	—	191	—
1972	158 544	—	22 831	—	144	—
1973	215 278	—	31 708	—	147	—
1974	203 362	—	32 411	—	159	—
1975	171 808	4 200	21 122	1 032	123	246
1976	153 539	21 800	20 474	6 220	133	285
1977	104 943	41 300	11 440	9 691	109	235
1978	53 739	54 800	5 460	12 891	102	235
1979	24 615	74 904	2 865	20 227	116	270
1980	16 877	83 134	2 131	26 176	126	315
1981	13 852	83 731	1 109	25 528	80	305
1982	10 036	97 085	633	21 504	63	221
1983	6 339	117 172	473	29 184	75	249
1984	6 220	153 460	322	41 747	52	272
1985	4 681	162 430	416	50 602	89	312
1986	3 354	161 910	346	51 997	103	321
1987	2 355	158 785	251	50 343	107	317

been about 3000–3500 t. Much higher levels of effort were recorded in earlier years, the peak of 215 278 days being recorded in 1973. It is interesting to note that in 1960–61 the average effort was about 160 000 days — the same as it is today. Whether annual bait utilisation then was similar to that today or was lower, reflecting the lower average catches of tuna by sailing masdhonis compared to mechanised ones, is a matter of speculation.

Tuna catch per unit bait (CPUB)

The average daily catch of tuna by mechanised masdhonis during 1985–1987 is estimated at 317 kg Table 4). If an annual bait consumption of 5120 t over 160 000 days is assumed, this gives an estimate of 10 kg of tuna per 1 kg of bait. Given uncertainties in the estimates, and the possibility of annual, seasonal and regional differences in catch rates the average may lie within the range 7–13 kg of tuna per 1 kg of bait. This compares well with estimates of average tuna CPUB from Japan, Hawaii and the Eastern Tropical Pacific (7.5–15.9) but is much lower than estimates from the Western Tropical Pacific (22.4–30.4) as reported by Sakagwa (1986).

Fishery Interactions

That tuna pole-and-line fishing in fact comprises two fisheries, one for livebait and the other for tuna, is well known. In the Maldives both are normally carried out on the same day, the livebait being caught first thing in the morning before going offshore for the tuna. Time spent baitfishing is therefore time lost for tuna fishing. This is especially important since tuna is said to feed best in the morning. A few masdhoni owners have apparently started operating additional vessels purely to catch bait. If this practice became widespread it could have a significant impact on tuna catch rates.

Records of time spent on baitfishing (defined as time from leaving the island to finishing the baitfishing operation) were collected during the logbook survey. Results are summarised in Table 3 and Figure 1. The average time spent baiting was about 3.5 hours, although there is considerable variation between days. There may be significant differences in mean baiting time between seasons, species, islands and regions although these have yet to be quantified. (The group of short baitfishing times depicted were nearly all achieved by a masdhoni fishing for *Spratelloides* and *Stolephorus* from the island of G. Dh. Thinadhoo). When bait is scarce virtually the whole day may be spent searching for and catching enough bait for tuna

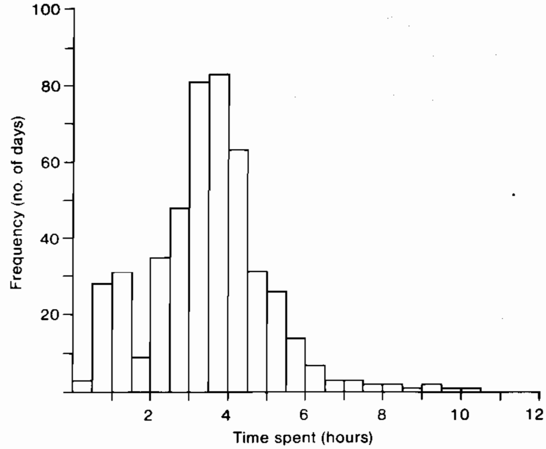

Figure 1. Time spent baitfishing (i.e. time from leaving island to completing the baiting operation).

fishing the next day. Baitfish are, however, only rarely completely unavailable in the Maldives. In the logbook survey (1987) chummers from four islands (R. Alifushi, Dh. Kudahuvadhoo, L. Hithadoo and G. Dh. Thinadhoo) were asked to record the reasons why they did not go fishing on any particular day. Of 389 days on which no fishing was carried out, on only one was lack of bait given as the reason. (The major reasons were public holidays, including Fridays, other business, poor fishing and bad weather).

Fishermen do suggest that bait abundance, particularly that of rehi (*S. gracilis*), has decreased over the years, but the evidence for this is purely anecdotal. Reef fishing activities, particularly tangle netting for sharks are believed to disperse bait schools. Long term weather changes are also cited. Collecting of black corals is sometimes said to deplete boadhi (apogonid) stocks. Coral mining activities are not generally thought to affect bait resources.

Reef fisheries have never been of prime importance in the Maldives, and catches are not accurately recorded. Current catches are, however, of the order of 10 000 t/yr. A baitfish catch of about 5000 t is therefore a significant component of the total fish removal from the reefs. The species involved in the edible reef-fish fishery and the livebait fishery are to a large extent different. Efforts to expand the reef fishery might not therefore be expected to have much direct impact on the bait fishery. Since the fisheries for edible reef fish concentrate on the carnivorous species such as snappers (Lutjanidae), groupers (Serranidae) and jacks (Carangidae) which presumably prey on bait species, increased effort might even increase bait abundance. There is some overlap between the two fisheries. Adult caesionids are taken in small quantities for human consumption and as bait for larger fish. Adult mushimas (*Selar crumenophthalamus*) are caught by small pole-and-line and eaten in large quantities; however, juvenile mushimas form only a very minor component of the bait catch. Rehi (*S. gracilis*) is eaten in small quantities (deep fried like whitebait) but only the left-overs from fishing are used.

There is some bycatch of non-target reef species in the bait fishery. Personal observations suggest that surgeon fish (Acanthuridae) and wrasses (Labridae) are the main species taken, but many fish species are involved. The percentage of the catch which comprises non-target species varies between 0–30%. Many undesired species will be returned alive to the sea, but there may still be a few hundred tonnes removed annually.

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Development of the Pole-and-Line Fishery in Solomon Islands with Reference to the Baitfishery and Its Management

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Abstract

The pole-and-line fishery for skipjack tuna in Solomon Islands has grown since its inception in 1971 to become a mainstay in the national economy, producing 33 051 t of tuna in 1988, and utilising 2 498 t of baitfish. The development of both the pole-and-line fishery and the night-time fishery for baitfish are described. A system for monitoring and control of the domestic pole-and-line fleet's baitfishing activities is outlined, along with recent investigations of the major baitfish species.

SOLOMON Islands, with a 1986 population of around 286 000, consists of many islands extending over 1400 kilometres in the Southwest Pacific, between longitudes 155° 30′E and 170° 30′E, and between 5°10′S and 12°45′S (Figure 1).

Fish has traditionally comprised a major component of the protein diet of the people of Solomon Islands. Prior to 1971, fisheries products were harvested mainly by subsistence methods such as hand-gathering, and limited use of nets and lines.

Since 1971, there has been growth of a cash economy which has made fisheries products sources of both food and income. There has also been quite remarkable growth in commercial tuna fishing to the point where the fishing industry is now pre-eminent in foreign exchange earnings and private-sector employment. In 1988, approximately 37 842 t of marine products, primarily tuna and tuna products, worth SI$84.7 million, were exported, accounting for just under 50% of that year's total foreign exchange earnings of SI$170.6 million. In comparison, the 1971 earnings represented only 14% of the total. Clearly, the tuna fishing industry now plays a major role in the Solomon Islands economy.

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Commercial fisheries in Solomon Islands are based primarily on skipjack tuna (*Katsuwonus pelamis*) resources which are estimated to have a sustainable yield of (at least) 75 000 t per year (Gibson, 1985). Solomon Islands Government's (SIG) views on skipjack were largely influenced by the results of a Skipjack Survey and Assessment Programme (SSAP) carried out in Solomon Islands waters by the South Pacific Commission (SPC). This tagging study executed in 1977 and 1980 showed that skipjack were abundant in the fished area of the country (Kleiber, Argue and Kearney, 1983). The estimates of population size were the highest for the countries of the SPC area; the 1980 estimate of 89 000 t represented 3% of the estimated standing stock for the whole SPC study area, and this from a fished area in Solomon Islands of less than 0.5% of the total study area (Argue and Kearney, 1982).

The domestic skipjack tuna fishery utilises the pole-and-line and purse seine methods. Annual production during recent years has been between 35 000 and 40 000 tonnes. Skipjack account for over 90% of the catch of pole-and-line vessels, or catcher-boats as they are called in Solomon Islands, each year, with the remainder comprised of juvenile yellowfin tuna (*Thunnus albacares*). A small percentage of by-catch species are also taken including rainbow runner (*Elegatis bipinnulatus*), dolphin-fish (*Coryphaena hippurus*) and frigate mackerel (*Auxis thazard*), and these generally account for around 1% of the total. These by-catch species are often retained and exchanged for fruit and vegetables with local villagers.

1988 saw a record catch of tuna from the waters of Solomon Islands, totalling 51 780.3 t for all gears (Table 1). Of this, operations of the two domestic tuna companies, Solomon Taiyo Ltd. (STL) and National Fisheries Developments Ltd. (NFD) accounted for 43 771.6 t (85%) of the total, with 33 051 t (or 76% of the total domestic catch) taken by the pole-and-line fleet; 2497.6 t of baitfish were caught by local pole-and-line vessels during the year (SIG, 1988).

Clearly, pole-and-line fishing is the mainstay of the tuna industry, although this situation may change with an expected increase in domestic purse seining operations. However, due to the greater employment factor of the pole-and-line method, plus the disbursement of funds to rural communities through baitfish royalty payments and the superior prices commanded by pole-and-line caught fish on world markets, indications are that the pole-and-line fishery is likely to play a dominant role in the nation's tuna industry for the foreseeable future.

Considering the relative importance of the domestic pole-and-line fishery to the national economy, the Fisheries Department of the Ministry of Natural Resources has devoted considerable effort to fostering further developments in this fishery, as well as maintaining a regulatory role. The parallel baitfishery, which supplies the domestic fleet with a nightly supply of high quality baitfish, is in its own right an important commercial fishery; providing as it does monetary payments to rural populations for access by the pole-and-line fleet to lagoon/reef areas for the purpose of taking bait. To this end, the Fisheries Department has implemented and developed over the years a system of monitoring the catch and effort of both the pole-and-line (Nichols and Maruyama, 1988) and baitfish fisheries (Evans and Nichols, 1984). As commercial pole-and-line fishing has expanded, concerns have been voiced over the possible effect that baitfishing may be having on reef fish communities, the perceived risk being that baitfishing removes the small fishes upon which reef fish prey, which are in turn important to rural people as a food source and a means of generating cash incomes.

This paper outlines the development of the commercial pole-and-line and baitfish fisheries within Solomon Islands and the methods the Solomon Islands Fishereis Department has developed for monitoring and control of these activities. A recent program to investigate the biology of

Table 1. Tuna fishery overview, by gear types and year.

	Domestic				Foreign access			
Year	Pole & line	Group p/seine	Single p/seine	Longline[a]	Jap. longline[b]	Jap. pole/line[b]	U.S. seiners[c]	Total (t)
1988	33 051.7	6 646.0	4 073.9	—	7 662.7	188.0	158.0	51 780.3
1987	23 925.1	7 333.0	537.0	—	788.3	79.8	—	32 663.2
1986	38 645.0	5 943.2	—	—	2 910.1	61.5	—	47 559.8
1985	25 234.9	5 762.9	—	242.2	4 547.8	3,323.4	—	39 111.2
1984	30 599.6	5 447.2	—	363.0	1 128.4	414.5	—	37 952.7
1983	29 266.4	5 415.3	—	552.0	2 175.8	0.0	—	37 409.5
1982	17 322.2	3 091.2	—	350.7	3 139.7	383.5	—	24 287.3
1981	22 626.0	2 873.4	—	209.0	4 827.7[d]	801.9	—	31 338.0
1980	21 935.5	961.8	—	818.0	2 739.1[e]	545.9	—	27 000.3
1979	23 800.9	—	—	715.0	2 603.8	535.1	—	27 654.8
1978	17 454.7	—	—	300.0	192.1	19.1	—	17 965.9
1977	12 115.2	—	—	287.0	—	8 138.0	—	20 540.2
1976	15 799.1	—	—	212.0	—	19 865.0	—	35 876.7
1975	7 169.1	—	—	—	—	8 255.0	—	15 424.1
1974	10 311.5	—	—	—	—	6 831.0	—	17 162.5
1973	6 512.7	—	—	132.0	—	269.0	—	6 913.7
1972	7 905.0	—	—	—	—	45.0	—	7 950.0
1971	4 711.4	—	—	—	—	—	—	4 711.4

Notes:
[a] NFD operated longliners
[b] Source: SPC Tuna and Billfish Assessment Programme (figures revised July '87)
[c] Operating within a limited area of the Fishery Limits under the Multilateral Fishing Treaty
[d] Includes 183.4 t taken by Korean vessels
[e] Includes 39.8 t taken by Taiwanese vessels

the major baitfish species and address the concern of possible adverse interactions with reef fisheries is also outlined.

The Development of Pole-and-Line Fishing in Solomon Islands

Prior to the 1970s, fishing in Solomon Islands was traditionally of a subsistence nature, with few commercial activities in existence (Van Pel, 1956; Adams, 1965). In the late 1960s and early 1970s the expanding Japanese distant pole-and-line skipjack tuna fleets were looking to the south-west Pacific for available sources of skipjack and yellowfin tuna, and live baitfish.

Joint ventures by various companies were started in Papua New Guinea in the late 1960s, and in 1971 Taiyo Fishing Company of Japan approached the then Governing Council of the British Solomon Islands Protectorate for permission to undertake a tuna fishing survey.

A Memorandum of Understanding between the two parties was drawn up for a 15 months survey to be carried out wthin Solomon Islands territorial waters to begin on 1 June 1971. By August 1972, a total of 10 214 t of skipjack were caught (plus a small percentage of juvenile yellowfin) by up to 15 pole-and-line vessels fishing to two refrigerated motherships. No export duties were charged, but a fee of SI$500 per boat month was levied; the survey thus realised $66 500 in fees for 133 boat months of operation, but more importantly it showed the commercial viability of skipjack fishing using the pole-and-line method in Solomon waters.

While fishing continued after June 1972, proposals were submitted by Taiyo to enter into a joint venture agreement with SIG for the long-term development of the fishery. A 10 year Joint Venture Agreement (JVA1) was signed on 4 November, 1972 and the joint venture company formed. Solomon Taiyo Ltd (STL) began trading on 2 February, 1973.

In August 1973, freezing and cold storage, quay and office facilities (Fig. 1) were constructed on the island of Tulagi, in the Florida Islands (24 miles north of Honiara on Guadalcanal) and a 175 000 cases/year cannery began operating in October. A smoked fish (arabushi) plant opened a short time later, with a processing capacity of 3 t of skipjack per day. Tulagi base has wharves of 12 m and 15 m in length, both with water depth of around 6.5 m.

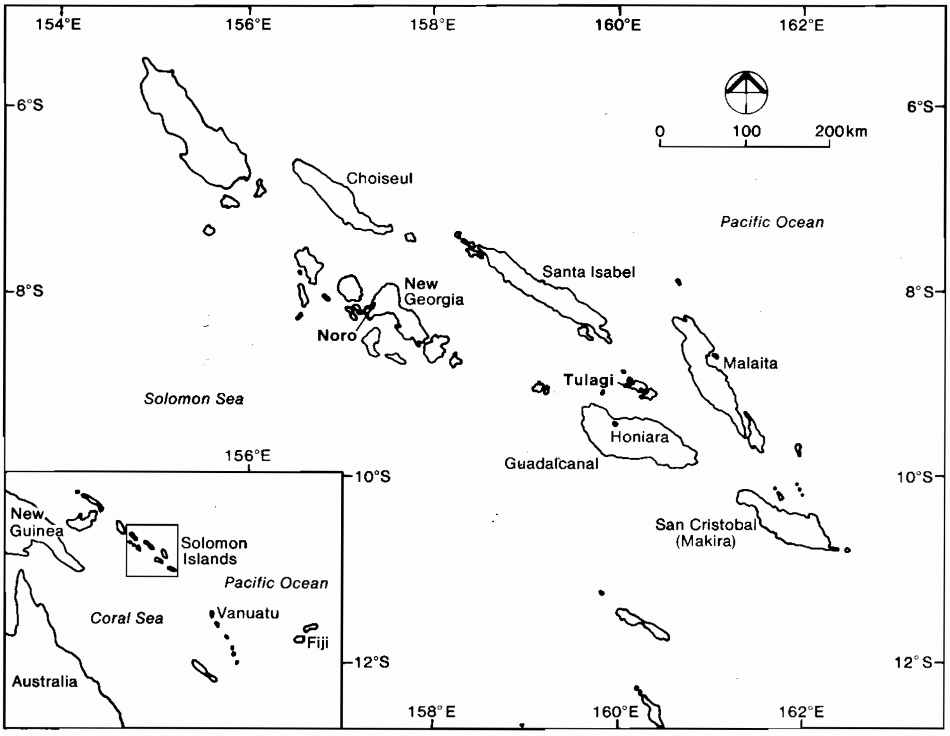

Figure 1. The Solomon Islands, showing position of Noro and Tulagi.

A second base at Noro, on the island of New Georgia, Western Province, was commissioned in 1975 and has a 40 m long main wharf in 7.5 m deep water and a 90 m long fishing vessel wharf. The base has a brine freezing system (60 t/day) and a 600 t, −25°C cold store. A new cannery was commissioned in 1989 at Noro base (with a projected throughput 15 000 t per year), in line with national development objectives to increase the value-added processing of fish within the country. A small arabushi factory is also located at Noro. All domestic tuna fishing vessels currently land their catches at either Noro or Tulagi base.

Owing to the success of STL in exploiting the rich tuna resources of Solomon Islands, a second Joint Venture Agreement (JVA2) was signed in 1981 between SIG and Taiyo. This agreement runs through to 1992. To date, the domestic tuna fishery continues to dominate the fisheries sector in terms of economic gain to the nation. In 1977, a second commercial tuna fishing company National Fisheries Developments Limited (NFD), was established as a joint venture between SIG and STL. The company was formed to build up a national fishing fleet and crew the vessels with Solomon Islanders. The aim was to stimulate local involvement in the tuna industry and to supply additional fish to STL. By 1986, 10 pole-and-line vessels had been completed and were fishing; two additional vessels were also provided under Japanese aid. During 1989, NFD's fleet constituted 11 pole-and-line vessels, all operating from Tulagi base. In addition, a pole-and-line vessel from National Fishing Corporation of Tuvalu has occasionally been operated under charter terms by the company.

Solomon Taiyo Ltd and National Fisheries Developments Ltd.

The number of vessels entering the domestic pole-and-line fishery has increased steadily over the

Table 2. Solomon Islands pole-and-line fleet, 1989.

Vessel/base	Baitwell size class	No. of bait boats	No. of bait tanks	Total bait tank capacity (cu.m.)
Tulagi Base:				
Solomon Fisher	Large	3	6	60.0
Solomon Catcher	Small	2	4	24.0
Solomon Warlord	Small	2	3	24.0
Solomon Victor	Small	2	3	24.0
Solomon Hunter	Small	3	4	24.0
Solomon Challenger	Small	2	3	24.0
Solomon Harvester	Small	3	3	18.8
Solomon Marksman	Small	2	3	24.0
Solomon Seeker	Small	2	4	24.0
Solomon Commander	Small	2	3	24.0
Solomon Pathfinder	Small	2	3	24.0
Noro Base:				
Soltai 05	Large	3	6	56.0
Soltai 06	Large	2	6	56.0
Yutoku 21	Large	4	4	56.0
Soltai 11	Large	3	4	56.0
Soltai 12	Large	3	4	56.0
Soltai 07	Large	2	6	54.0
Tokuyo 03	Medium	2	4	31.4
Tokuyo 07	Medium	2	4	31.4
Tokuyo 08	Medium	4	4	31.4
Soltai 08	Medium	3	4	31.4
Tokuyo 10	Medium	4	4	31.4
Tokuyo 01	Medium	2	4	31.4
Kyotoku 01	Medium	4	4	31.4
Tokuyo 05	Medium	2	4	31.4
Seitoku 08	Medium	4	4	31.4
Soltai 10	Medium	3	4	31.4
Sachi 03	Medium	3	4	31.4
Tokuyo 06	Medium	3	4	31.4
Soltai 03	Medium	3	4	31.4
Ryoko 01	Medium	4	4	31.4
Soltai 02	Medium	3	4	31.4
Soltai 01	Small	3	4	22.4

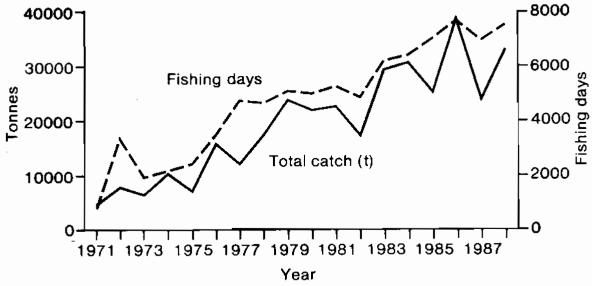

Figure 2. Solomon Islands domestic pole-and-line fishery, catch and effort statistics, 1971–1988.

years; in 1989, STL operated 10 of its own pole-and-line vessels as well as 12 Okinawan pole-and-line vessels under a local charter arrangement; the company also owns a group purse-seine operation (small catcher vessel plus two refrigerated carrier vessels and support vessel). Table 2 details the structure of the pole-and-line fleet today, with details of the bait-carrying capacity of each vessel. The performance of the pole-and-line fleet for the years 1971–1988 is shown in Figure 2.

Prior to 1988, STL owned both shore bases, at Noro and Tulagi and provided unloading and support services to the entire domestic fleet: under the terms of the current Joint Venture Agreement, STL is obliged to purchase the catches of NFD vessels. Early in 1989, STL moved operations to Noro, and NFD took over the facilities at Tulagi.

On average, the NFD vessels take catches which are far below those of STL owned or Okinawan chartered boats. This is generally a reflection of less-experienced fishing masters on NFD's vessels, the relatively low bait carrying capacity, coupled with fewer fishermen on board and shorter sea endurance times for these smaller vessels. The two larger vessels provided under Japanese aid fished on a par with the more successful boats in the fleet, however.

The Baitfishery of Solomon Islands

The pole-and-line fishing method requires a nightly supply of suitable live baitfish (Evans and Nichols, 1984). The bait are broadcast into the sea and attract the skipjack towards the catcher-boat. An instrumental factor in the successful development of pole-and-line fishing in Solomon Islands has been the presence of abundant, readily available stocks of high quality baitfish species; with an annual bait catch in excess of 2 000 t since 1985, the Solomons baitfishery is the largest in the south Pacific. Table 3 and Figure 3 detail catch and effort statistics for the baitfishery.

Industrial baitfishing operations

In Solomon Islands, baitfishing is carried out from the pole-and-line boats themselves. It is a night-time fishery, utilising the well-documented bouke-ami method (Kearney, Lewis and Smith, 1972; Evans and Nichols, 1984). Baitgrounds are referred to not in the usual sense of general area limited by the extent of the stock but as discrete areas which come under the control of custom reef owners. Stocks of baitfish, mainly engraulid anchovies (eg. *Stolephorus heterolobus* and *Stolephorus devisi*), plus sprats (*Spratelloides* spp.) and

Table 3. Solomon Islands baitfishery — catch and effort statistics (all baitgrounds), 1973–88.

Year	Buckets	Tonnes	Boat nights	Hauls	Bkts/N	Kgs/N	Bkts/H	Kgs/H
1973	222 171	488.8	1 722	—	129	284	—	—
1974	144 070	317.0	1 279	—	113	248	—	—
1975	244 198	537.2	1 563	—	156	344	—	—
1976	313 571	689.9	1 967	—	159	351	—	—
1977	420 892	926.0	2 913	—	144	318	—	—
1978	446 865	983.1	3 597	—	124	273	—	—
1979	567 996	1 249.6	4 858	—	117	257	—	—
1980	608 956	1 339.7	4 903	—	124	273	—	—
1981	611 045	1 344.3	4 439	10 569	138	303	58	127
1982	672 198	1 478.8	5 335	14 496	126	277	46	102
1983	895 780	1 970.7	6 846	17 527	131	288	51	112
1984	813 570	1 789.9	6 548	18 167	124	273	45	99
1985	1 015 537	2 234.2	7 593	20 024	134	294	51	112
1986	1 075 263	2 365.6	8 150	21 878	132	290	49	108
1987	956 333	2 103.9	7 372	21 671	130	285	44	97
1988	1 135 289	2 497.6	8 008	21 351	142	312	53	117

Note: One bucket of bait = approx. 2.2 kgs wet weight of baitfish.
Weight of bait catch for years 1973–1980 has been adjusted by a raising factor of 1.87 to compensate for under-reporting of catches during those years.

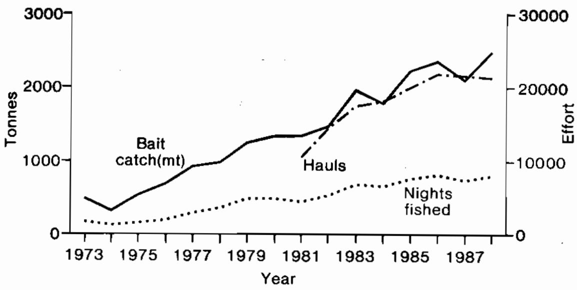

Figure 3. Solomon Islands Baitfishery, catch and effort statistics (all baitgrounds), 1973–1988.

other clupeids are very widespread and occur in shallow protected reef/lagoon areas. Access is sought by the fishing companies to baitfishing areas located near tuna fishing grounds, the major criteria being accessibility by vessels, distance from shore bases and ease of bait capture (eg. sufficient water depth for the nets, low tidal movements, etc.).

Each pole-and-line vessel has two or three smaller vessels, called baitboats, which remain on-site during the day but proceed to their favoured bait anchorages on the baitground at dusk to await their vessel. The baitboat is usually a 6m skiff with an inboard diesel engine which operates both the drive and a generator. At the buoy, the generator is used to power a 2 kW underwater light suspended 10–15 metres below the boat. The sole operator then settles down to await the catcher-boat.

When the pole-and-line vessel returns to its 'regular' baitground, the vessel also suspends two lights itself, and these are used for the first haul. Often, sufficient bait is taken with a single haul on the catcher boat's own light: upon such occasions the baitboat(s) shut off their underwater lights. The choice of baitground on which to fish is a personal matter for the Captain, but it is usually in close proximity to either the vessel's home shore base, or near a favourite fishing area. The baitgrounds closest to the shore bases, e.g. Munda and Rarumana baitgrounds near Noro base, and the Tulagi baitgrounds near Tulagi base, generally have a greater proportion of baitfishing effort expended upon them. When the Captain decides to move to a new area, the baitboats move also, either under their own power or carried on board the catcher-boat.

Once the net is raised and the baitfish caught, a small skiff is used to facilitate 'drying-up' the bouke-ami net, and facilitate transfer of baitfish from the bouke-ami net to the baitwells on the catcher-boat. The baitfish are herded into an ordinary domestic bucket, which is lowered into the water; a number of buckets are usually used in rotation. As only one bucketful of bait comes aboard at any one time, it is easy to count the number of buckets taken for any one haul.

The biomass of baitfish in each bucketful is variable, and has lead to problems in determining an appropriate factor for converting catch in buckets to weight (Hida and Wetherall, 1977). Research by the Fisheries Department has indicated that a bucket contains on average 2.2 kg of bait in Solomon Islands.

Upon transfer to the catcher-boat, the baitfish are held in water-circulating bait-tanks, or baitwells, each provided with low illumination. Stocking densities of these bait-tanks varies between vessels, but on average between 40–60 buckets are placed in each well. Any baitfish surplus to requirements are released.

If all baitwells can be filled with just one haul then this is the only effort expended. However, at certain times (eg. at full moon, when baitfish are less attracted to the lights due to greater incident moonlight) more hauls may be necessary, and in such cases the bouke-ami net is set again on the nearest bait-boat's light. This procedure is repeated until sufficient bait is obtained.

The aim of each vessel is to have fully-stocked baitwells at the beginning of each day, thus buckets taken per night is probably more a simple measure of requirement than of stock availability. The number of buckets per haul and hauls made per night are, therefore, better measures of catch per unit effort (CPUE) and effort respectively. Once sufficient bait has been secured for the next day's fishing, the pole-and-liner leaves the baitground and moves to the tuna grounds.

Over the years the baitfishery has expanded considerably in Solomon Islands. From 1971 to 1974 baitfishing mainly occurred at Thousands Ships Bay in Ysabel Province and at the baitgrounds adjacent to Tulagi in the Ngella Islands of Central Province. With the opening of Noro base in the Western Province in 1975 the major baitgrounds of Roviana and Marovo Lagoon became subject to baitfishing effort. By 1989, there were 87 registered baitgrounds, of which 9 were in Central Isles Province (all close to the Tulagi base), 1 in Guadalcanal Province, 46 in Western Province (mostly in the Marovo and Roviana Lagoons), 10 in Malaita Province, 1 in Makira Province and 20 in Isabel Province.

Customary ownership and the baitfishery

Baitgrounds in Solomon Islands are always inshore areas located in protected, relatively shallow lagoons. This brings them within the customary jurisdiction of reef-owners with whom arrangements must be made in order to allow baitfishing to occur. Historically, this responsibility has been assumed by STL management on behalf of their own fleet and that of NFD, although during 1989 NFD were becoming increasingly active in pursuing agreements for new baitgrounds in their own right.

Customary ownership or tenure over sea areas still exists as a perceived and inviolable right of coastal people in Solomon Islands. Ownership is a complex concept in relation to sea areas; Solomon Islanders have strong attitudes towards sea areas, especially those close to shore or associated with recognisable physical structures such as lagoons and offshore reefs.

As with all access arrangements to areas where traditional rights of tenure or usage of natural resources have become 'custom', baitfishing

BAITGROUND ROYALTY AGREEMENT

1. We the undersigned solemnly declare ourselves to be the legal owners/representatives of the owners of the

____
reef area as designated on Department of Lands and Surveys, Honiara map reference______________________________

2. We the undersigned owners/representatives of the owners hereby accept full responsibility for any legal costs, damages or claims which may arise during the course of this agreement, from any dispute relating to ownership of the__________________________ reef area.

3. It is agreed that Solomon Taiyo Limited and National Fisheries Developments Limited catcher boats (both owned and chartered) may baitfish in the _________________________ reef area on the condition that royalties are paid in accordance with the Solomon Islands Nationwide Baitfishing Agreement, as detailed in Schedule 1 of this Agreement.

4. Royalty payments to be paid monthly by Solomon Taiyo Limited into a savings bank account in the names of the undersigned owners/representatives of the owners of the____________________ reef area.

5. The savings bank account to be opened at the Australia and New Zealand Bank, Honiara/National Bank of Solomon Islands, Honiara.

6. This Agreement may be reviewed by either party if unusual or unforeseeen circumstances should arise but such reviews are to take place during the months of February to April inclusive in any year.

Signed as owners/representatives of the owners of the
____reef area.

1. ____)

2. ____)

3. ____)

4. ____)

5. ____)

6. ____)

____)
pp SOLOMON TAIYO LIMITED

AT______________________________ ON THE _______ DAY OF__________ 19

BAITGROUND ROYALTY AGREEMENT

Schedule 1

We the under signed owners/representatives of the owners of the

______________________________ reef area agree to the following royalty payment rate per night as laid down in Solomon Island Nationwide Fishing Agreement.

	FISHING SEASON 1988
Smaller Type Vessels	$19
Standard 25 metre vessels	$28
Larger Type Vessels	$36

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________
6. ______________________________

____

pp SOLOMON TAIYO LIMITED

SIGNED AT ____________ ON THE ____________ DAY OF ____________

Figure 4. Baitground Royalty Agreement Format used by Solomon Taiyo Limited.

access can only be maintained through negotiation of an agreement and the payment of 'compensation' or, in effect, royalty payments for access to the fishery. During the early years of development of the baitfishery, discussions with reef owners was on an individual or ad hoc basis. However, since 1980, it is usual for STL's industrial relations officer to tour the major baitgrounds prior to the start of the new pole-and-line season after the Christmas recess in order to discuss any problems that may have arisen during the previous year, to recompense any under-payments of royalties, and to discuss the opening of new baitgrounds, or re-evaluate the boundaries of existing ones.

As a consequence, the number of grievances has fallen and a large number of new baitgrounds have been opened since 1980. The form of the negotiated agreement is very simple (Fig. 4). It includes a reference to the baitground and the rates of payment for each vessel size class, as well as the names of the trustees who will be signatories for the bank deposit account into which royalty payments are paid.

At some time during the negotiation for a new baitground, the boundaries of the baitground are defined. Generally there is fair agreement between adjacent baitgrounds on the limits of jurisdiction by the separate groups of reef owners. Lines are drawn on a reference set of maps. Trustees/reef owners are asked to sign the map as a declaration of ownership, and these are usually held by the Fisheries Officer in attendance. The trustees of baitgrounds are usually chiefs or persons nominated by them who take on the responsibility of ensuring payments and other administrative details of baitground access follow the correct procedures. They usually become the signatories to the saving bank accounts which are opened for them by STL and into which royalty payments are made.

Baitfishing royalty payments

Royalty payments are made in return for access to baitgrounds for the purpose of taking bait. Baitfish are not, nor ever have been, traditionally harvested for food to any great extent in Solomon Islands.

Payments are made for each night of effort expended on a baitground since the presence of a vessel cannot be easily disputed. Indeed, if payments were based on catch (numbers of buckets taken) this would undoubtedly lead to under-reporting of the bait catch and put in doubt the major source of relatively reliable data on baitfish exploitation.

In 1978, a semi-formal Baitground Owners Association was formed by the larger baitground owners, which pressurised the industry to raise royalty payments and to introduce a differential payment scale based on the physical bait-well capacity of the catcher-boats. As a result, royalties were substantially increased, the rates being paid according to three vessel size classes: small, medium and large. Table 4 summarises royalty payment rates payable by vessel size class since 1973.

Until recently, STL assumed responsibility for paying of baitfish royalties into the appropriate baitground bank accounts on behalf of all pole-and-line vessels. Records are compiled by STL on a monthly basis showing the bait fishing activities on each baitground for each catcher boat, using (prior to 1980) the catcher-boat's logsheet, and from 1981 onwards, the baitfishing records made by the baitfish recorder on each vessel using a separate 'baitfishing logsheet' (see below). The number of nights fished by small, medium and large vessels are multiplied by the appropriate royalty rate to calculate the total amount due for payment into the baitground account. A bank transfer to the account is then effected by STL.

This system has, since introduction of the new baitfishing logsheet system, worked fairly well. Complaints sometimes arise in cases of abuse of funds by baitground trustees, an area in which both SIG and the commercial companies are not concerned: settlements are usually made amicably or through the customary law court.

Table 4. Baitfishing royalty payments, 1973–1989. Rates payable per night (SI$) by vessel size class.

Year	Small	Medium	Large
1973	0.50	0.50	0.50
1974	1.00	1.00	1.00
1975	1.50	1.50	1.50
1976	2.00	2.00	2.00
1977	2.50	2.50	2.50
1978	10.00	15.00	20.00
1979	10.00	15.00	20.00
1980	10.00	15.00	20.00
1981	12.00	18.00	24.00
1982	14.00	21.00	28.00
1983	16.00	24.00	31.00
1984	16.00	24.00	31.00
1985	19.00	28.00	36.00
1986	19.00	28.00	36.00
1987	19.00	28.00	36.00
1988	19.00	28.00	36.00
1989	19.00	28.00	36.00

Monitoring and Management of the Baitfishery

Background

With the formation of the Baitground Owners' Association, the claim by baitground owners that they were being underpaid for access was met by substantial increases in payments but their other concerns needed to be reconciled: these were that the system of reporting was inaccurate and that the baitfishery was having serious influences on the traditional fishery for the large fish which prey on the baitfish. These basic claims required independent assessment and revision of techniques for reporting: thus, the Fisheries Department initiated a new system to monitor baitfish catches and distribution of effort.

Hitherto, the baitfish catch, universally recorded in 'buckets', and the location of capture had been reported on the same logsheet as the tuna catch and this had been the sole responsibility of the fishing master or skipper. Effort was simply recorded as 'boat-nights fished'. Although of paramount importance the fishing masters treated baitfishing, or at least recording of it for official purposes, as a minor aspect of their work; they had had relatively open access to large quantities of high quality bait for so long and at such little cost that the attention paid to this access assumed little importance in their minds.

Examination of the logsheet records and analysis for the years 1974 to 1980 on baitfish catch shows massive discrepancies in recorded catch from what was known to be the capacity of the baitwells and the requirements for a day's fishing. The system clearly needed reform.

The issue of principal contention, according to the baitground owners, was the accuracy of fishing locations. Government and STL files are littered with complaints of under-payment of royalties. Many baitground owners have kept records of which vessels fished and on which nights, and have compared these with payments that they have received.

In the years prior to 1981, there were no accurate maps of baitgrounds distributed to fishing masters. There was no coherent system of numbering or naming baitgrounds, and no precise instructions were issued to fishing masters on recording procedures. In addition, baitgrounds were ill-defined and agreements were made with one group of baitground owners over areas which included areas owned by other people. The latter problem generated internal conflicts on distribution of payments within those areas.

A major problem which STL encountered when entering into agreements for the opening of a baitground was insufficient information on exactly who baitground owners were, who had the right of trusteeship and exactly which areas came under the responsibility of any particular group.

At the beginning of the 1981 fishing season a completely new set of management methods for regulating, recording and reporting catch and effort for the baitfishery was put into operation. This contained improvements in the regulations, under the Fisheries Act (1972), controlling baitfishing operations, as distinct from skipjack fishing. A new system of definition of baitgrounds and improvements to the method of their designation was initiated, which included Baitground Mapbooks. New baitfish record sheets were produced and distributed to fishing vessels and baitfishing recorders were designated and trained in their use. In addition, a sampling program for biological investigation of the baitfishery was started.

The law and regulations

A major concern of baitground owners and coastal people in general has been the lack of precise control on the activities of pole-and-line vessels in near-shore waters. While baitfishing in customary reefs and lagoons has always been subject to a formal baitfishing agreement, actual skipjack fishing was not regulated in this way. Other than the possession of a national 'Local Fishing Vessel Licence', vessels were not limited by law from fishing right up to the shore or near villages.

Under the Fisheries Act (1972), as amended 1977, the Minister responsible for fisheries has the power to implement such regulations as he considers necessary for the general purposes of the Act. These might include measures for excluding certain types of fishing from specific or general areas and the requirements for the reporting of fishing operations.

Control of near-shore fishing activities by licenced vessels was implemented through the Fisheries (Amendment) Regulations of 1977, which stipulates that 'the vessel shall not be used for fishing operations in any waters within five hundred yards of low water mark or within one nautical mile of any village: Provided that the Principal Licencing Officer may if he thinks fit waive this condition by endorsing the licence to this effect'.

However, this regulation was deemed insufficient and open to argument, so further regulations were introduced; The Fishing (Local Fishing Vessels) Regulations, 1981 in which a similar limitation was maintained with the exception of baitfishing. This was the first time that baitfishing had been directly referred to in any legislation.

In addition to what has become known as 'the 500 metre rule', other aspects of Government requirements were introduced: the Fishing (Local Fishing Vessels) (Amendment) Regulations, 1983 stipulate that...

'(f) vessels must not, save for baitfishing, fish within five hundred metres of low water mark or within one nautical mile of any village or fish within any local fishing area specified by the Principal Licencing Officer until an agreement in writing, between the licencee and the person or persons who have, over those waters, customary ownership, trusteeship recognised by the responsible area council or councils or jurisdiction recognised under the Provincial Government Act (1981), has been signed by or on behalf of the parties, verified by the Provincial Government and received by the Principal Licencing Officer' and...

'(g) if licenced for pole-and-line fishing —

(i) not baitfish in any area unless such area is shown on the current set of baitground maps approved by the Principal Licencing Officer and is the subject of an agreement between the customary baitground owners and the owner of the vessel, or its charterers;

(ii) carry on board at all times the latest set of baitground maps approved by the Principal Licencing Officer; and

(iii) keep a daily record of baitfishing operations in a form approved by the Principal Licencing Officer;

(h) carry on board at all times the current set of local fishing area maps approved by the Principal Licencing Officer;

(i) keep a daily record of all other fishing operations in a form approved by the Principal Licencing Officer;

(j) submit a copy of each daily record of baitfishing and other fishing operations, or with the agreement of the Principal Licencing Officer a summary total thereof, to the Principal Licencing Officer as often as he shall require'; etc.

Compliance with these regulations does not severely hamper the activities of the pole-and-line fleet, but protects the interests of rural communities and satisfies the requirements of the Fisheries Department.

Definition of baitgrounds

The set of baitground maps referred to in the above regulations was published by the Fisheries Department in 1981. It contained all those baitgrounds which had previously been opened through bilateral negotiations between their owners (trustees) and STL. It also contained explanations of the set of maps and a complete list by province of all official baitgrounds, including registered names and numbers for each baitground.

The series of maps has been modified and revised over the years, using information gained during the off-season tour by STL and Fisheries Department officers. Boundary lines have been redrawn through discussions with baitground owners; new baitgrounds have been added and a few withdrawn. These mapbooks delineate the official baitgrounds of the Main Group Archipelago (MGA), all of which have full baitfishing agreements with the owners and nominated trustees for the baitground bank account. The Fisheries Department undertakes to ensure that all pole-and-line vessels have a complete, up-to-date, mapbook on board at the beginning of each season.

Baitfishing records

Prior to 1981 all records of baitfishing were recorded on the pole-and-line vessel's logsheet provided by the Fisheries Department. For reasons of inaccuracy described above it was decided to record baitfishing data on a separate logsheet system. Furthermore, the responsibility for completion of the baitfishing logsheet was revised. The skipjack records remained the task of the fishing master or skipper while baitfishing records were placed in the hands of a designated member of the Solomon Islands crew, the Baitfish Recorder.

Since the baitfishing records are of value to the fishing master, the companies and Fisheries Department, the record books were prepared with the following criteria: they needed to be easy to complete, contain sufficient information for the analysis of catch and effort, and suitable for the

BAITFISHING LOGSHEET

1	Date	

VESSEL

2	Name		3	No.	

BAITGROUND

4	Name		5	Number	

NUMBER OF BUCKETS PER NET:

1	2	3	4	5	6

6	Total Nets	

7	Total Buckets	

Captain ____________________

Observer ____________________

FISHERIES DIVISION S.I.G.

GP 279/81

Figure 5. Baitfishing record logsheet format used by baitfishing recorders on domestic pole-and-line vessels.

calculation of baitfishing royalties to baitground owners. A single sheet per night format was decided on with four copies produced using different coloured leaves of perforated carbonless copy paper. The copies were thus easy to remove and sort for a variety of purposes (Fig. 5).

The record sheets are prepared into small books with sufficient pages for one month's baitfishing. The book was designed to have a pocket for tucking in completed records and a flap for separation of the four carbonless copies from the next daily record. As each monthly record book is completed it is returned to the manager at each base who then distributes the copies as required: one to Fisheries Department, one to the company head office, one retained by the fishing base, and one retained by the pole-and-liner itself.

Baitfishing logsheets require the signature of both the fishing master and the baitfish recorder so that a check is made on its accuracy, for which both take responsibility.

It is on the basis of the information contained in these sheets that STL and NFD make payments to the baitground owners, since the header information on each daily record contains the vessel's name and number, and the name and number of the baitground fished that night. The data provided is also used by the Research and management Section of the Fisheries Department to monitor catch and effort expended on individual baitgrounds, and maintain baitfishing operations data for each vessel.

Baitfish recorders

Prior to each fishing season since 1981, STL and NFD are asked to nominate two Solomon Islands crew members from each vessel to undertake a one day training course in the use of baitground maps, and the correct procedure for entering data on the baitfishing logsheets. The most experienced man is chosen from each vessel with an alternate crew member for back-up. For this duty the Baitfish Recorder is paid a basic monthly salary supplement by the employee's company.

The training course is run by Fisheries staff and is comprised of the following elements:

- map reading and the identification of the baitground being fished,
- familiarity with regulations governing baitfishing,
- familiarity with the baitground names, numbers and the provinces where they are located,
- the importance of accurately recording the number of buckets taken for each haul,
- filling in the baitfishing record sheets.

This familiarisation course is run during a pre-season meeting with the captains, officers and baitfish recorders, which takes place every year. During this meeting, the opportunity is taken to up-date the baitground mapbooks, reiterate the correct method of filling in both pole-and-line and baitfishing logsheets, and to give the commercial fishermen an idea of the types of analyses that are carried out with the data recorded, and how this is of use to Government, the industry and the resource owners alike.

Data collection, compilation and analysis

The production of statistics, summaries and analysis of the data collected from the baitfishery had been largely manual until the introduction of microcomputer systems to the Research and Management Section of the Fisheries Department. In recent years, data processing has been computerised using the Department's Hewlett Packard (HP) micro-computer hardware.

The copies of daily baitfishing records are usually received within 21 days of the end of each month and entered on to computer data files before the end of the month. Thus it is possible to have a fairly current running record of catch and effort by both vessels and across the 87 baitgrounds of the Solomon Islands baitfishery. Separate discs are prepared and maintained for each year.

The original data-entry and analysis software was written in BASIC on an HP87 micro-computer. The system was upgraded in 1985 and re-written in D-base2 on HP150 micros (Rawlinson, 1987). The system assumes a minimum knowledge of computer operations by operators, and has in-built error checking capability and a data verification display on screen which allows for the correction of errors before data is written to the disc-based files. Data entry is achieved through on-screen menus which the user fills in, placing data items in the appropriate boxes on the menu.

The raw data is stored on yearly files; each record represents a night's fishing. Date, vessel, baitground number, number of hauls and buckets by haul are entered in date order direct from the daily baitfishing records. An edit facility in the system allows for correction of errors before the data is written to the vessel's file on disc.

The raw data on individual vessel files allows analysis of catch and effort data for individual or grouped baitgrounds (for example, all baitgrounds in a province or other defined area), and by individual vessel or vessel class. The former analysis is used to compare baitgrounds in order to make judgements concerning the stability of yields and the general level of productivity by area. The latter is used to compare baitfishing efficiencies of catcher-boats both between and within different size and ownership classes. In

Table 5. Summary of catch and effort data for individual baitgrounds in Central Isles and Western Provinces, 1988. (Only baitgrounds that were fished during the year included. Baitgrounds near shore bases are marked with an asterisk.)

Baitground number and name	Boat nights	Hauls	Buckets	Buckets/ haul	Buckets/ boat night	Hauls/ boat night	Boat nights % province	Hauls % province	Buckets % province
Central Isles Province									
*1. Ngadapoa	37	122	4 321	35.4	116.8	3.3	2.8	3.4	3.3
*2. Haghalu	79	226	7 644	33.8	96.8	2.9	6.0	6.3	5.9
*3. Ha'a	227	627	20 633	32.9	90.9	2.8	17.4	17.5	15.9
*4. Halavo	68	175	5 961	34.1	87.7	2.6	5.2	4.9	4.6
*5. Avi'avi	38	106	3 630	34.2	95.5	2.8	2.9	3.0	2.8
*6. Mbola	22	54	1 784	33.0	81.1	2.5	1.7	1.5	1.4
*7. Taroaniara	125	301	11 006	36.6	88.0	2.4	9.6	8.4	8.5
*8. Ndandala	711	1 977	74 766	37.8	105.2	2.8	54.4	55.1	57.6
Total/mean	1 307	3 588	129 745	36.2	99.3	2.7	100%	100%	100%
Western Province									
21. Raduvu	334	881	49 405	56.1	147.9	2.6	5.8	5.7	5.5
22. Punutu	225	644	34 956	54.3	155.4	2.9	3.9	4.2	3.9
23. Nama	263	768	45 303	59.0	172.3	2.9	4.5	5.0	5.0
24. Patutiva	1 129	2 691	173 449	64.5	153.6	2.4	19.5	17.4	19.3
25. Vura	3	11	273	24.8	91.0	3.7	0.1	0.1	0.0
26. Penjuku	638	1 361	91 134	67.0	142.8	2.1	11.0	8.8	10.1
27. Sinevolo	34	56	4 675	83.5	137.5	1.6	0.6	0.4	0.5
28. Ketoketo	228	619	36 679	59.3	160.9	2.7	3.9	4.0	4.1
29. Vituana	120	226	16 662	73.7	138.9	1.9	2.1	1.5	1.9
30. Manambusu	308	869	55 361	63.7	179.7	2.8	5.3	5.6	6.2
31. Kokete	403	1 007	58 031	57.6	144.0	2.5	7.0	6.5	6.5
32. Mbatuna	4	9	241	26.8	60.3	2.3	0.1	0.1	0.0
33. Telina	77	189	12 335	65.3	160.2	2.5	1.3	1.2	1.4
34. Nggerasi	55	182	8 233	45.2	149.7	3.3	0.9	1.2	0.9
*35. Munda	271	792	34 111	43.1	125.9	2.9	4.7	5.1	3.8
36. Randuvu	1	5	23	4.6	23.0	5.0	0.0	0.0	0.0
37. Ghizo	1	1	75	75.0	75.0	1.0	0.0	0.0	0.0
40. Vatoro	4	11	185	16.8	46.3	2.8	0.1	0.1	0.0
53. Kokolope	1	2	197	98.5	197.0	2.0	0.0	0.0	0.0
55. Posarae	7	22	929	42.2	132.7	3.1	0.1	0.1	0.1
56. Lambagha	52	142	8 102	57.1	155.8	2.7	0.9	0.9	0.9
57. Mbili	1 076	3 046	176 848	58.1	164.4	2.8	18.6	19.0	19.7
58. Kumboro	1	2	194	97.0	194.0	2.0	0.0	0.0	0.0
60. Toumoa	3	6	570	95.0	190.0	2.0	0.1	0.0	0.1
64. Simbo	3	10	387	38.7	129.0	3.3	0.1	0.1	0.0
*65. Rarumana	552	1 893	90 942	48.0	164.8	3.4	9.5	12.3	10.1
Total/mean	5 793	15 445	889 300	58.2	155.2	2.7	100%	100%	100%

addition, monthly catch and effort statistics and catch per unit effort or CPUE (number of buckets taken per haul) for all baitgrounds allows the Fisheries Department to monitor CPUE trends: even the most heavily fished baitgrounds tend to have fairly stable CPUE over time. The data presented in Table 3 and Table 5 are examples of the type of statistics that can be produced by the system. An analysis of historical catch and effort data for the Solomon Baitfishery is presented elsewhere (see Rawlinson et al., these Proceedings).

There has never been a need to enforce formal management measures such as restricted effort in the Solomons baitfishery. The pole-and-line fleet is free to enter and baitfish on any of the 87 currently registered baitgrounds around the country; the large number of available baiting areas has tended to have a 'self-regulatory' effect on the fishery: if bait catches in any particular baitground are perceived to have declined by the Fishing Masters, they simply move to another area. Rawlinson and Nichols (these Proceedings) and Tiroba et al. (these Proceedings) present evidence that even on heavily baitfished sites, catch per unit effort has not declined, and exploitation rates for the important species are low to moderate, implying that the bait resource is able to sustain current levels of fishing effort. However, this situation requires careful monitoring in future especially if the pole-and-line fleet expands.

Biological Research into Baitfish Resources

During mid-1982, the Fisheries Department initiated a sampling program utilising the Department's Fisheries Observers who are placed on board the commercial pole-and-line fleet. The aim of this program was to collect representative samples of the bait catch in order to begin investigations of the biological parameters of the baitfish species (Evans and Nichols, 1984). Samples collected were analysed in the laboratory and yielded preliminary information regarding species composition of the baitfishery, length-frequency time series, and information on the reproductive biology and population dynamics of the dominant species (in particular, the Engraulid anchovies *Stolephorus heterolobus* and *S. devisi*). The methodology employed was based on similar studies undertaken in Papua New Guinea (Dalzell and Wankowski, 1980).

Owing to the importance of this research, and in the face of financial constraints and lack of expertise, the Fisheries Department approached the Australian Centre for International Agricultural Research (ACIAR) in 1986 with a view to forming a 3-year collaborative research project to expand biological research into the baitfish stocks, including an investigation into the level of interaction between the baitfishery and the subsistence reef-fish fishery in areas of high baitfishing activity. A Memorandum of Understanding was signed between SIG and ACIAR, and the Commonwealth Scientific and Industrial Research Organization (CSIRO) was contracted to undertake the work. Field sampling commenced in early 1987; findings from this collaborative research project are reported elsewhere (see Nichols, 1988; Rawlinson, 1989); a major finding being that the majority of reef fish species that are important in the diet of rural populations do not predate baitfish (Blaber et al., in press). This collaboration has also helped to develop the field and analytical skills of national biologists within the Fisheries Department.

Conclusion

The Solomon Islands' domestic pole-and-line fishery has developed since its early beginnings in 1971 to become the major private sector employer and a major earner of foreign exchange. The concomitant development of a highly successful parallel night-time fishery for live baitfish has been instrumental in the development of this fishing methodology.

The Fisheries Department's system of data recording, compilation and analysis for the baitfishery, in place since 1981, has resulted in SIG being in a position to monitor very accurately the baitfishing activities on the baitgrounds. This, coupled with a recently completed three- year collaborative research effort with CSIRO of Australia into the biology of the major species in the baitfishery, has yielded valuable information regarding the level of interaction between baitfishing and reef fisheries for food-fish, and the growth, mortality and sustainability of the baitfish resource. Moves are now afoot for the Fisheries Department to undertake calculation of royalty payments payable to baitground accounts, at least for one commercial company.

Although the purse-seine method is becoming increasingly important in the country, it is anticipated that the pole-and-line fishery will continue at its present level for the foreseeable future.

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The Fiji Tuna Baitfishery

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Abstract

The Resource Assessment and Development Section of the Fisheries Division of the Ministry of Primary Industries has collected and analysed data on baitfish catches submitted monthly by pole-and-line vessels operating in Fiji waters since 1977. The lagoonal baitfish resources of Fiji presently support a fleet of 7–12 vessels, depending on the number of non-Fiji vessels chartered. The islands of the Fiji group contain over 100 recognised baiting sites, only a few of which the fleet utilises. With proper management the resource should be adequate to support a reasonable increase in baitfishing effort, but such effort must be spread. This paper summarises bait catches over the years with respect to seasonal variation, species composition and catch per unit effort for different areas, and also discusses biological work done in the past on two major bait species: *Herklotsichthys quadrimaculatus* and *Spratelloides delicatulus*. Plans for the future involve the compilation of a 'Bait-Site Atlas' giving pole-and-line skippers a profile of each site to enable optimal baiting, and resolution of the increasing conflicts between the requirements of bait-boats and traditional fishing rights custodians.

POLE-AND-LINE vessels, which undertake the vast majority of commercial skipjack fishing in Fiji waters, rely on adequate supplies of live bait to stimulate the feeding behaviour which results in tuna biting hooks.

The bait is usually captured at night in shallow coastal waters using the bouke-ami method, and the catch consists mainly of very small fish with large numbers of juveniles. The baitfish are attracted to the vicinity of the boat by submerged and overhead lights. Bait is scooped from the nets in a bucket and then transferred alive to a bait tank ready for use in fishing. Most vessels prefer to catch bait at night, to begin tuna fishing at dawn, due to the high rate of mortality in bait tanks.

The Fisheries Division of the Ministry of Primary Industries monitors changes in bait catches in order to help pole-and-line vessels in their activities. Tuna fleets supply bait information by completing standard data return forms. The skippers fill in details of bait catch, effort, location, and estimated species composition. All vessels are provided with coloured photographs of baitfish with Fijian, English, and species names. Daily catch returns are sent in at the end of each month.

Baitfish catch data since 1980 are based on bucket units and catches recorded before 1980 have been standardised into these units. This unit is not ideal, since there is some variability depending on the bait species landed, but it is the best compromise suitable for commercial boat crews. Catch per unit effort (CPUE) is expressed as the buckets per set of bouke-ami net.

Despite the success of large purse seiners in tropical areas of the Pacific, the pole-and-line method remains a viable economic enterprise at the latitude of Fiji. In addition, smaller vessels with comparatively high crew numbers fit well with national development objectives. Baitfish are one of several issues facing the Fijian Government with regard to managing the multi-use aspects of fish resources.

This paper summarises bait catches by pole-and-line vessels operating in Fiji waters over the period 1977–1989 in respect of seasonal vari-

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ation, species composition and CPUE for different areas, and also discusses biological work done in the past on two major bait species — *Herklotsichthys quadrimaculatus* and *Spratelloides delicatulus*, together with a discussion on management of the baitfishery in relation to traditional fishing rights.

Bait Fishing Areas

In Fiji the areas between the reef and shore offer safe anchorage for ships, although numerous coral heads may be present. Many islands have stretches of sandy beach broken at places by cliffs, coral reefs and dense stands of mangroves. The major areas of shallow water are found on the leeside (northwest) of the two major islands of Fiji. Numerous rivers and streams on the larger islands empty into the sea throughout the year. The frequent rain keeps the small streams running and feeding the main rivers. These features are important when defining baitfish species assemblages.

Although over one hundred defined baiting sites are used from time to time by pole-and-line vessels, probably less than half of these are regularly visited. As vessels operate individually rather than on a fleet basis, effort is widely distributed. Catch data for this large number of sites have been grouped into eight zones which reflect some administrative boundaries as well as some internal consistency in habitat type.

Salient features of these zones and the more important individual sites within them are summarised below and in Figure 1.

Environmental and Social Background

Climate

Three distinct climatic zones are generally recognised, the wet zone on the windward side of the more mountainous islands, the dry zone on the leeward side of the larger islands, and small island zones. The region lies within the southeast tradewind belt. Spells of northerly and north westerly winds occur during the hurricane season from December to March, when light and variable winds predominate. Strong tradewinds from September to December restrict fishing operations.

Currents

The Fiji group lies within the influence of the predominantly westward going south sub-tropical currents, the strength of which is dependent mainly upon the strength and regularity of the southeast tradewinds. The current is most marked

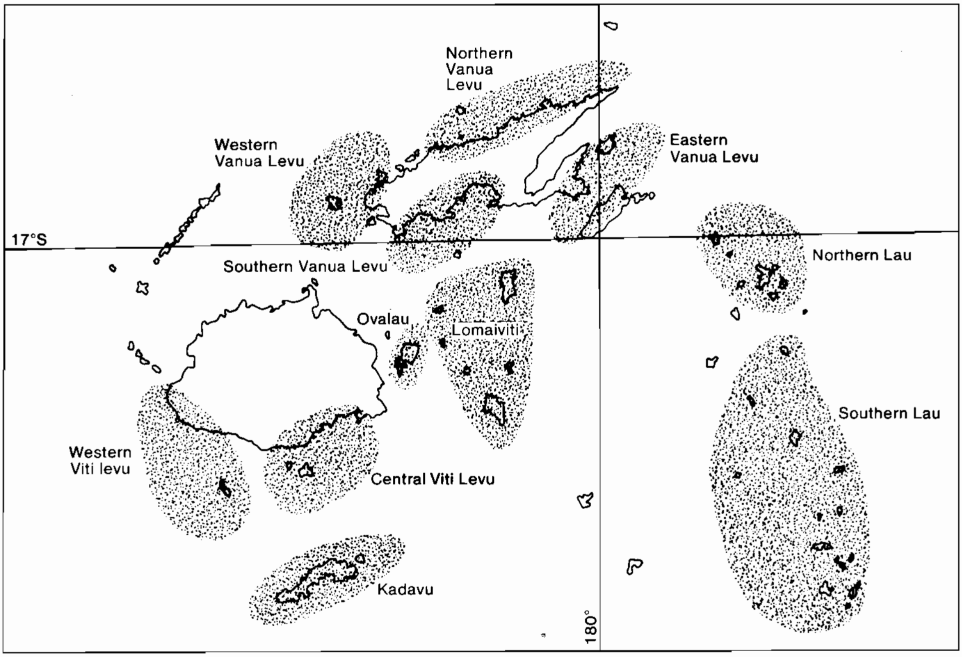

Figure 1. Map of Fiji showing baitfishing zones.

Characteristics of the major baitfishing zones.

Zone	Characteristics	Important sites
Levuka	Deep lagoon within fringing reef. Cannery nearby.	Levuka, Rukuruku, Nasova.
Lomaiviti	Sheltered lagoon anchorages on lee side of islands.	Sawaike, Nawaikama (Gau), Nabuna (Koro), Namena, Makogai.
Central	Mainland bays, plus the extensive Bega lagoon.	Lami Bay, Serua, Deuba Vaga Bay, Malumu Bay.
Kadavu	Large sheltered harbours in south. Lee shore in north.	Galoa, Soso, Yaruva Namara, Kavala.
Southern Vanua Levu	Deep mainland bays.	Kubulau, Naisonisoni Savarekareka, Vatulele, Valaga bay (Savu Savu).
Northern Vanua Levu	A large area inside the Great Sea Reef and amongst various islands.	Kia, Bekana Harbour, Mali Is Harbour, Sausau Bay, Cukuni Is, Udu Point, Mali Is.
Eastern Vanua Levu	Sheltered waters in lee of islands and reefs.	Qamea, Kio, Viani Bay.
Northern Lau	Vanua Balavu lagoon and smaller island lagoons.	Qilaqila, Vanuabalavu, Qelelevu, Wailagilala.
Southern Lau	Island lagoons.	Moala, Yagasa, Ogea, Matuku, Oneata.
Western Viti Levu	Shallow bays in Viti Levu's lee.	Nawala Point (Nadi), Momi Bay.
Western Vanua Levu	As for Northern Vanualevu but access difficult.	Rukuruku Bay.

from September to November but its rate seldom exceeds one knot.

Customary Fishing Rights

In Fiji, the land under the sea is Crown property. However, there is legislation to protect customary fishing rights which guarantees Fijian mataqalis (the land owning family group) their customary supply of food from the sea. The law also gives mataqalis a say in the management of commercial (licenced) fishing activity on the reefs and shell-fish beds within areas subject to customary fishing rights, but the scope of the law is at variance with customary concepts. The law refers to usage rights, which are not compensatable, but certain areas claim ownership rights over the fish resources leading to periodic claims for monetary compensation for baitfish taken by pole-and-line boats.

When considering customary rights it is relevant to note that many of the baitfish species do not have Fijian names and are not utilised by the traditional fisheries.

Baitfish Catch

Species Composition

Lewis et al. (1983), in a field guide to baitfishes, provides a listing of the various baitfish species caught in Fiji as well as keys to their identification. Species which contribute to the bouke-ami catch in Fiji have been documented in previous surveys (Kearney, 1978, 1982; Ellway and Kearney, 1981 and Fisheries Division Annual Reports). Seven species groups dominate the catch. These are:

1 Sprats:
Blue sprats (*Spratelloides delicatulus*), with smaller quantities of silver sprats, *S. gracilis*.

2 Sardines:
Spotted sardine (*Sardinella sirm*), with a small percentage of blue sardine (*S. clupeoides*).

3 Herring:
Gold-spot herring (*Herklotsichthys quadrimaculatus*).

4 Hardyheads:
Two species, *Atherinomorus lacunosus*, still widely known as *Pranesus pinguis*, and the more desirable *Hypoatherina ovalaua* dominate catches.

5 Mackerels:
Rastrelliger kanagurta predominates, with the more estuarine *R. brachysoma* contributing in some areas. *R. faughni* also occurs.

6 Cardinals:
Rhabdamia gracilis, with smaller amounts of *R. cypselurus*.

7 Anchovies:
Various species dominate this grouping in different areas at different times, including *Stolephorus heterolobus*, *S. devisi*, *S. indicus*, *S. bataviensis* and *Thryssa baelama*.

Other species, notably fusiliers (Caesionidae), weak herring (*Dussumieria* spp.), and scads (*Selar*, *Decapterus*) also make occasional contributions to the catch.

Catch and Effort

Forms are provided to all pole-and-line vessels where details of bait and tuna catch data are recorded. Before June, 1981, three forms giving details of catches, bait catch by species and tuna length frequency were used. These were replaced by a single form bound in a booklet.

Baitfishing information recorded on the form includes: date, position, catch per set of the net (in buckets), total bait catch, and estimated species breakdown (%) by the seven groupings listed earlier, plus an 'others' category.

Each vessel is supplied with plastic-coated colour photographs of the main species within the groupings, with English, Latin, Japanese and Fijian names on the reverse side. Preserved specimens were also shown to the recorders to avoid any misunderstanding about the baitfish species grouping and thus improving the accuracy of catch composition reports.

Overall Trends

Catch composition varies with site and season. Catch rates have remained fairly stable over the period the fishery has been in operation (Table 1) and an average of 38 buckets of bait are caught per set. Catch versus effort plots (Fig. 2) show that baitfishing effort to date has not been sufficiently hard to create a levelling off of catches at the higher effort levels.

The strongly linear appearance of the data points may reflect some underlying assumptions on apparent abundance as discussed by Wetherall (1977). Dalzell and Wankowski (1980) have reported a linear catch effort relationship in the Papua New Guinea baitfishery. With many suitable areas in Fiji as yet unfished, there is, in all probability, scope to increase existing catches by moving into new areas. The fleet of boats can be dispersed or concentrated, depending on the availability of tuna schools, weather conditions, steaming time etc.

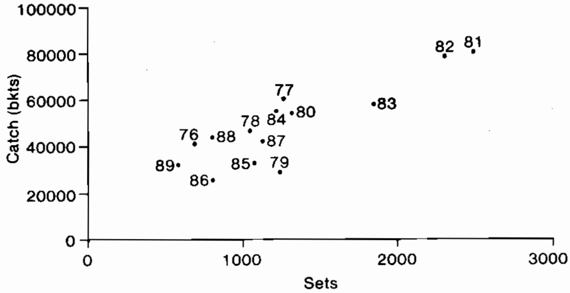

Figure 2. Catch versus effort plots.

Seasonal Variation in the Baitfish Catch

Table 1 summarises baitfish catch and effort data by year. Figure 3 represents a plot of nights spent baiting per month. Figures 4 and 5 represent total number of sets per month, and catch per set, and Figure 6 is the total bait fish catch per month.

Both the average monthly catch/set and total catch (Figures 5 and 6) show distinct seasonality,

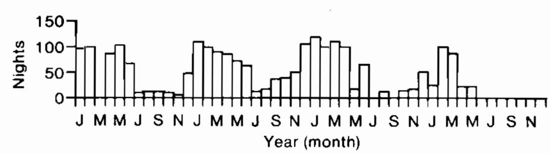

Figure 3. Plot of nights baiting (all vessels) per month.

Table 1. Summary of baitfish catch and effort by locally operating pole and line boats, 1976–1989.

Year	Catch (bkts)	Nights	Sets	Sets/Night	Buckets/Set
1976	41 249	436	681	1.56	60.57
1977	60 116	840	1259	1.50	47.49
1978	46 987	755	1041	1.38	45.14
1979	29 302	1 005	1 231	1.23	23.80
1980	54 302	1 068	1 314	1.38	41.30
1981	80 485	1 777	2 482	1.32	32.42
1982	78 901	1 741	2 294	1.30	34.39
1983	57 947	1 363	1 837	1.40	32.00
1984	54 998	890	1 210	1.50	45.00
1985	33 305	735	1 068	1.40	31.00
1986	25 679	570	799	1.40	32.00
1987	42 261	800	1 122	1.40	38.00
1988	43 836	566	799	1.40	55.00
1989	32 281	398	574	1.40	56.00
Total	681 648	12 944	17 711	1.37	38.49

Sources: Before 1983 — Fisheries Division annual Reports. 1983–1989 data are directly from the Fisheries Division data-base.

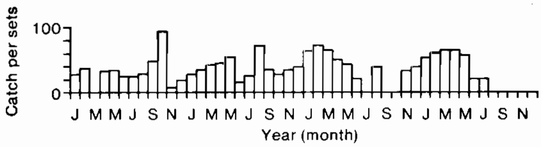

Figure 4. Total number of sets per month.

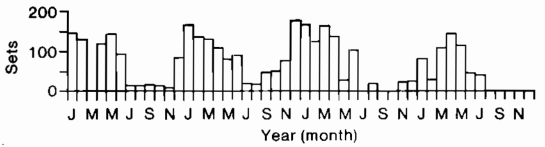

Figure 5. Catch per unit effort (catch per set).

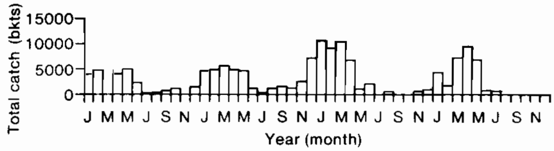

Figure 6. Total baitfish catch per month.

with catch rates generally increasing steadily from low levels in October/November to a peak in April and May, then declining over the June-August period.

In response to this seasonality in catch rates, effort figures (both sets and nights fishing per month) display a similar seasonal pattern in Figures 3 and 4. This seasonal fluctuation has been regular since the fishery began and, within any given year, is strongly correlated with mean monthly sea surface temperature.

Catch by Area

The proximity of potential tuna fishing grounds is one of several factors which influence the geographical distribution of baitfishing effort. As the experience of the fishing masters has increased along with their understanding of patterns of tuna availability, changes in the distribution of effort have occurred. In general the following conditions influence where boats will fish:

— the proximity of good tuna fishing;
— expected weather conditions;
— distance from unloading sites;
— the location of productive fish aggregation devices or payaos;
— access agreement with traditional owners.

Table 2 lists catch and effort by zone 1982–1989. Also included is the percentage species composition.

All the major islands in the groups have baitfish resources.

Lomaiviti recorded the highest baitfish catch of 23% of the total for this period, followed by Northern Vanua Levu with 21%, Vanua Balavu with 16%, Central Viti Levu with 11% and Levuka with 9%. Eastern Vanua Levu, Kadavu and Savusavu support large quantities of baitfish but generally provide supplementary catches.

Southern Lau recorded the highest overall catch rate of 44 buckets per set although the overall catch from this area is comparatively small. It would be worthwhile to investigate further the potential of this area.

The second highest catch rate was recorded in the Levuka zone, followed by Lomaiviti. Close to these zones were Northern Vanua Levu, Eastern Vanua Levu and Vanua Balavu.

Other areas also showed a reasonably high catch rate. It is worth drawing attention at this point to the fact that many sites showed a large change in yield or catch rate depending on the anchorage within the site. It is possible for a vessel to experience very poor catch rates just a few hundred yards from the site where a very high catch was experienced previously, or for catch rates to fluctuate markedly on a daily or weekly basis at the same site. This could be due to a highly concentrated and mobile bait population, but seems more likely to be the result of dilution of bait or seasonal changes.

Species Composition

Species composition showed variation between zones, although sprats and sardines generally comprised up to 20% of the catches in the period 1982 to 1989 (Table 2). A comparison between the two major zones: 'mainland' (North and South Vanua Levu, Central Viti Levu), and 'island' (Ovalau, Lomaiviti, and Northern Lau) showed anchovies and mackerel to be more abundant at 'mainland' sites, and sprats and cardinal fish at 'island' sites, with sardine and herrings showing little variation.

Biological Studies

The research section of the Fisheries Division has collected length frequency data for *Herklot-*

Table 2. Percentage species composition of baitfish catches in 'mainland' versus 'island' zones.

Species	Sprats	Sardines	Herrings	Silversides	Mackerels	Cardinals	Anchovies	Other
Mainland	21	20	15	4	7	10	14	9
Island	20	15	21	5	6	15	9	9

sichthys quadrimaculatus, Rhabdamia gracilis and *Spratelloides delicatulus.* The method of baitfish capture and biological data are described in detail by Lewis et al. (1983).

Attention has been focused on the biology of the major component species of the bait fishery (Lewis et al., 1983). However, very little data on the age, growth and mortality of these species is available. Dalzell et al. (1987) found that all three species have short life spans. *H. quadrimaculatus* and *R. gracilis* are annual species with life spans probably of 10–12 months, while the maximum life expectancy of *S. delicatulus* is possibly about six months. The consequences of a short life span and concomitant high natural mortality rate means that many fish will die before completing their growth. It would pay therefore to fish relatively hard and with a small size at first capture so as to catch the fish before they die of natural causes.

R. gracilis is a mouth brooder, in common with other apogonids. As such, it is likely to have a low fecundity. Further removal of the adults would have a direct effect on recruitment since survival of adults is necessary for protection of newly hatched larvae.

Herklotsichthys quadrimaculatus. Williams and Clark (1983) recorded 'daniva' only in shallow water during the day, with both juveniles and adults moving into deeper water at night where feeding occurs. Such diel movements are probably typical of Fiji populations also. The species' maximum size in Fiji probably approaches 13 cm. It is regarded as good bait, mainly because of its keeping qualities, and gathers near the surface under night-lights. It is sometimes toxic to humans in the form of clupeotoxism. Conand (1984) observed a single spawning peak for *H. quadrimaculatus* in New Caledonia waters that extended from October to December and gave rise to length frequency distributions similar to those in Fiji.

Spratelloides delicatulus. No taxonomic problems are known to exist with blue sprats, but little literature on the biology of the species exists. A study on the biology, in Papua New Guinea (Dalzell and Wankowski, 1980) however, provides a useful frame of reference.

Blue sprats (known locally as caru or caca in some areas) occur in smaller schools, usually in the clear deeper lagoon waters. They are rarely seen close inshore and are not well known to village fishermen. The species is strongly attracted to lights and gathers at the surface where it is easily captured. The species attains 7cm in length and large individuals are regarded as excellent bait. The maximum life expectancy of *S. delicatulus* is about 6 months. High intensity fishing would be a reasonable fishing tactic for the short-lived *S. delicatulus* since observations by Lewis et al. (1983) suggest this species also has a protracted spawning period between October and June and possibly throughout the year.

Management Issues

The rational management of Fiji's baitfish resources, which lie almost entirely within the customary fishing areas and are the mainstay of the Fiji pole-and-line fleet, is one of the priority tasks of the Fisheries Division.

The tuna fishing and canning industry employs over 1000 people and contributes over 10% of Fiji's total domestic exports by value. Fiji has gradually built its place in the world market and today, PAFCO (Pacific Fishing Company) tuna is recognised world wide as being of the highest quality. At present, IKA Corporation (a Government Statutory Body) owns a fleet of five pole-and-line vessels and a further two Fiji pole-and-line vessels are privately owned. A variable number of foreign pole-and-line boats fish in Fiji waters and supply tuna to PAFCO, these generally include two Japanese boats and one New Zealand boat, with occasional Kiribati or Tuvalu vessels.

The bait requirements of pole-and-line fishing in Fiji occasionally come into conflict with local interpretations of customary fishing rights. Normally, commercial fishermen must obtain a permit to fish in customary fishing rights areas, and it has become accepted practice (although not legally sanctioned) in some areas to charge a 'goodwill' fee for this permission. There have been several cases where fishing rights owners have complained that pole-and-line boats should pay a fee to fish for bait in their areas. Quite apart from legal rulings, which state that customary fishing rights are not rights of ownership over the resource, there are the enormous difficulties that would be caused if each tuna vessel had to obtain a yearly permit from each of the 100 or so baiting sites that it might want to access each season. However, legal interpretations may change, and the concept of 'goodwill' payments for use of customary fishing grounds is gradually becoming an accepted practice, so it may become necessary to introduce some sort of permit system for pole-and-line vessels.

Such permits would preferably be issued at the provincial level but, realistically, this alone is unlikely to solve the problem as expectations of compensation could not legally be met. Pole-and-line vessels have been advised to improve their relationships with people in the baitfishing areas and, in particular, to prevent the crew doing 'extracurricular' illegal fishing in lagoons.

In the short-term, the problem could be eased by diverting effort to little-used baiting grounds and the Fisheries Division is hoping to perform another survey of baitfishing grounds with the aim of producing a comprehensive baitsite 'atlas' detailing likely species assemblages with sonar profiles and including detailed radar and bathymetric charts to assist anchorage changes during the night. This will be a large task, requiring the full cooperation of all pole-and-line skippers. Resources, in terms of skilled manpower and funding, are limiting and this workshop is timed fortuitously for the exploration of possible avenues of assistance.

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The Status of the Tuna Baitfishery in Kiribati

T. Tekinaiti*

Abstract

Kiribati consists of three groups of islands: the Kiribati, the Phoenix and the Line groups, with 33 coral atolls scattered between latitudes 10°N and 13°S and longitudes 150°E and 160°W in the central Pacific Ocean. The declaration of the 200 nautical mile extended zone around the three groups of islands has given Kiribati national jurisdiction over 3.6 million sq km of ocean, the second largest zone in the south Pacific. The entire future of the country's economy may well depend on the exploitation of the tuna resources found within the waters of the 200 mile extended economic zone. The national fishing company, Te Mautari, was incorporated in 1981 as a commercial pole-and-line tuna fishery. This method of fishing requires a consistent supply of live bait and this can be caught in the Kiribati lagoons but needs to be supported by cultured bait. Over the last few years the company has developed to such an extent that in 1988 a fleet of four vessels caught 2566 tonnes, worth US$1 million in foreign exchange to the Kiribati government. This paper describes the status and problems of the tuna baitfishery in Kiribati and the use of cultured bait.

Pole-and-line fishery

Te Mautari Limited (TML) started operation in 1981 with two experimental pole-and-line vessels. It has now grown to a fleet of six vessels including a 300 tonne motherboat. The two vessels, Nei Baeao and Nei Moaika arrived at the end of November, 1988 and started fishing operations in 1989. The main species caught in Kiribati waters are the skipjack tuna (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*) and bigeye (*Thunnus obesus*). Live bait is required to attract tuna close to the fishing boats where they are poled onboard using barbless hooks (McCarthy 1985). In addition to pole-and-line fishing the company also buys fish from artisanal fishermen for export. Since 1988 TML has extended its activities to two outer islands (Butaritari and Abemama). Selected fishermen were equipped with 5.4m skiffs and 25hp outboard engines which they use for catching tuna and reef fish. The fish are frozen and stored at each island centre before they are transported back to Tarawa by the mothership. Each centre is expected to supply a total of 250 t of tuna/year. A small percentage of this is resold through the company outlet on Betio. TML exports an average of about 1160 t/yr to the canneries in American Samoa and Fiji.

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Baitfishery

Wild bait

The success of the pole-and-line fishery in Kiribati depends on several factors the most important of which is bait availability. Stone and Kristjonsson (1980) reported that the existing stocks of wildbait coupled with cultured bait are sufficient to support a fleet of eight catcher vessels.

The main wildbait species available in Kiribati lagoons are listed in the TML Corporate Plan 1985-1989 as follows: blue-backed sprat (*Spratelloides delicatulus*), gold spot herring (*Herklotsichthys quadrimaculatus*), sardine (*Amblygaster sirm*), hardyheads (Family Atherinidae) and others. A more recent survey by Ianelli (1988) reported that the bait species (as listed above) are also dominant in all bait grounds irrespective of the capture method. The methods include boukeami (using a light to attract the fish at night and using a net to catch the bait), and beach seining during the day.

Ianelli (1988) recorded that sardines have become less predominant in the bouke-ami catches in recent years while the catch of the gold spot herring has increased and predicted that future occurrence of a fluctuating species composition seems likely. The report advised that expansion of baitfish operations should proceed cautiously.

Bait fishing areas

There are four islands in the Kiribati group which are known to be favourable areas for baitfishing activities. Most are in the northern group (i.e. Butaritari, Abaiang and Tarawa) and one in Central Kiribati. The other islands with lagoons are unsuitable as they are too shallow, without a suitable entrance, too distant or too dangerous to conduct normal baitfishing methods (Ianelli, 1988).

Baitfish research

Baitfish samples are collected from four sites on a monthly basis from commercial bouke-ami sets. When the TML fleet concentrates baitfishing at one lagoon, then cast nets are used to obtain samples. In addition baitfish logsheets are issued to each vessel master to complete and the data obtained will be used for future analyses.

Bait availability and longevity

The major factor limiting the tuna fishery is baitfish shortage. This is due to the seasonal behaviour of wildbait and the concentration of bait availability at certain sites.

The seasonal behaviour of wildbait is experienced during the off moon season when the wildbait is scarce and the bouke-ami method fails to attract wildbait. At this time the vessels purchase live bait from the milkfish farm.

Wildbait availability is concentrated in Northern Kiribati which is not adjacent to the fishing area. In addition, the wildbait only survives onboard the vessels for two to three days. Obtaining bait from one area and carrying it aboard vessels over long distances will result in high mortality and restrict areas of fishing operation.

Use of Cultured Bait

As a result of concerns over bait shortages which restrict the pole-and-line operation, a pilot aquaculture project was initiated in 1971. There was an initial examination of the potential of cultivating baitfish in Kiribati by a FAO/UNDP aquaculture expert (Uwate, 1984). This was followed up by the setting up of fish farms using milkfish (*Chanos chanos*) as bait.

Culturing baitfish has the advantage that production and growth can be controlled.

Milkfish were chosen because they are known to have suitable characteristics for use as live bait. They are resistant to sudden changes in salinity and tolerate low oxygen content, are hardy and adapted to high temperature conditions; their rate of growth is good and they adjust well to crowding (Gopalakrishnan, 1972). Comparisons between bait species indicate that the mortality of milkfish, when handled correctly, is the lowest for any of the major baitfish groups.

The milkfish farm covers a land area of 80 hectares with a potential annual production of 91 tonnes. This would be feasible if sufficient milkfish fry could be caught (Uwate 1984). The farm is currently purchasing milkfish fry from neighbouring islands to supplement fry which enter naturally with the incoming tide. The input requirement was estimated at about 165 000 fry/month. The fry collected are stocked in the nurseries (treated with organic and inorganic fertilizer and chicken manure) until they reach fingerling or bait size when they are transferred to rearing ponds (bait ponds). The fingerlings cultured are purchased by TML to supplement their wildbait catches. Floating cages have been constructed and placed in Betio harbour where the fishing vessels usually moor for tuna unloading and replenishing of supplies. The main aim of this cage operation is to make bait available whenever required by the TML pole-and-line vessels and at the same time condition the milkfish live bait to the seawater environment. The floating cages have a capacity of 200 buckets, and at the moment the stocking rate is 35 buckets/m^3.

The future of the TML pole-and-line vessels will continue to rely on cultured milkfish as bait due to fluctuations in natural bait catches. Ianelli (1988) recommended that the current size of the fleet cannot be expanded unless the production of the milkfish farm is increased.

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The Baitfishery in Kiribati and Its Impact on the Tuna Industry

M. MacInnes*

KIRIBATI has a vast exclusive zone (EEZ) surrounding its three main island groups, the Gilbert, Phoenix and Line Islands, representing a larger controlled zone than most of the other Pacific Island States; this area which straddles the equator, with most within five degrees north and south, is rich in tuna resources.

Te Mautari Ltd, (TML), the Government owned fishing company, was incorporated in 1981, with the objective of carrying on the business of commercial fishing for tuna and fish marketing.

The company commenced operations with a pole-and-line research vessel 'Nei Manganibuka', followed, up to the present, by five other pole-and-line vessels. The first 'Nei Manganibuka' has since proved uneconomic and has been taken out of service.

The development of fisheries in Kiribati must be viewed within the context of all the extreme difficulties which beset the introduction of any business venture in a country which is remote from supplies, servicing and markets. It has a relatively poorly developed infrastructure and supporting facilities in terms of energy, transport, communications, and repair facilities.

Other than marine fisheries, natural resources are extremely limited, and Distant Water Fishing Nations (DWFNs) operating in Kiribati waters have the comparative advantages of proximity to markets and all the associated logistic support, such as competitive fuel prices, processing, and distribution of tuna, necessary to a successful fishing fleet operation.

Numerous studies have been undertaken on the establishment of a Kiribati funded fishery, with most of the studies having been assessed as viable, however, when taken to full commercial operation, all such ventures have failed.

It must be pointed out that the financial failure of TML since 1981 must be shared with other national enterprises in the Pacific region, and the reasons for such failure have been many, it is not the writer's intention to deliberate on this matter, except in the technical areas of pole-and-line fishing and the wild bait resource; further, that my comments are based on observations through four years as Manager of TML.

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Kiribati Wild Bait Fishery

Pole-and-line fishing was very correctly chosen as the best method to introduce I-Kiribati to the prosecution of the tuna fishery. However, the planners had not taken into consideration the principal constraint of the lack of a hardy wild bait resource and the high mortality of atoll lagoon bait species. They made the assumption that:

a. both tuna and wild bait fish are not seasonal,
b. sufficient bait could be supplied by the development of milkfish culture ponds.

Pole-and-line fishing was chosen as the acceptable fishing method, due to its relatively low cost operational technique, it does however, depend greatly on a renewable resource of hardy and longliving wild bait, which allows the vessel fishing master to have the widest field of operation in which to search for tuna schools. This is demonstrated most ably by the Japanese pole-and-line fleet which can stay at sea for months without having to replenish their bait wells.

In nine years of operation TML has so far failed to clearly establish a fishing pattern both seasonally and annually, one of our major difficulties being the prediction of the annual catch. Experience has shown however, that there is a season for skipjack, when between the months of March and September the schools are in the immediate area of the Gilberts. Also, our records show that these are the best months for wild bait.

From the month of March through till October meteorological conditions settle down with the wind blowing steadily from the east, and from October through till February the winds commence to blow sporadically from the west, resulting in a disruption of bait capture.

During 1986/87 there was considerable change in the weather pattern (possible El Niño effect) with the wind coming from the west for approximately 47% of the year, this dramatically affected the bouke-ami operation in respect of surface disturbance, turbid water, and disruption of bait schools. With these conditions catcher vessels were reduced to taking from the bouke-ami approximately 30–40 buckets instead of the expected 80–100 buckets and, to capture the bait, vessels had to move close inshore.

McCarthy's (1985) excellent notes and illustrations of the most common wild tuna baitfish indicate seven different species which are captured by the bouke-ami operation, the most abundant of these are:

Spratelloides delicatulus (Blue Sprat)

It is very attractive to skipjack, and McCarthy (1985) indicates that although fragile it can live up to three days in the baitwell. Our experience is that this is true only if a few buckets are in the baitwell, but with 20 buckets the bait (both juveniles and adults) are dead within 15 hours and the largest percentage within nine hours.

Amblygaster (Sardinella) sirm (Spotted Sardine)

This species with gold spots, is only a small percentage of the catch, but the same fish without gold spots (*Amblygaster clupeoides*) is very abundant (as much as 50% of the catch), neither species lives longer than 15 hours in the baitwells. It is also noticeable that the larger fish (100–150mm) are dead within six hours whereas smaller fish are hardier.

Herklotsichthys quadrimaculatus: (Gold Spot Herring) *(H. punctatus)*

This species makes excellent bait, but only represents 5% of the catch. It will however, live in the baitwells for up to three days.

As mentioned earlier, one of the important keys to a successful pole-and-line operation is hardy and long living tuna wild bait. In the case of TML it was assumed that bait would live for up to three days and, having made that assumption, the larger, high horsepower vessel was chosen to prosecute the fishery.

Experience now shows that the most abundant and attractive wild bait and, for that matter, the cultured milkfish bait, die within approximately 15 hours and is therefore only effective for chumming up to a maximum of nine hours or 90 nautical miles from the baiting lagoon.

Personal observation indicates that vessel crews are aware of the importance of keeping wildbait alive and active for chumming, and take all the necessary steps to ensure careful handling.

Although considerable study of wild bait has taken place in Kiribati lagoons, much still has to be learned and even with the reduced number of species available compared to Papua New Guinea, Solomons or Fiji, when examining an atoll baitfishery, conclusions that may be drawn from the study of one part of the lagoon need not apply to another. The following are offered as remarks and assumptions:

1. Atoll species appear to be weaker and therefore subject to higher mortality. This could be due to high water temperatures, lack of oxygen, and/or lack of food.

By way of example, one of our vessels when departing from Fiji waters earlier this year lifted approximately 40 buckets of Gold Spot herring, taking it to Tarawa where the bait lived in the baitwells remaining strong and active for about five weeks before chumming. The same species captured in Kiribati will only live for a maximum of three days.

2. To what extent do meteorological conditions influence the bait mass in the lagoon? Again with personal observation, in 1986/87 with the prevailing easterly winds being interrupted, and strong westerly winds blowing for much of the year, surface water started to flow in an easterly direction and continued for many weeks after the wind speed dropped. Skiffs which had got lost, and are normally picked up anywhere between Nauru and Indonesia, were found in the region of Baker Island, some 600 nautical miles to the east.

During this period poor bait hauls were experienced and baitfish could only be found in any quantity along the shore line of the lagoon. Is it a reasonable assumption that nutrients are not finding their way to the surface under these conditions?

3. There is much conflicting information on how many pole-and-line vessels should fish the lagoon baitmass, and I am not sure that sufficient evidence is available to make a valued judgement.

The all important *Spratelloides delicatulus* (Blue Sprat) is the mainstay of the TML fleet, and should we get the MSY of that species wrong and hit it too hard then we have economic problems ahead of us for some time.

The only hard evidence that I can quote of possible over fishing is that when two vessels are baiting within two miles of each other and only one vessel attracts the bait, particularly the Blue Sprat, then it is time to move to another lagoon, even if it means extending the distance to the tuna schools.

Conclusions

The problem that TML encountered on commencing the pole-and-line operation was the economics of operating large, high horsepowered vessels with a bait mass which suffered high mortality. As with other Pacific nations such as Fiji and Solomon Is. we have now learned to match the vessel size and horsepower with (in the case of Kiribati) bait mortality, and today our new vessels can operate with moderate efficiency within the constraints presented to us; however, we must try to extend our area of operation and this can only happen if we can extend the life of the bait mass. Unfortunately we are observing Japanese pole-and-line vessels fishing for large yellowfin which, because our bait will not survive, is just outside our field of fishing operations. It is therefore a matter of considerable priority that we address ourselves to solving this problem.

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II Baitfish Biology and Reproduction

Biology of Tuna Baitfish of Seychelles

J-P. Hallier*

Abstract

Several surveys have been carried out on the Seychelles tuna baitfishes: on the Mahe Plateau in offshore areas and in coastal areas. On the Mahe Plateau, two species *Decapterus maruadsi* and *D. macrosoma* are a suitable size for use as baitfish (<15 cm) when juvenile. *D. maruadsi* is more abundant but undergoes seasonal fluctuations in abundance. It spawns from March to June. After one year *D. maruadsi* fork length reaches 14 to 15 cm, and after two years, 21 to 22 cm when it spawns. The stock was assessed at 55 000 tonnes. *D. macrosoma* is present all year round but in small amounts. Spawning seems to occur from March–April to September with a maximum in June–July. It only reaches 10 cm FL after one year and 17 cm after two years when it spawns. The stock is estimated at 2000 tonnes. In coastal areas, two species, *Herklotsichthys punctatus* and *Atherinomorus lacunosus* were the most abundant baitfish species. *H. punctatus* apparently spawns more or less all year round. *Atherinomorus lacunosus* has two well marked spawning seasons, one in April–June and another in September–December.

THE Seychelles are an archipelago situated in the south-west Indian Ocean from 3°45′–10°20′ S and from 46°10′–56°10′ E (Fig. 1). Land area is very limited (453 km^2) but the islands are spread over a very wide oceanic zone which gives the Republic of Seychelles an Economic Exclusive Zone (EEZ) of more than one million km^2.

Island geology is of two types:

- mountainous, granite islands which are all in the north of the archipelago and lying on the 27 500 sq km Mahe Plateau where sea depths vary from 10 to 80 metres, and
- islands of low relief and made up of coral and sand which are either isolated, and rising from the floor of the ocean (Coetivy, Platte), or on the edge of the Seychelles Plateau (Bird, Denis) or grouped together in smaller archipelagos such as Amirantes, Farquhar or Providence.

All Seychelles islands are influenced by the monsoon system of the Indian Ocean. Winds blow from the south-east from May to September and from the north-west from November to March. The two monsoons are separated by the intermonsoon periods of April–May and October–November which are characterised by very little wind.

Being mostly equatorial, Seychelles receives plenty of rain (yearly average 2000 mm) especially on the elevated granitic islands where small streams are numerous, the largest receiving high precipitation despite the small size of the island (145 km^2 for Mahe, the largest island). However, a dry season (June–September) does exist, mainly on the low lying islands especially for the southern island groups (Assomption, Cosmoledo, Aldabra, Farquhar). More than 95% of the 66 000 Seychellois are found on the three granitic islands Mahe, Praslin and La Digue. Mahe, where the capital Victoria is located, accounts alone for 55 000 inhabitants.

The Mahe Plateau lies from 3°45′ S to 5°45′ S and stands in the path of the Equatorial Counter Current which flows east from December to April. This Plateau is relatively productive and supports a local fishery with landings of 4000 t annually, thus helping meet the high local demand for fish. The Seychellois are among the highest fish consumers in the world.

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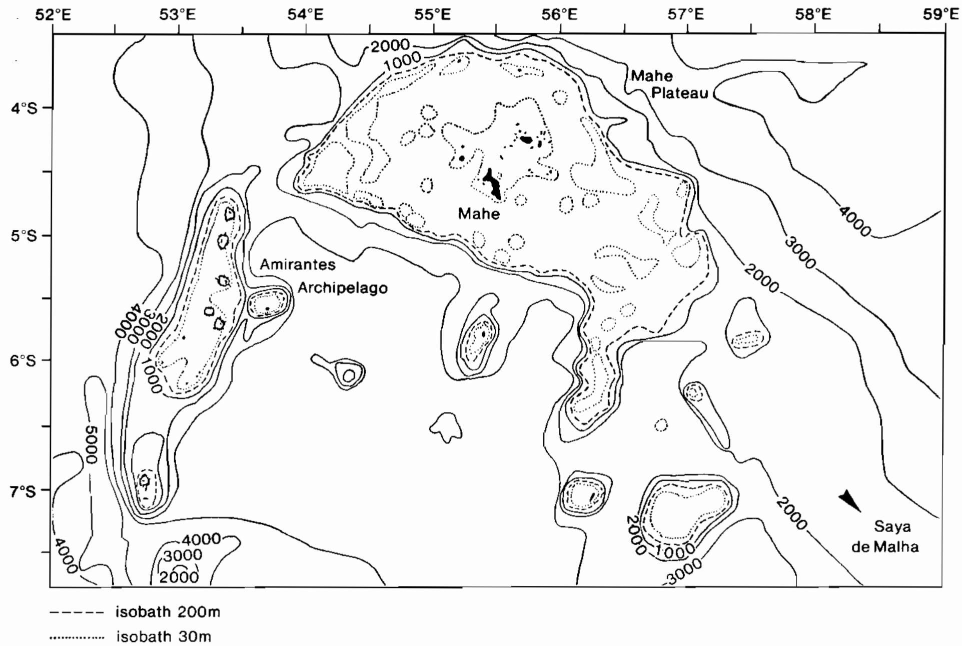

Figure 1. Seychelles Islands and the Mahe Plateau.

The Seychelles is the centre of an annual 200 000 t. purse seine fishing industry making Victoria the leading tuna fishing port in the Indian Ocean.

Fishing generally and tuna fishing in particular have always been of prime concern to the Seychelles Government. For this reason several tuna surveys have been conducted in the past around the Seychelles. Purse seine trials were performed from 1980 to 1983, pole-and-line trials in 1980–81 with four French-built vessels and in 1981–82 with two Spanish-built vessels.

In order to support a pole-and-line fishery, data on tuna baitfish resources in the Seychelles have been gathered through different surveys and research programs.

Tuna Baitfish Surveys

These surveys were of two types as a consequence of the different areas they covered:
— the open sea of the Mahe Plateau
— the coastal areas.

Baitfish surveys on the Plateau

These surveys were mainly performed by research vessels using acoustic methods for the assessment of the biomass, and pelagic or bottom trawling to catch the corresponding fish:

— R.V. 'Professeur Metsyatsev' in July 1976 and October 1977 (Shubnikov, 1978)
— R.V. 'Fridtjof Nansen' in July 1978 (Anon, 1978),
— R.V. 'Nauka' in February–March 1979,
— R.V. 'Coriolis' in September–November 1979 and August–September 1980 (Marchal et al., 1979, 1981). This vessel also carried out trials with lamparo and bouke-ami,
— German trawlers 'Ostsee' and 'Nordsee' January–November 1981 (Steinberg et al. 1982).

Other data were gathered during the pole-and-line surveys by the French vessels from January 1980 to March 1981 and the Spanish vessels from July 1981 to March 1982.

The French pole-and-line vessels caught bait using lamparo and bouke-ami gear. The Spanish pole-and-line vessels were targeting baitfish from the Plateau by fishing at night without lamparo, spotting and catching the fish using sonar and a 380 × 65m purse seine.

On the Plateau, species caught were mainly small Carangidae (*Decapterus* spp. *Selar crumenophthalmus*) mixed with small amounts of Clupeidae (*Sardinella sirm*) and Scombridae (*Rastrelliger kanagurta*).

The ideal size for tuna baitfish is related to the tuna size and the species targeted. It is generally thought that 6 to 8 cm baitfish are adequate for skipjack (*Katsuwonus pelamis*) and 10 to 15 cm baitfish for yellowfin (*Thunnus albacares*) (Yuen, 1977). Tuna baitfish over 15 cm in length are rarely utilised.

Coastal baitfish surveys

Day-time fish surveys were conducted either from the beaches using beach nets or from small vessels using a purse seine. Purse seine was also used at night as well as bouke-ami, baitfishes being attracted by underwater lights. These trials were undertaken by the Seychelles Fisheries Division (Ratcliffe, 1974,1978) and by the French Scientific Research Institute for Development through Cooperation (ORSTROM). This research program was conducted from March 1982 to February 1983 along the coasts of Mahe Island.

Baitfish Biology

Some of the data used comes from surveys conducted by different research vessels, but most data are from the two cruises of ORSTROM's R.V. 'Coriolis' for the baitfish of the Mahe Plateau (Marchal et al., 1979, 1981) and from the ORSTROM–Seychelles Fisheries Division baitfish research program on coastal baitfish (Anon, 1983; de Moussac and Poupon, 1986).

Baitfish of the Mahe Plateau

Species

The two main species being studied are *Decapterus maruadsi* and *D. macrosoma* as they are the most abundant small pelagic fish of the Mahe Plateau.

Areas and periods of occurrence

Decapterus maruadsi schools densely near the bottom during the day and tends to disperse in mid-water during the night.

Decapterus macrosoma is always close to the bottom; therefore trawling yields are the same day or night.

Spatial distribution on the Mahe Plateau for the two species from March to November is shown in Figure 2.

Decapterus macrosoma appears to be present all year round in every location surveyed but in small numbers. While *D. maruadsi* seems to undergo large seasonal fluctuations in its abundance, there is a strong tendency for it to be found in greatest quantities at the edges of the Plateau.

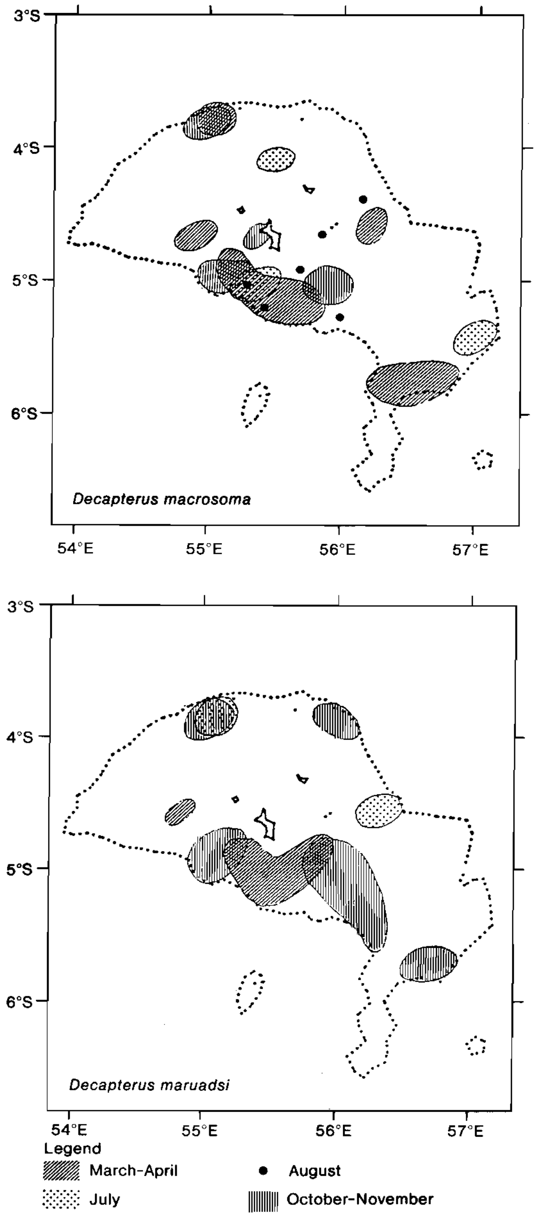

Figure 2. Periods and areas of occurrence of the two *Decapterus* spp.

Baitfish size distribution

From Figure 3a it is apparent that juveniles of *D. maruadsi* appear in the catch in July but often their large size renders them unsuitable as baitfish. This is less often the case for *D. macrosoma* (Fig. 3b) for which fish less than 15 cm are abundant.

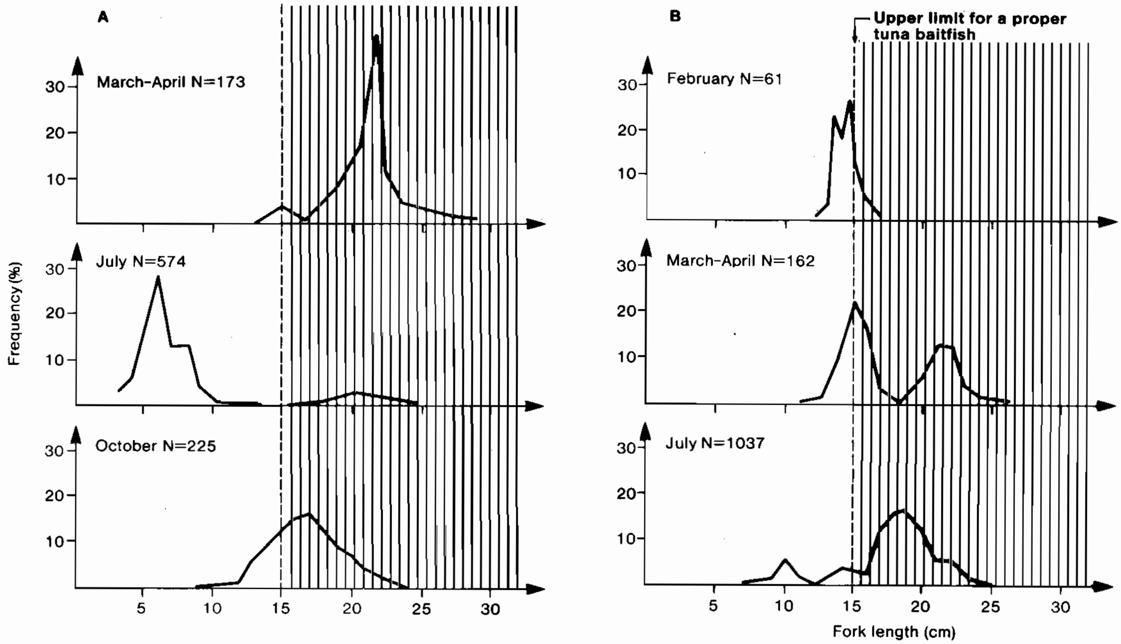

Figure 3. Monthly size frequency distributions: A) *Decapterus maruadsi* and B) *Decapterus macrosoma.*

Maturity and spawning

The maturity stages for male and female *D. maruadsi* listed in Table 1 clearly demonstrates that spawning must occur from March to June. During that period most fish measure 19 cm to 22 cm (Fig. 3). Spawning could either occur on the Plateau, the spawners moving afterwards outside the Plateau, or spawning could take place outside the Plateau with the juveniles moving onto the Plateau in July. In our samples mature fish of less than 20 cm were found.

Birkett (1979) stated that *D. maruadsi* reaches sexual maturity at the end of its second year when it moves into deeper water (over 100 m) to spawn. No data were available to support this hypothesis. For *D. macrosoma* (less abundant than *D. maruadsi*) the limited samples available suggest that spawning occurs from March–April to September with a maximum in June–July (Tarbit, 1980). Contrary to *D. maruadsi*, *D. macrosoma* would spend all its life on the Plateau where spawning would occur. Size at first spawning was assessed at 16cm–22cm in two years. Size at first spawning was assessed at 16cm–17cm by Tarbit (1980).

Growth

With the hypothesis of one spawning season in March–June, a growth curve is proposed for *D. maruadsi* (Fig. 4). Fishes born in April–May would measure about 14–15cm after a year and would reach 21–22 cm in two years when they spawn.

Table 1. Gonad stage distribution for adult *Decapterus maruadsi* (Tarbit, 1980).

	Occurence of juveniles in samples (% of total no. of fish)	Adult gonad maturity stages										Number of fish sampled
		Males (%)					Females (%)					
		II	III	IV	V	VI	II	III	IV	V	VI	
March–April	5.2	–	19	58	–	22	5	47	16	–	30	173
July	83.2	83	11	–	–	5	61	23	15	–	–	574
October (South–east coast)	6.5	97	3	–	–	–	96	–	–	–	4	75
October (North–coast)	0.5	48	50	–	–	2	57	6	7	–	30	150

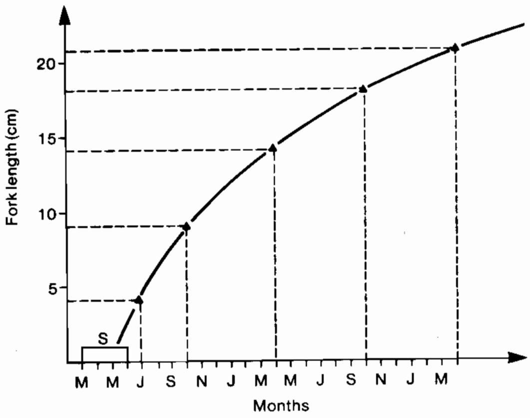

Figure 4. *Decapterus maruadsi* growth curve.

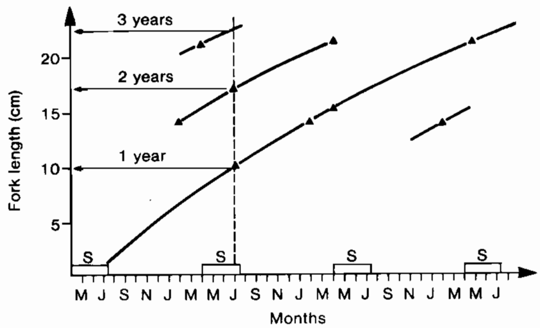

Figure 5. *Decapterus macrosoma* growth curves.

For *D. macrosoma*, when following the different modes, growth seems to be slower than for *D. maruadsi* (Fig. 5): at one year fish would reach only 10 cm and at year two 17 cm.

Stock assessment

Birkett (1979) using acoustic methods estimated the Mahe Plateau small pelagic fish stock at 115 000 t. This estimation comprises not only the *Decapterus* species but all other small pelagic fish, of which *Decapterus* spp. are the most numerous.

Using the same acoustic techniques, but with a more detailed analysis, Marchal et al. (1981) estimated the nectobenthic fish stocks at 66 000 t, *D. maruadsi* would comprise the largest part of this amount.

Using a different method (an average density of 8.6 t/sq mile multiplied by a 6,600 sq mile trawling area) Marchal et al. (1981) calculated a biomass of 57 000 t. Of this, *D. maruadsi* would represent 55 000 t and *D. macrosoma* 2000 tonnes.

The Gulland (1971) equation $C=M\times 0.5\times B$ (C is MSY, M is the natural mortality coefficient and B is the biomass) can be used to assess the maximum sustainable yield as these stocks are not exploited. For short lived species such as *Decapterus* sp. M is taken as equal to one and therefore MSY for *D. maruadsi* is estimated at 27 500 t and at 1000 t for *D. macrosoma*.

Decapterus spp. as baitfishes

For baitfishing *D. maruadsi* has several disadvantages:

- fishes of the appropriate size for bait (6 to 15 cm) are only available for part of the year,
- this species undergoes very large population fluctuations with periods when it disappears completely on the Plateau (Tarbit, 1980).

On the other hand, *D. macrosoma* appears to be a more reliable baitfish:

- it is present year round (Spanish pole-and-line vessels caught it almost exclusively (Cort, 1982),
- it is found over the entire plateau,
- suitable baitfish sizes are available almost all year round.

However, the sustainable catch of *D. macrosoma* under 15 cm FL is estimated at only 200 tonnes. This amount could not support an important industrial pole-and-line fishery. If these two species are to be exploited as baitfish for other purposes, more research will be necessary, especially on:

- fluctuations in seasonal abundance
- migratory movements
- aging, growth, reproduction and feeding biology
- more accurate stock assessment.

Coastal baitfishes

For every fishing trial, an 80 fish sample for each of the two main species was taken and studied for size, sexual maturity, weight of whole fish and reproductive condition of gonads (Anon, 1983).

Species

The baitfish species caught during the day by beach or purse net, or at night with lamporo and bouke-ami or purse seine nets are:

- *Herklotsichthys punctatus* or sardines
- *Atherinomorus lacunosus* (previously *Pranesus pinguis*) or hardyheads
- *Spratelloides* sp. or sprats
- *Amblygaster sirm* or sardine de France
- *Selar crumenophthalmus* or big eye mackerel
- *Rastrelliger kanagurta* or Indian mackerel.

The first two species listed were by far the most abundant while the last three were scarce and almost always too large as baitfish. Therefore, only *Herklotsichthys punctatus* and *Atherinomorus lacunosus* were studied. *Spratelloides* sp. were rare except on baitfish trials made near coral islands, especially in the lagoon of Desroches island. *Amblygaster sirm* was found in very small numbers, always of large size and near granitic or coral islands.

Areas and periods of occurrence

Sardines and hardyheads were found on both coasts of Mahe, being more abundant on the east coast and the southern and northern parts of the west coast.

A lower abundance was noticed from June to August except on the north-west coast but this situation could be a consequence of the weather conditions: strong south-east winds occur around Mahe during this season.

Baitfish size distribution

Monthly size distributions are given in Figure 6 for *Herklotsichthys punctatus* and in Figure 7 for *Atherinomorus lacunosus.*

Suitable baitfish sizes are available all year round.

Marichamy (1968) found larger *H. punctatus* up to 145 mm in the Andaman Sea. For *H. punctatus* small sizes appear in the catches in June–July while for *A. lacunosus* this takes place in April, in July–August and in November.

Maturity, spawning and fecundity

Five maturity stages are used, the last, stage V, describes the gonad of a fish ready to spawn. There is great variability in the percentage of stage V *H. punctatus* females (Fig. 8a). During six months (May, June, August, October, November and January) the percentage of stage V is greater than 30%.

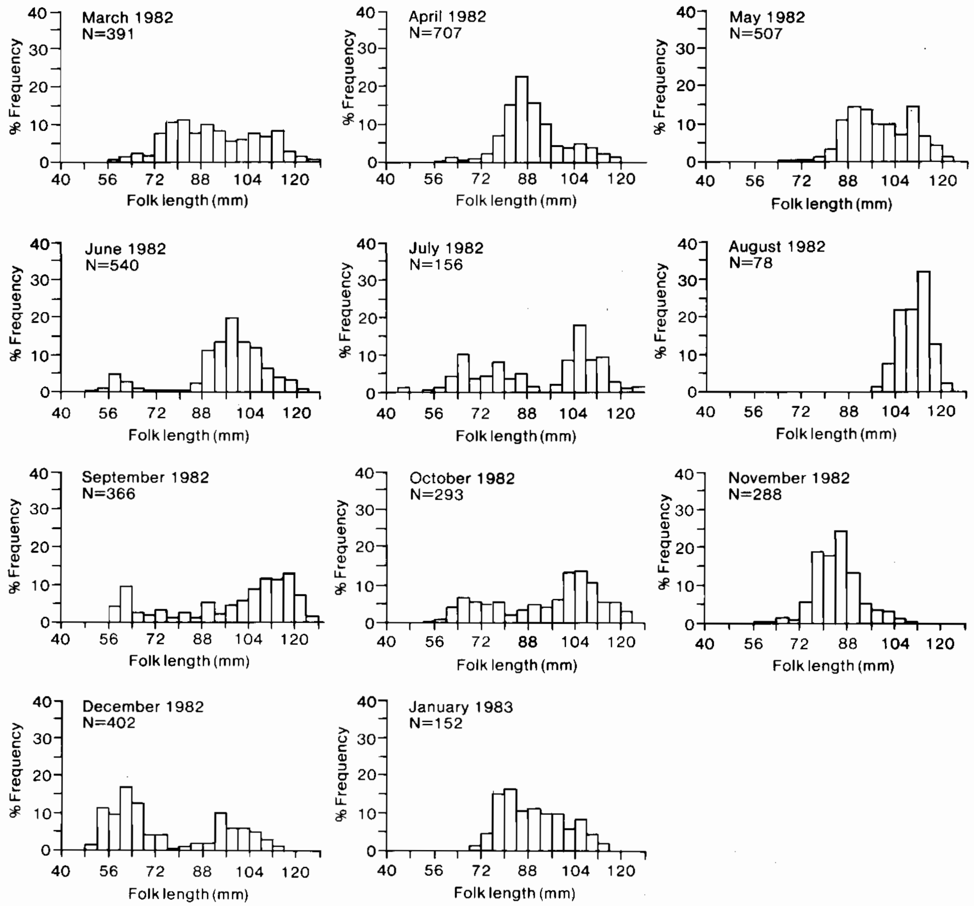

Figure 6. Monthly size distributions for *Herklotsichthys punctatus* from March 1982 to January 1983.

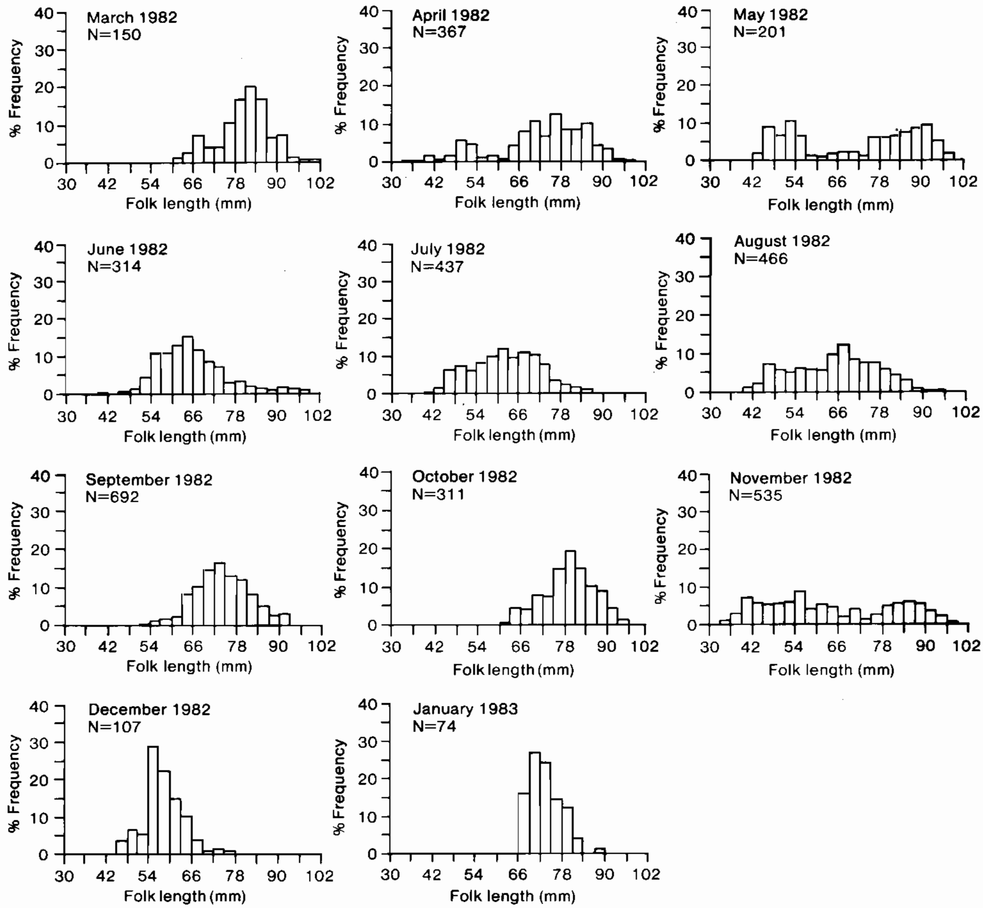

Figure 7. Monthly size distributions for *Atherinomorus lacunosus* from March 1982 to January 1983.

It seems therefore that *Herklotsichthys punctatus* spawns more or less all year round with more active spawning periods in August, October–November and January–February. Spawning activity is slowest in April. Marichamy (1968) noticed in the Andaman Sea that *H. punctatus* has several spawning periods each year but peaks in May–June and October–November.

Atherinomorus lacunosus has two well-marked and protracted spawning seasons in April–June and in September–December (Fig. 8b). These periods roughly correspond to the inter-monsoon periods. Measurements of ovocyst diameters give a polymodal distribution for both species which suggests a particular female may spawn several times during the same spawning season or the same year (Fig. 9).

Fecundity was estimated for the two species using the number of ripe ovocysts (diameter $>450\mu$.). An important source of variation recorded in both species was the size of the fish but variation also occurred in the same size of fish.

The relationships of fecundity, size and weight are as follows:

—*Herklotsichtys punctatus*

Fecundity (F) with fish size (FL) in mm

$F = 9053.7 \times \text{Log FL} - 36312.0 \quad r = 0.64$

Fecundity (F) with fish weight in grams

$F = 3468.0 \times \text{Log W} - 3939.6 \quad r = 0.67$

—*Atherinomorus lacunosus*

Fecundity (F) with fish size (FL) in mm

$F = 5.32 \times e^{0.057\,FL} \; r = 0.87$

Fecundity (F) with fish weight (grams)

$F = 95.32 \times e^{0.278\,w} \; r = 0.89$

Fecundity of *H. punctatus* varies from 3000 to 10 000 eggs, that of *A. lacunosus* is much lower and is between 150 and 1600 eggs.

Size at first spawning (50% females at stage V) was 8 cm for *H. punctatus* and 6.4 cm for *A. lacunosus*.

In the Andaman Sea the fecundity of *H. punc-*

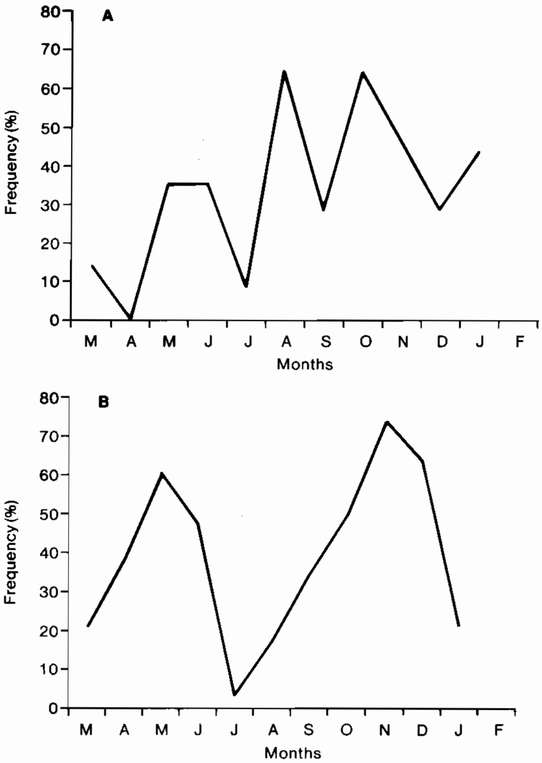

Figure 8. Frequency of stage V gonads: A) *Herklotsichthys punctatus* and B) *Atherinomorus lacunosus.*

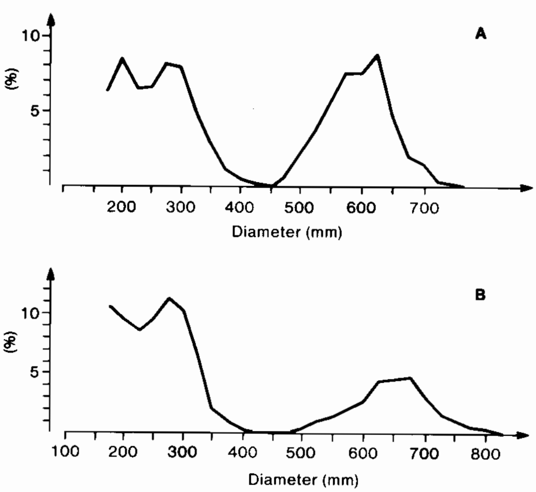

Figure 9. Ovocyst diameter distribution in the stage V gonads A) *Herklotsichthys punctatus* and B) *Atherinomorus lacunosus.*

tatus of 12.5 cm was between 6500 and 10 700 eggs (Marichamy, 1968).

Growth

Growth studies with otolith and scale readings were tried but without success. Fish size frequency distribution was used; modes were separated utilising the Bhattacharya (1967) and the Gheno and Le Guen (1968) methods (Fig. 10).

The von Bertalanffy (1938) equation parameters were obtained using the Gulland and Holt (1959) graphic method:

Herklotsichthys punctatus

$Lt = 133\ [1-e^{-2.56\ (t\ +0.1)}]$

$L_\infty = 133$ mm

$k = 2.56$

$t_o = -0.10$

Atherinomorus lacunosus

$Lt = 97\ [1-e^{-2.556\ (t\ -\ 0.18)}]$

$L_\infty = 97$ mm

$k = 2.556$

$t_o = 0.18$

According to these growth curve equations all *H. punctatus* in our samples were less than one year old, but *A. lacunosus* live longer than one year. However, the growth curve for the hardy-

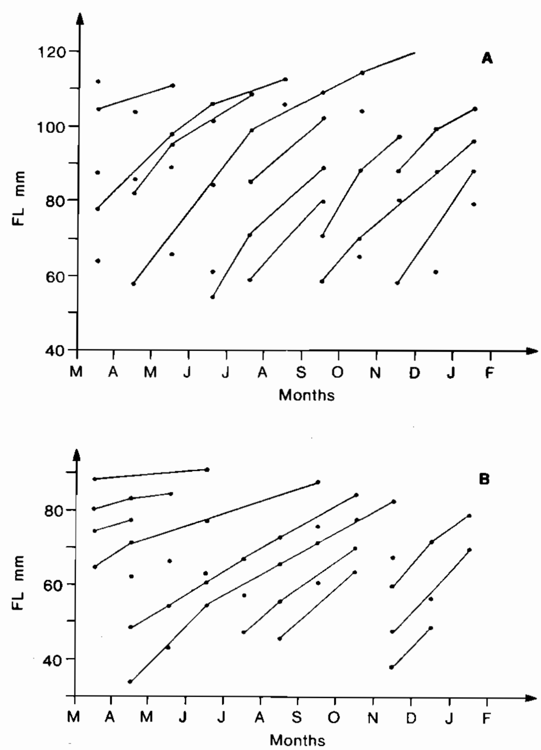

Figure 10. Size mode relationship A) *Herklotsichthys punctatus* and B) *Atherinomorus lacunosus.*

heads does not fit well with the observed size modes especially for large size fish. With insufficient data available, no stock assessment was possible.

Length-weight relationship

Length-weight relationships were calculated for both species. Student t tests reveal a different relationship for male and female *Atherinomorus lacunosus* but no difference for *Herklotsichthys punctatus*:

$W = 9.5 \times 10^{-3}\ FL^{3.18}$ for *H. punctatus*

$W = 9 \times 10^{-3}\ FL^{3.12}$ for *A. lacunosus* males

$W = 8 \times 10^{-3}\ FL^{3.18}$ for *A. lacunosus* females

Discussion

Decapterus maruadsi is found in large numbers mainly on the edge of the Mahe Plateau but offers only limited opportunities as a tuna baitfish. Only juveniles (FL $<$ 15 cm) are suitable and these are available only part of the year. Furthermore their numbers fluctuate widely from year to year.

Decapterus macrosoma juveniles can also be used as tuna baitfish. This species is available more often and with smaller fluctuations in abundance but the stock cannot sustain a high level of exploitation.

Overall, coastal baitfish resources are limited and mainly composed of two species, *Herklotsichthys punctatus* and *Atherinomorus lacunosus*. The former is considered a good baitfish, the latter is among the less effective of tuna baitfish (Argue et al., 1987).

In conclusion a Seychelles Government-based pole-and-line tuna fishery would probably have its development hampered by availability of baitfish. In view of this the Seychelles Government has, for the time being, given up the idea of developing a pole-and-line tuna fishery. Therefore studies of the biology of the tuna baitfishes were discontinued after the completion of the 1982–83 baitfish program. Since then, a very important purse seine tuna fishery has developed in this region. The Seychelles are therefore purchasing a purse seine fleet in order to gain access to the tuna resources of the Western Indian Ocean.

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Life-Histories of Clupeids in North-Eastern Australia: preliminary data

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Abstract

This project was initiated in order to determine the relationships between offshore concentrations of billfish (black marlin and sailfish), the clupeids they eat on the fishing grounds, and coastal resources. In particular we were interested in the possible role of coastal habitats, including mangroves, as nursery areas for the baitfish. The study has developed into one of the comparative life-histories of major clupeid species in the region. These include *Amblygaster sirm*, *Sardinella albella*, *S. brachysoma*, *S. gibbosa*, *Herklotsichthys castelnaui*, *H. koningsbergeri*, *H. lippa* and *Escualosa thoracata*. Preliminary data on distributions of adults and juveniles of these species are presented.

THIS project forms part of a larger study examining coastal pelagic resources in the Townsville region of North-Eastern Australia, with particular emphasis on the significance of coastal resources to offshore concentrations of billfish (Williams, in press). The Cape Bowling Green billfish (sailfish and juvenile black marlin) grounds, which are the focus of the study, occur 8 to 19 km off Cape Bowling Green in water 24–36 m deep (Fig. 1). The billfish concentrations occur seasonally (SE trade season) in open water over a flat, apparently featureless, bottom in the middle of the shipping lanes. They are closely associated with large schools of clupeid baitfishes which are the presumed cause of the concentrations. Two similar fishing grounds occur to the north of Cape Bowling Green. All three grounds occur offshore of, and just downstream from, major areas of coastal mangroves and wetlands. This observation has led to several hypotheses concerning possible connections between the offshore fisheries and coastal wetlands. One of these hypotheses is that the coastal wetlands are the nursery grounds supporting the offshore baitfish.

Apart from the present study, no significant ecological studies of tropical clupeids have been carried out in Australia although Hoedt (1984, these proceedings) has done some preliminary work on engraulids off Townsville. Indeed we are only beginning to come to grips with the taxonomy (Wongratana 1980, Whitehead 1985) and new species are still being described (Wongratana 1983, 1987). The overall aim of our baitfish study

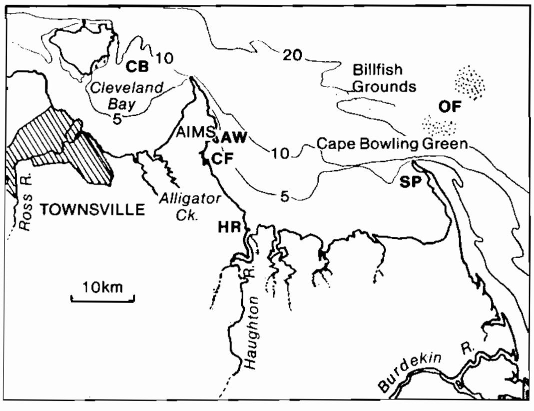

Figure 1. Location of study sites. HR = Haughton River, CF = Chunda Flats, AW = AIMS wharf, SP = Cape Bowling Green Spit, CB = Cleveland Bay, OF = Offshore billfish grounds.

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is to carry out a comparative study of the life-histories of the major species present, including distributions, growth, reproduction and longevity, and then to relate these life-history characteristics to the physical oceanographic processes in the study area.

At the present stage field work has just been completed. The aim of this paper is to present some preliminary data on the distributions of adults and juveniles of six of the major species.

Material and Methods

Study sites

Bowling Green and Cleveland Bays are situated between latitudes 19°10′S and 19°25′S and longitudes 146°45′E and 147°30′E. Both bays are predominantly less than 10 m deep. Both shoal to the east, with the eastern half of each bay being predominantly less than 5 m and the western half from 5–10 m deep (Fig. 1). All Bay samples were collected from trawls in Cleveland Bay (CB). Major areas sampled were waters less than 5 m between the Ross River and Alligator Ck. and waters of 10–15 m at the mouth of the bay. The trawl was a standard local prawn net of approximately 4 cm stretched mesh.

The offshore site (OF) was the billfishing grounds in 24–36 m of water. Sampling was not as consistent at this site due to problems of availability of suitable boats and the extreme difficulties of working in a very exposed area. Samples from here resulted from limited gill-netting with the same nets as used at the shallow water sites, but used in conjunction with lights at night, or were collected on the Hari-hide jigs used by the game-fishermen for collecting bait.

At all the following shallow water sites, a variety of sampling techniques were used. Only those that provided the data presented in this paper are indicated here.

The Haughton River (HR) is the main river system draining into Bowling Green Bay. It is shallow, mostly less than 5 m deep with many sandbars and lined by mangrove forests. The major sampling site was at the mouth of a mangrove creek approximately 8 m wide and about one kilometre from the mouth of the river. Fish were sampled here with 30 m multi-mesh monofilament gill-nets. These nets comprised three 10 m panels, one each of 19 mm, 32 mm and 45 mm stretched mesh.

The Chunda Flats (CF) and AIMS (Australian Institute of Marine Science) Wharf (AW) sites are in Chunda Bay on the extreme western side of Bowling Green Bay, adjacent to the AIMS Marine Operations Centre. The Chunda Flats are wide inter-tidal sand flats between the mouths of two small mangrove-lined creeks. Sampling on these flats was carried out with a 150 m long beach seine (two 50 m wings of 30 mm mesh and 50 m main net of 13 mm mesh). The AIMS wharf is approximately 200 m from the Chunda Flats and runs out from an artificial breakwater in water that is usually 4–5 m deep. The water is often turbid but generally clearer than that at the Bowling Green Spit site. Sampling here was with the same gill nets used in the Haughton River.

The Bowling Green Spit (SP) site is on the south-western side of Cape Bowling Green, approximately 200–400 m from the end of the sand spit. Sampling here was carried out with the same gill-nets as used at the other sites, run out from the beach and perpendicular to it in 0–3 m depth. The water was consistently more turbid than at the previous two sites, probably due to a combination of fine silt in the area, derived from the Burdekin River, and considerably stronger tidal currents.

Data analysis

All samples except those from the offshore site were collected at approximately monthly intervals for more than a year. The data presented here come from only a partial enumeration of all these samples. The samples that have been used, however, are sub-samples taken throughout the year at each site in order to avoid bias caused by differences between sites. In each subsample, individuals of all species were counted so as not to bias relative abundances within any site. The data are presented as all samples pooled within each site. The resulting picture is consistent with the impressions we have built up during the entire sampling operation.

Results

Species collected

Clupeids collected during this study included the clupeins *Amblygaster sirm*, *Escualosa thoracata*, *Herklotsichthys castelnaui*, *H. koningsbergeri*, *H. lippa*, *Sardinella albella*, *S. brachysoma*, *S. gibbosa*, the dussumieriin *Dussumieria elopsoides* and the dorosomatins, *Anodontostoma chacunda* and *Nematalosa come*. In this paper we concentrate on the six most abundant clupeins collected, the three *Herklotsichthys* spp. and the three *Sardinella* spp..

Herklotsichthys castelnaui

H. castelnaui is clearly the most estuarine of these species. The size of adults collected from the river,

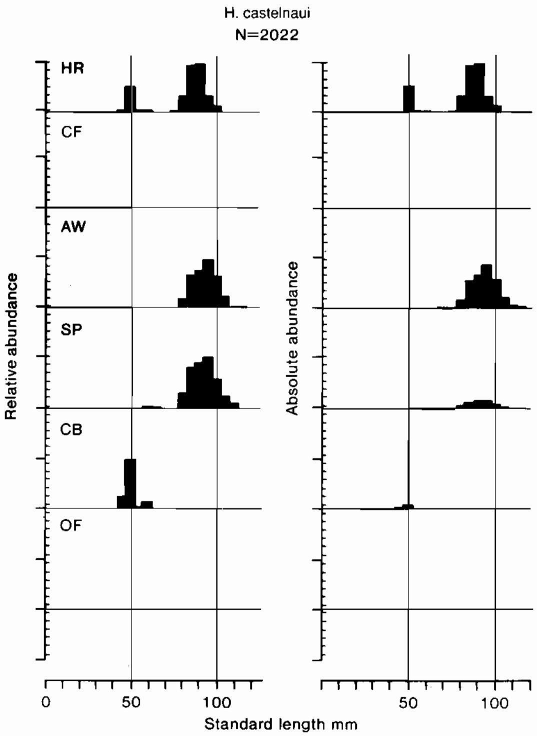

Figure 2. Size-frequency of *Herklotsichthys castelnaui* at each site. Left-hand column is scaled so that the size interval of maximum frequency at each site is of equal height.

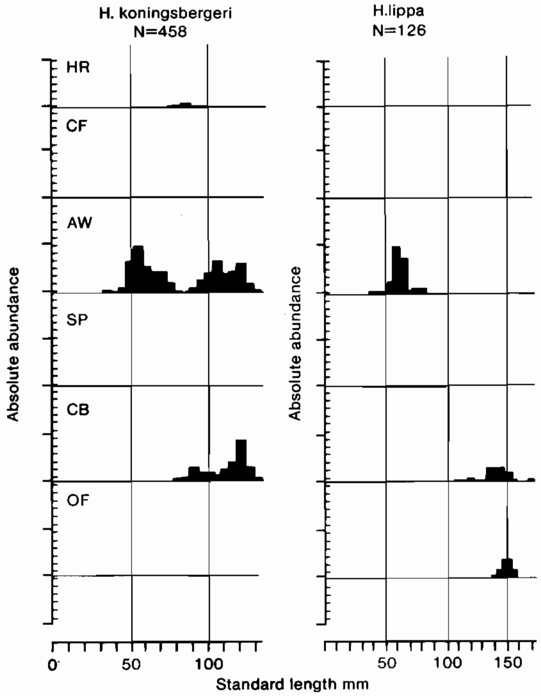

Figure 3. Size-frequency of *Herklotsichthys koningsbergeri* and *H. lippa* at each site.

AIMS wharf and the Spit differed little, although those from the river may be marginally smaller (Fig. 2). Juveniles are most abundant in the river. The only fish of this species collected in the trawls were juveniles taken in 2.5 m at the mouth of the Ross River. Numbers of adults were relatively high at the AIMS wharf but this may be due to its proximity to the mouth of Ticklebelly Creek which contains *H. castelnaui.*

H. koningsbergeri and H. lippa

Both these species were not often caught in shallow waters (Fig. 3). *H. koningsbergeri* was caught in large numbers from the AIMS wharf as well as the Picnic Bay jetty on Magnetic Island although their presence at these sites was highly variable. This species was regularly caught out in the Bay (CB) where the fish were predominantly very large individuals. Neither *H. koningsbergeri* nor *H. lippa* were caught in Bay waters of less than 10 m. Juveniles of both species were caught in significant numbers only at the AIMS wharf. Large *H. lippa* were caught only at the mouth of the Bay and further out on the offshore grounds.

Sardinella albella and S. brachysoma

Adults of these two species were regularly caught in the river although not in the same numbers as *H. castelnaui* (Fig. 4). These adults also appear to be significantly smaller than those collected outside the river. Size distributions of these two species show no marked differences at any of the sites. The size distribution of fish caught in the Bay is similar to the adults caught at the AIMS wharf. The smallest juveniles of both species were found on the Chunda Flats and at the AIMS wharf. Larger juveniles were present both in the river and at the Spit. These two species differ markedly in their distribution around Bowling Green Bay. Whereas 43% of *S. albella* came from the AIMS wharf and only 25% from the Spit, 67% of *S. brachysoma* came from the Spit but only 5% from the wharf. Similarly larger numbers of *S. albella* than *S. brachysoma* were caught out in the Bay but more *S. brachysoma* than *S. albella* were caught in the river.

S. gibbosa

Adult *S. gibbosa* have the most distant offshore distribution of all the species examined with the possible exception of *H. lippa* (Fig. 5). Juveniles were most abundant on the Chunda Flats and

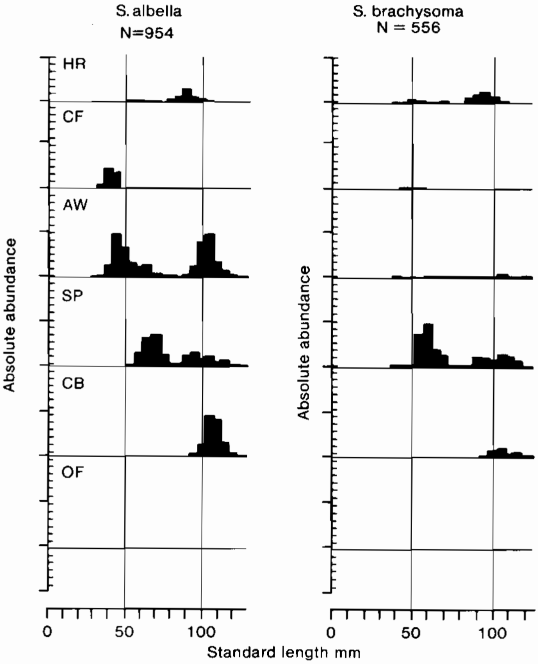

Figure 4. Size-frequency of *Sardinella albella* and *S. brachysoma* at each site. Percentage frequencies refer to percentage of all individuals of that species which were caught at that site.

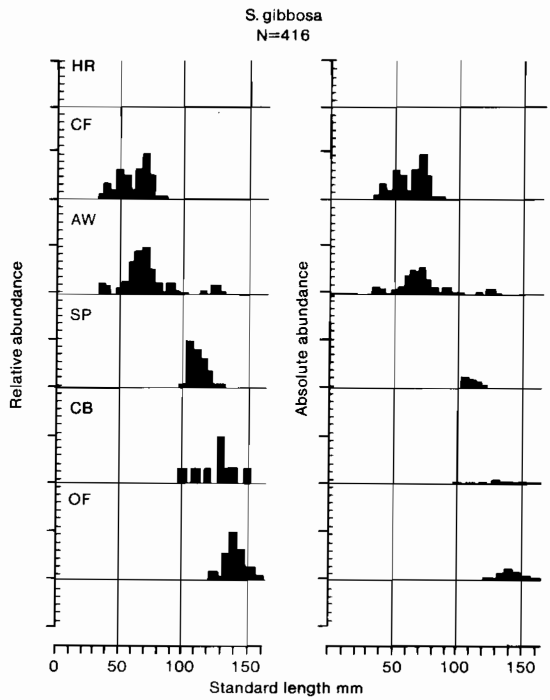

Figure 5. Size-frequency of *Sardinella gibbosa* at each site. Left-hand column is scaled so that the size interval of maximum frequency at each site is of equal height.

around the AIMS wharf but were not collected in the river or at the Spit. Intermediate-sized fish were found at the Spit and to a lesser extent in the Bay and at the AIMS wharf. Adults were collected offshore only on the billfish grounds.

Discussion

Given the preliminary nature of these data, some caution needs to be taken in interpretation. It does, however, emphasise major differences in distributions among the clupeids found in the region, and different kinds and degrees of dependence upon the coastal resources. It also serves to generate specific hypotheses that can be more rigorously tested with further data.

It is interesting that juveniles of even the species that were collected only offshore as adults were at times abundant inshore. The appearance of large schools of juvenile *S. gibbosa* along the beaches in Bowling Green Bay in late October–November has been observed by us for each of the last five years. Although at times dominated by *S. gibbosa*, these schools, which are continually harassed by predatory fishes and seabirds, also contain some *S. albella* and *S. brachysoma*. Similar schools of juvenile *S. gibbosa* and *S. albella* are the basis of the important 'Choodai' fishery in India (e.g. Sekharan, 1955). The relative abundance of species other than *S. gibbosa* in these schools awaits further analysis. In at least one of the two summers sampled, juveniles of *Amblygaster sirm*, which together with *S. gibbosa* appears to be the major species supporting the billfishes (on the basis of stomach contents and relative abundances on Hari-hide jigs on the fishing grounds), also arrived in large schools, along the beaches.

Sardinella albella and *S. brachysoma* form a particularly interesting species-pair. To the unaided eye they are almost identical. The major taxonomic character separating them is the pattern of striations on the scales. Until the present analysis we also found them extremely difficult to distinguish ecologically. The apparent similarities were so great as to cause us to run some enzyme electrophoresis studies to determine whether in fact they were good species. The results supported the primary taxonomy, as it did for all the clupeins found in the region (Stoddart, Williams and Cappo, unpublished data). The present data suggest that the distribution of *S. albella* may be more 'offshore' than that of *S. brachysoma*. The relative distributions of the juveniles of the two species is presently unclear. From the Indian data, (Sekharan, 1955) it would not be surprising if many *S. albella* were mixed with the schools of *S. gibbosa.* This would be a curious situation, however, if we are correct in suspecting that the two species spawn in quite different locations. Large numbers of juvenile *Sardinella 'albella'* have been found in the mangrove forests of Alligator Creek in Cleveland Bay by Robertson and Duke (1990) but these authors did not attempt to distinguish *S. albella* from *S. brachysoma* (A.I. Robertson, pers. comm.).

Apart from being of major importance in supporting offshore concentrations of billfish, *S. gibbosa* and *A. sirm* are the major item in the diet of spanish mackerel (*Scomberomorus commerson*) (McPherson, 1987), an offshore species of major commercial importance in northern Australia. The presence of large numbers of the juveniles of these two baitfishes in shallow nearshore waters and the probability that the nearshore zone is the major nursery site of these species, establishes a strong link between offshore fisheries and coastal resources.

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Biology of Whitebait Anchovies of Indian Waters

G. Luther*

Abstract

The present status of knowledge of the biology and fishery of the whitebait anchovies of Indian waters is presented. Whitebait is a common pelagic fish commercially exploited along the Indian coast south of 17°N. Ten species of whitebait of two genera, *Encrasicholina* and *Stolephorus*, occur in Indian seas. Of these, *E. devisi* and *S. waitei* together account for the bulk (85%) of the whitebait catch. The former schools closer to the surface than the latter. *E. punctifer* occurs in deeper waters than the other species. The whitebait fishery generally has two seasons, May-July and October-November. However, the bulk of the catch of *E. punctifer* is available during June-July. Whitebait have protracted spawning seasons with intensities during March-July and November. Growth and mortality rates of *E. devisi* and *S. waitei* and length weight relationships and fecundity of the other important species have been estimated. Fish of 4–8 months age form the mainstay of the fishery of *E. devisi* and *S. waitei*, and only very few fish of these two species survive beyond 12 months of age. Potential yield estimates of whitebait indicate scope for a threefold increase. *E. devisi* and *E. punctifer* are hardy, can survive in captivity for 1–3 months, more so in a medium of reduced salinity, and therefore could serve as good live-bait for tuna.

WHITEBAIT is the common name applied to the fishes of the genera *Encrasicholina* and *Stolephorus* in India. Our current knowledge on the resource potential and some aspects of the biology of the whitebait of the Indian seas is largely due to the investigations of the UNDP/FAO Pelagic Fishery Project (1971–75) along the southwest coast of India extending from Ratnagiri on the West coast (17°N) to Tuticorin (8°48′N) (Anon, 1974a,b, 1976a,b; Menon and George, 1975). Other works relate to certain selected centres namely Vizhinjam (Luther, 1972, 1979; Luther et al. 1984) and Mangalore and Cochin (Rao et al. 1982; Rao 1988a,b). This paper gives an account of the current status of our knowledge of the biology and fishery of whitebait anchovies of the Indian seas.

Whitebaits constitute one of the major food resources of many large sized pelagic fishes such as tunas, seerfishes, ribbonfishes, barracudas, carangids, sharks, wolf herrings as well as of sciaenids (Luther, 1979).

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Material and Methods

Data on the present status of exploitation and on some aspects of the biology of the whitebait were taken from the Annual Reports and Marine Fish Calendars published for several centres by the Central Marine Fisheries Research Institute (CMFRI). Results on the size composition, age and growth, mortality, spawning and fecundity were largely based on the author's observations at Vizhinjam during the period 1970–83. Length in this account refers to the total length of fish. The standard maturity scale (I–VII stages) was adopted for classification of maturity stages of gonads. However, two types of partially spent stages (VIIa and VIIb) could be recognised in this study. Other details are given in the relevant sections.

Observations and Discussion

Species composition and dominant species

According to Whitehead et al. (1988) 10 species of whitebait belonging to the genera *Encrasicholina*

Fowler 1938 and *Stolephorus* Lacepede 1803 occur in the Indian seas. They are *E. devisi* Whitley 1940, *E. heteroloba* Ruppell 1837, *E. punctifer* Fowler 1938, *S. andhraensis* Babu Rao 1966, *S. baganensis* Hardenberg 1933, *S. commersonii* Lacepede 1803, *S. dubiosus* Wongratana 1983, *S. indicus* von Hasselt 1823, *S. insularis* Hardenberg 1933, and *S. waitei* Jordan and Seale 1926. A key to species of the above two genera has been provided by Wongratana (1987).

E. devisi and *S. waitei* are the two dominant species on most parts of the Indian coast, together accounting for about 85% of whitebait landings. *E. punctifer* and *S. indicus* are the other important species.

Present status of exploitation of whitebait

Whitebait landings have improved over the past nineteen years from 26 000 tonnes during 1970–74 to around 77 000 tonnes during 1983–88. The contribution of whitebait to the total fish landings rose from 2% to 3–6% during the above two periods. Most of this catch (97%) is obtained along the southern maritime states, Karnataka (17%), Kerala (45%), Tamilnadu (20%), Pondicherry (1%) and Andhra Pradesh (14%).

Shore seine, boat seine, gillnet, bottom trawl and purse seine are employed in the exploitation of whitebait. Excepting the netholivala (gillnet) operated along the coast south of Quilon, no other gear is operated specially for whitebait anywhere in India. The operational depths of the last four fishing methods vary from season to season, the general ranges being 15–40 m and 8–20 m below the surface for boat seine and gillnet respectively; 20–50 m bottom depth for bottom trawl; and 10–30 m bottom depth for purse seine, the common depth being 20 m.

Distribution and movement

Results of the UNDP/FAO Pelagic Fishery Project along the south west coast (Anon, 1974a,b, 1976a,b) indicate that whitebait are distributed mostly in areas with bottom depths of 10–50 m. They exhibit typical diurnal vertical migration. Generally *E. devisi* is abundant in waters between 15 and 45 m bottom depth while *E. punctifer* is dominant in waters beyond 45 m bottom depth. *S. waitei* is a shoreward species being found mostly in waters less than 20 m depth while *E. punctifer* is the most seaward one.

Distinct seasonal migrations of whitebait were also observed in the above survey. In November/December more or less the whole whitebait stock is spread along the south west coast. In April a southward movement begins and the stock starts accumulating in the Gulf of Mannar during June–August/September. After the monsoon (June–August) the whitebait again disperse along the coast north of Quilon (9°N) during September/October–December. These seasonal movements of the whitebait stock have been found to be directly related to the transport of water masses along the west coast. Such studies, however, are lacking for the east coast.

Comparison of the catches of the two dominant species *E. devisi* and *S. waitei* by boat seine which is operated in mid-water reveals that the two species are more or less equally abundant (Table 1). But *E. devisi* is dominant, forming 83–98% of the whitebait catch in purse seine and gillnet (netholivala) operated at or near the surface and *S. waitei* is the dominant of the two species, forming 64–73% of the whitebait catch in trawlnets operated close to bottom. Thus these two species exhibit different vertical distributions, the schooling depth of *S. waitei* being at a lower depth than that of *E. devisi*. Hence deployment of more mid-water trawls may help to harvest efficiently the whitebait resource of the Indian seas.

The monthly variations in the catches of the four important species of whitebait at Vizhinjam during 1970–78 are given in Figure 1. It may be seen from this that two fishery seasons occurred for the four whitebait species. One peak occurred in October for all the four species coinciding with the post-monsoon season, while the second peak occurred in July, June, May and July respectively for *E. devisi*, *S. waitei*, *S. indicus* and *E. punctifer*. The major peak occurred in October for the first two species, in May for the third and in July for the fourth. In fact, the bulk (93%) of the annual catch of *E. punctifer* occurred during June-July,

Table 1. Species composition (percentage) of whitebait in different gears at different centres.

Locality/gear	Vizhinjam			Cochin		Mangalore		Visakhapatnam		
Species	BS	SS	GN(NV)	BT	PS	BT	PS	BS	SS	BT
E. devisi	34	71	85	23	83	28	98	40	95	21
S. waitei	37	11	14	73	5	64	0.5	6	3	70
E. punctifer	25	6	Neg	Neg	10	Neg	1.0	Neg	Neg	Neg
Other species	4	12	Neg	4	2	8	0.5	54	Neg	9

BS: Boat seine; SS: Shore seine; GN: Gill net (NV, Netholivala)
BT: Bottom trawl; PS: Purse seine; Neg: Negligible.

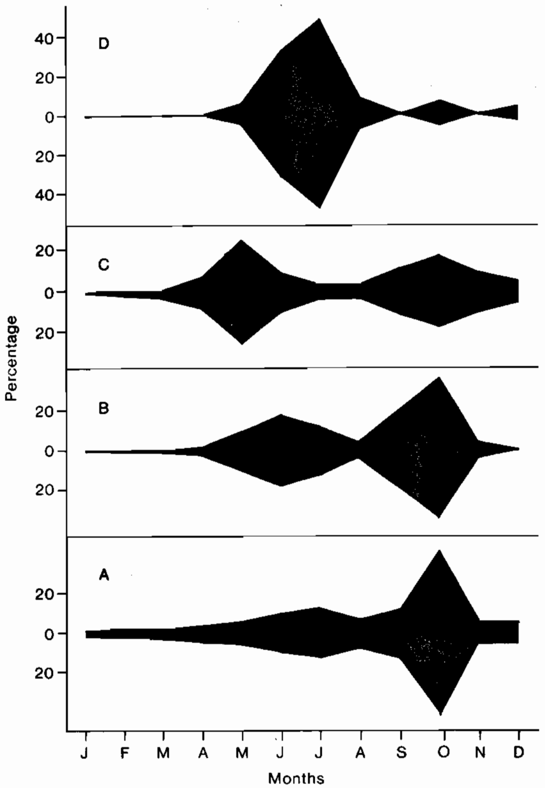

Figure 1. Seasonal trends in the catches of whitebait species at Vizhinjam during 1970–78 (A) *E. devisi*, (B) *S. waitei*, (C) *S. indicus*, (D) *E. punctifer*.

coinciding with the south west monsoon period (June-August). These differences in the time interval between the two peak fishery seasons may indicate the time interval between the two successive spawning peaks, it being two months for *E. devisi* and *E. punctifer*, three months for *S. waitei* and four months for *S. indicus*.

Maturity and spawning

Mature fish formed about 70% of the adult fish in the different months for *E. devisi* but only 12% for *S. waitei* at Vizhinjam indicating that the spawning grounds of the latter are beyond the operational depths of the gear employed. On account of this, the size at first maturity (Fig. 2) was found to be at about the usual size of 60–64 mm for *E. devisi* (Anon, 1974a; Luther 1979; Rao 1988a). But in the case of *S. waitei* since mature fish were scarce in the Vizhinjam area the length at first maturity is at a larger size of 105–109 mm, in contrast to that found at Mangalore, 75–79 mm (Rao 1988a), and for the south-west coast, 80–84 mm (Anon 1974a). It would thus

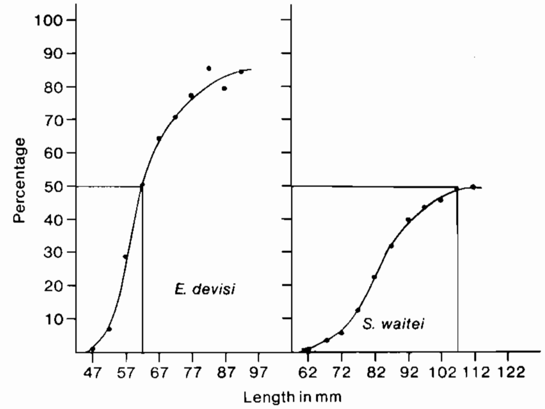

Figure 2. Size at first maturity of *E. devisi* and *S. waitei* at Vizhinjam.

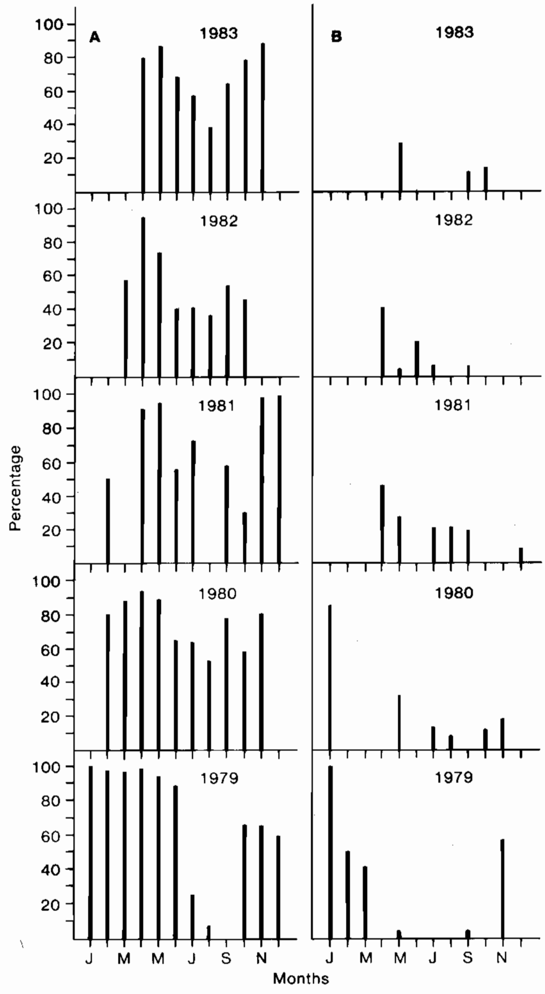

Figure 3. Monthly trends (as percentage of adult fish) in the distribution of mature fish at Vizhinham. (A) *E. devisi*, (B) *S. waitei*.

appear that the size at first maturity may be a function of the relative abundance of mature fish in a locality (Luther, 1986).

The size at first maturity for *E. punctifer* is at 45–49 mm and for *S. indicus* at 122 mm at Vizhinjam. *S. macrops (=S. insularis)* and *S. commersonii* are mature at 67 mm and 112 mm lengths respectively at Cochin.

The spawning season is protracted for whitebait (Fig. 3). The main spawning season for *E. devisi* is October-May along the west coast, and February-March, June-August and October-December along the east coast. For *S. waitei* it is during November-May along the west coast and during February-March, June-September and December along the east coast. For *E. punctifer* it is during June-August and October-December; for *S. indicus* it is during September-April and for both *S. macrops (= S. insularis)* and *S. commersonii* it is the same, taking place during December-March.

An individual fish spawns more than once during a spawning season (Dharmamba, 1959; Luther 1979; Rao 1988a,b). Studies on the development of ova to maturity, though currently inconclusive, suggest that an individual on attaining the minimum size of maturity sheds three batches of eggs in quick succession. The time lag between the first and second batches could be more than that of the last two. After this the individual may rest for 2–4 months, depending on the species, and start to repeat another set of multiple spawning.

Fecundity

Ripe ovaries that may shed the first, second and third batches of eggs were identified from their external appearance and the extent to which they fill the body cavity. Total count of the eggs of the most mature group of ova was made for these three categories of ripe ovaries and regression equations were calculated for the relationship between length of fish and fecundity for the three batches of eggs. From these equations, the average fecundities at different lengths were obtained. Estimates for similar lengths were summed to obtain the fecundity of a species for one set of multiple spawning comprising three batches of eggs. The ranges in fecundity of four species of whitebait with the length ranges examined given in parentheses are as follows: *E. devisi* (60–95 mm) 1698–6785 eggs, *E. punctifer* (50–95 mm) 1236–8971 eggs, *S. indicus* (115–160 mm) 4293–22 213 eggs, *S. waitei* (80–120 mm) 303–4812 eggs.

Whitebait larvae

Sree Kumari (1977) George (1979) and Girijavallabhan and Gnanamuthu (1982) reviewed the work done on the whitebait larvae of Indian waters. According to UNDP/FAO Pelagic Fishery Project reports (Anon, 1974b, 1976a) mixed species of whitebait larvae are the most numerous of the clupeoids along the southwest coast of India and are met with in almost all months, with the dominant period of occurrence from March to July and a secondary dominance in November. Relatively dense concentrations of the larvae are seen in the area south of Kasargod to the Gulf of Mannar with high core values over the outer shelf in the area from 7°30′N to 11°30′N. According to these reports *S. heterolobus* and *S. zollingeri* occur in large numbers. The other dominant species of whitebait larvae encountered are those of *S. bataviensis* and *S. baganensis*. Larvae of whitebait formed 12–13% of the total fish larvae in the International Indian Ocean Expedition samples (Shomura, 1970).

Food and feeding

Luther (1972) reported the food of *E. devisi* and *S. waitei* as comprising mainly copepods and other small crustaceans, besides small bivalves. Semi-digested food formed the rest (22–25%) of the stomach contents. Generally, larger food items were found in *S. waitei* than in *E. devisi*. However, Rao (1988a,b) confirming the above states that phytoplankton comprising *Coscinodiscus* was also found occasionally in the above two species. Ravindranath (1966) reported that phytoplankton and dinoflagellates together accounted for 40% of the stomach contents, though zooplankton formed the most important food item of *S. commersonii*.

Length–weight relationship

Measurements of total length in millimetres and weight in grams up to an accuracy of ± 10 mg were taken for individual fish without reference to its sex. The least squares method was applied for this study. As the scatter diagram of weight on length

Name of species	N	Length range (mm)	weight-length formula (Log W =)	r
E. devisi	1220	30–98	–5.64666 + 3.25137 Log L	0.9972
E. punctifer	500	40–100	–5.55893 + 3.210417 Log L	0.9992
S. waitei	670	55–114	–5.64782 + 3.25814 Log L	0.9989
S. indicus	1330	53–160	–5.69465 + 3.27585 Log L	0.7995
S. commersonii	110	65–134	–5.42045 + 3.13725 Log L	0.9977

indicated allometric growth a logarithmic regression equation was fitted to the data on *E. devisi*, *E. punctifer*, *S. waitei*, *S. indicus* and *S. commersonii*. The logarithmic equations for the five species together with data on the number of specimens examined (N) and their length ranges as well as the correlation coefficients (r) are given below:

Age and growth

Age and growth of *E. devisi* and *S. waitei* were studied from length frequency data collected over a period of 12 years (1970–81) at Vizhinjam. The observed frequency in different length groups in a sample from the catch of a day was raised to the sample-day's catch and the pooled frequencies of different sample days were in turn raised to the monthly catch, thus arriving at the weighted frequency (in numbers) for different months. The modal lengths from the frequency distributions were plotted against the respective months and the progression of the modal lengths of these cohorts in the successive months were traced connecting the relevant modes. Only such cohorts that started at a smaller modal size and that could be traced for at least for 3–6 months were selected for growth studies (Figs 4, 5). This facilitated correlating the cohort to its probable month of origin. The sizes of the same age groups at monthly intervals for *E. devisi* and at tri-monthly intervals for *S. waitei* were read from these empirical growth curves. From this treatment it was possible to obtain the average lengths attained by the species in consecutive periods. Thus *E. devisi* attained lengths of 24, 40, 53, 64, 72, 84 and 87 mm at 1, 2, 3 . . . 8 months of age respectively, and *S. waitei* attained lengths of 57, 82, 98.25, 110.5 and 118 mm at 3, 6, 9, 12 and 15 months of age respectively. The growth parameters estimated from the von Bertalanffy (1938) growth equation for the two species are as follows:

E. devisi: $L_t = 102.5\,[1 - e^{-2.7996(t + 0.0067)}]$

S. waitei : $L_t = 134.6\,[1 - e^{-1.5432(t + 0.1032)}]$

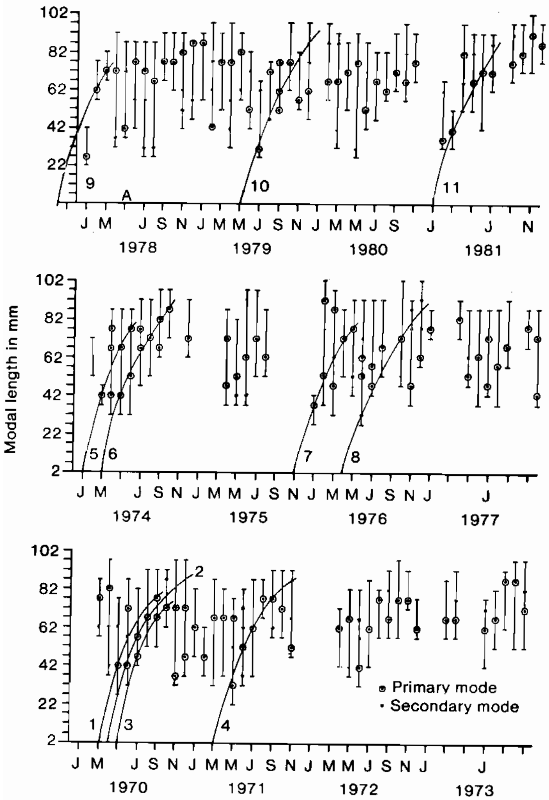

Figure 4. Tracing of the progression of modes by scatter diagram of modal length-month for *E. devisi* at Vizhinjam.

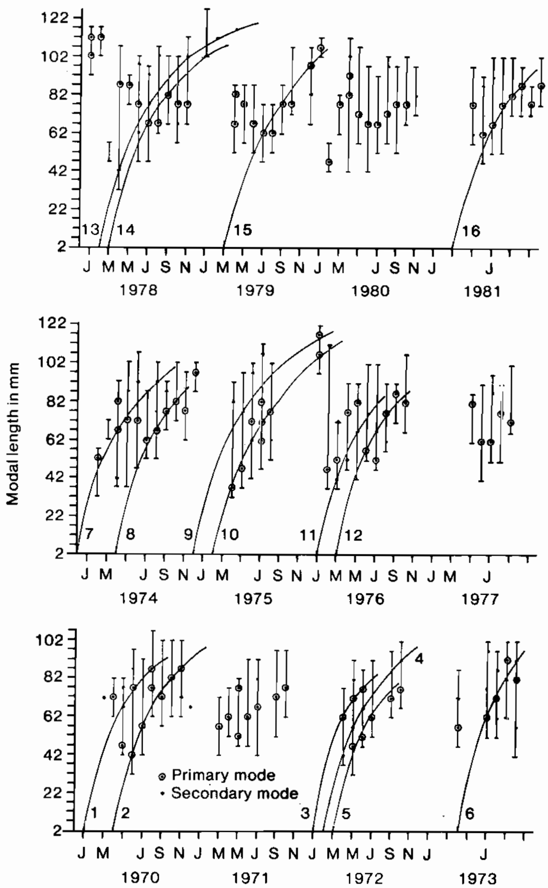

Figure 5. Tracing of progression of modes by scatter diagram of modal length-month for *S. waitei* at Vizhinjam.

The growth parameters obtained for the two species by Rao (1988a,b) for the Mangalore area and by Luther and Reuben (pers. comm.) for the Visakhapatnam area are as follows:

	L (mm, TL)	K	t_o
E. devisi			
Mangalore	113.00	2.0440	-0.0986
Visakhapatnam	100.69	1.8476	-0.0050
S. waitei			
Mangalore	116.00	1.9710	-0.0548
Visakhapatnam	134.39	1.5653	-0.0542

(the K and t_o values given by Rao (1988a,b) have been converted into yearly values to facilitate comparison).

The mean calculated length (mm) at different monthly ages derived from the growth equations for the two species at the above three centres are as follows:

Age (months)	3	6	9	12	15	18	21	24
E. devisi								
Vizhinjam	52.5	77.7	90.2	96.4	99.5	101.0	101.8	102.1
Mangalore	57.6	79.8	93.1	101.0	105.8	—	—	—
Visakhapatnam	37.9	61.1	75.7	85.0	90.8	94.4	96.7	98.2
S. waitei								
Vizhinjam	56.6	81.5	98.5	111.1	117.9	124.2	126.9	129.4
Mangalore	52.4	77.1	92.3	101.5	107.1	110.6	112.7	114.0
Visakhapatnam	50.9	77.9	96.2	108.6	116.9	122.6	126.4	129.0

From the above data it may be seen that the lengths attained at the end of 12 months of age are closer to each other for fish examined at Vizhinjam and Mangalore than at Visakhapatnam for *E. devisi*. In the case of *S. waitei* the sizes attained are closer to each other for fish examined at the three centres. It is possible that such differences in growth may occur between fish schooling closer to the surface, such as *E. devisi* and fish schooling in mid water such as *S. waitei* because of the vicissitudes in the density of their prey in the two depth zones.

E. devisi attains first maturity (60–64 mm) at 3.9 months of age whereas *S. waitei* attains first maturity (80–84 mm) at 6.2 months. About 90% of the catches of these two species occur in the size ranges of 57 mm–87 mm and 57 mm–92 mm respectively, that is between 3.4 and 8.0 months for *E. devisi* and between 3.0 and 7.7 months for *S. waitei* (Fig. 6).

Mortality rates

Length frequency data from the Vizhinjam area from non-selective gears, namely boat seine and shore seine for the period 1976–81, were analysed. The above two gears accounted for 75% of the annual catch of *E. devisi* and 90% of the catch of *S. waitei*. The coefficient of total mortality (Z) was estimated using the equation given by Beverton and Holt (1957). The natural mortality coefficient (M) was estimated from the equation proposed by Skeharan (1974). The exploitation rate (E) was computed from the equation

$$E = \frac{F}{Z}.$$

where F equals fishing mortality. The mortality and exploitation rates obtained for *E. devisi* and *S. waitei* were as follows:

	E. devisi	*S. waitei*
Z	7.9	7.3
M	4.4	3.8
F	3.5	3.5
E	0.44	0.48

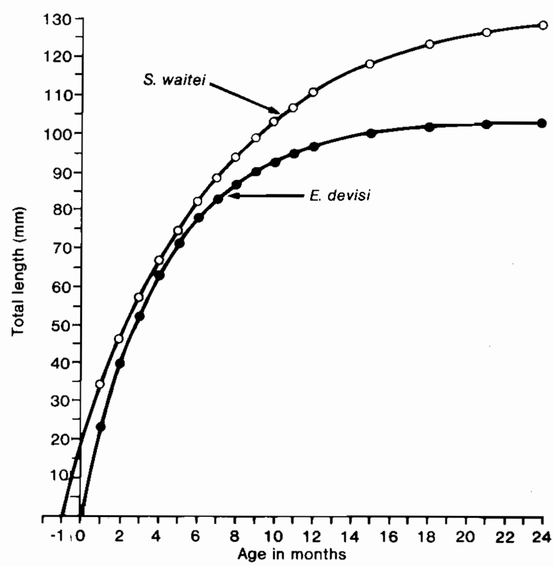

Figure 6. Growth curves of *E. devisi* and *S. waitei* obtained by fitting von Bertalanffy equation.

The high values of (M) accord with the small size and short longevity of the two species. The moderate fishing mortality of 3.5 exerted on both species may possibly be increased as the exploitation rate is less than optimum.

Survival in captivity

Results of the holding experiments carried out by Luther et al. (1984) on four species of whitebait indicate that *E. punctifer* is very hardy and can withstand captivity for about three months. *E. devisi* survived for about two months. *S. waitei* and *S. indicus* however did not last for more than a few hours in captivity. Mortality was low in the case of *E. punctifer* and *E. devisi* if the fish when captured were transferred immediately to low salinity water (21–28‰). Species of the genus *Encrasicholina* hold out the promise of serving as effective live-bait for tuna in Indian seas.

General Considerations

This review on the biology of the whitebait anchovy of Indian seas shows that whitebaits of the genus *Encrasicholina* may be suitable as live bait for tuna and calls for intensive efforts in understanding the areas of their distribution, abundance, spawning, growth and survival in captivity. Whitebait in general are recruited to the fishery at about three months of age and contribute to the fishery for the next five months. Senility may set in at this period of its life, and the bulk of the whitebait stock may perish. It may therefore be advisable to increase fishing pressure on whitebait in India soon after the south-west monsoon when large-sized fish that would have effected at least one set of multiple spawning are available to the fishery. A potential yield of 240 000 tonnes was estimated for whitebait in the exclusive economic zone of India (CMFRI, 1987) of which the share of the west coast, east coast and Andaman and Nicobar Islands may be in the proportion of 69%, 29% and 2% (CMFRI, 1978). This indicates scope for a threefold increase over the present yield of whitebait in India.

Acknowledgments

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The Reproductive Strategy of *Stolephorus heterolobus* in the South Java Sea

P.J. Wright*

Abstract

Stolephorus heterolobus is a small Indo-Pacific anchovy which is of commercial importance to many coastal fisheries. This paper describes an investigation of the reproductive strategy of the species. Data on the size, age (determined from daily otolith increments), and gonad development of 1238 adults, collected over a 21 month period, were used to investigate reproductive activity of a stock inhabiting the coast around Jepara, north central Java. Variations in the density and distribution of zooplankton were monitored for 12 months in conjunction with the sampling of fish. Rapidly growing individuals were found to attain sexual maturity earlier than slow growing individuals following the early attainment of a threshold weight (200 mg dry weight). A cytological examination of the ovarian development revealed that *S. heterolobus* is a serial spawner. This trait was associated with asynchronous spawning, both within the population, and the different adult groups that comprised the spawning stock. The mean inter-spawning interval was estimated from the proportion of females with ovaries containing day-1 post-ovulatory follicles, and ranged between 2–14 days over the 21 month study period. Reproduction did not appear to involve the expenditure of somatic reserves as neither relative condition nor biochemical composition varied significantly between pre- and post-spawned adults. Further, the high spawning frequency and egg batch biomass could only be explained by an energetic dependence on prevailing food availability. This reliance on prevailing prey availability was reflected in the significant correlations between prey density and both the percentage and minimum length of sexually mature adults in monthly samples. The implications of this strategy for predicting the size and stability of the exploitable stock are considered.

(A later analysis of adult samples collected near Munda in Solomon Islands supported many of these findings from the Jepara region).

Stolephorus heterolobus (Ruppell, 1837) is a short-lived tropical anchovy inhabiting coastal waters of the Indo-West Pacific Ocean. This species comprises a significant proportion of many inshore catches within South-East Asia (Burhanuddin et al., 1975; Tham, 1970; Tiews et al., 1970; Willoughby et al., 1984) and the Western Pacific (Lewis, 1977).

S. heterolobus has a group-synchronous mode of ovarian development and is capable of serial spawning (Wright, 1989). Evidence from both egg surveys and gonad morphology has shown that within populations of *S. heterolobus* spawning is virtually continuous (Delsman, 1932), although peaks in spawning activity have been reported in the Philippines (Tiews et al., 1970), Singapore (Tham, 1970) and Palau (Muller, 1976). Muller reported that spawning in a population from Palau was correlated with salinity but he was unable to establish the causal nature of this relationship.

In this study, female reproductive investment and spawning activity within a population of *S. heterolobus* inhabiting the coastal region around north Central Java is examined. Further, the relations between reproductive investment and both prevailing environmental conditions and prey abundance were investigated.

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Materials and Methods

Jepara is situated on the north coast of Central Java. The coastal area around Jepara is shallow (<35 metres depth at 12 km from shore) and shelving with a soft sediment.

Adults were obtained from monthly samples of *S. heterolobus* taken from commercial lift-net landings at Jobokuto market, Jepara, between November 1983 and July, 1985. The length and gonad development of all adults were recorded. The age of a sub-sample of adults was determined from daily otolith increment counts (Wright, 1989).

Gonad staging

Ovaries were classified into six developmental stages on the basis of both morphological and histological criteria (Wright, 1989). Testes were classified into four developmental stages on the basis of macroscopic and histological appearance (Wright, 1989).

Reproductive investment

Relative condition factor:

$$Kn = \frac{W}{\hat{W}} \text{ (Le Cren, 1951)}$$

(where W=weight of specimen and $\hat{W}$=mean weight for a specimen of length W, determined from a combined length/weight curve) was used for adults. Water, protein and lipid content of trunk somatic tissue was determined for a sub-sample of 65 specimens representing all gonad development stages for both populations. Water content was determined from the difference in somatic tissue weight before and after drying at 60°C for three days. Lipid was extracted using the chloroform-methanol mixture technique (Folch et al., 1957) and determined as a percentage of the dry weight. Protein was extracted using sodium hydroxide and the concentration determined using Peterson's modification of the micro-Lowry method (Peterson, 1977). Inter-spawning interval was estimated in monthly collections from the incidence of females with post-ovulatory follicles using the method of Hunter and Goldberg (1980).

Environmental data

Data on rainfall and hours of sunlight in the Jepara region were obtained from official statistics. Data on other environmental parameters, namely salinity, surface water temperature, current velocity and direction, and plankton abundance between June 1984 and June 1985 were obtained from Dr. N.G. Willoughby (Overseas Development Administration advisor to Universitas Diponegero, Semarang, Indonesia). A prey abundance index was calculated from plankton data based on the following formula:

$$\text{Prey Abundance Index} = \frac{\text{Mean Density of Prey Species}^{1}}{\text{Incidence of Prey Species}^{2}}$$

Results

Sexual and gonad composition of spawning stock

Of the 1238 adult *S. heterolobus* collected, 635 were males and 603 females, i.e. the sex ratio did not differ significantly from 1:1 $\chi^2=1.65$; $P<0.99$). Only three samples contained a ratio of males:females that deviated significantly from a 1:1 ratio, having two or three times more males than females. These samples also had a high incidence of ripe females and so the uneven ratios may be associated with spawning schools, as has been observed in *Engraulis mordax* (Longhurst, 1971).

Mature adults were found in collections from every month. No seasonal trend in the occurrence of adults with mature and ripe stage ovaries was evident (Fig. 1). Indeed all stages of gonad development were found in some samples indicating that reproductive development was not synchronised within the population. Differences between length classes were more marked than within length classes, suggesting that there might be some degree of synchrony between individuals within a cohort or school.

The proportion of mature adults in samples could not be correlated with any of the measured abiotic factors (P for ranked correlation <0.5 for rainfall, $r_s=0.26$; temperature, $r_s=-0.59$; sunlight hours, $r_s=0.38$; and tidal phase at spawning, $r_s=0.21$).

Reproductive investment

The minimum size at sexual maturity in the Jepara population was 56 mm total length (TL) and 200 mg dry weight. Fish attained sexual maturity between 240 and 360 days old (as determined from daily increment counts). Few adults larger than 67 mm TL (the upper limit for maturity) had gonads in an early stage of development. Mature females had a higher mean growth rate than immature fish for a given length (mature growth rate=2.94 mg day^{-1}, immature fish= 1.86 mg day^{-1}; based on otolith increments).

[1]Prey species refers to planktonic species comprising more than 3% by weight of the diet of *S. heterolobus* (see Willoughby et al., 1984).

[2]Incidence was based on occurrence of prey species in 31 hauls taken during a monthly sample.

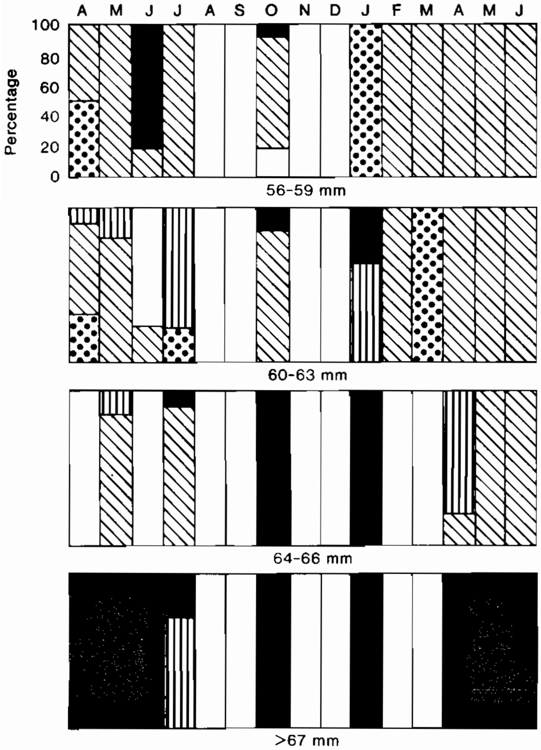

Figure 1. Monthly gonad composition of four size classes of adult *Stolephorus heterolobus* collected from Jepara, Central Java.
Key to gonad stages:
[dotted] = early developing
[hatched] = developing
[vertical lines] = maturing
[black] = ripe
[white] = no adults in monthly sample.

Oocyte batches comprised between 11–15% of a female's dry weight. A comparison of relative condition between adults in different stages of reproductive development indicated that ripe and post-spawned females tended to be heavier for a given length than females with immature or atretic ovaries (Mann-Whitney U-Test; $P<0.05$; Table 1). Furthermore biochemical analysis of the protein, lipid and water content of somas from

Table 1. Relative condition factor for immature and developing (stage II/I and II), mature (stage III & IV) and partially spent (V/III) female *Stolephorus heterolobus* collected from Jobokuto market, Jepara.

	Relative condition factor		
Ovarian stage	Mean	Range	Number
Immature	0.82	0.69–0.96	57
Mature/ripe	1.16	1.01–1.24	32
Partially spent	1.11	1.00–1.22	23
Atretic	0.88	0.70–1.085	25

Table 2. Proximate analysis of the somatic tissue (100 mg) from immature and developing (stage II/I and II), mature (stage III & IV) and partially spent (V/III) female *Stolephorus heterolobus* collected from Jobokuto market, Jepara.

	Percentage of somatic tissue		
Ovarian stage	Water	Protein	Lipid
Immature	76.9 ± 2.1	12.0 ± 0.5	3.7 ± 0.2
Mature/ripe	77.5 ± 1.4	11.6 ± 0.5	3.8 ± 0.1
Partially spent	77.4 ± 1.6	11.9 ± 0.4	3.8 ± 0.2

representative sub-samples of each reproductive stage indicated that there was no depletion of somatic reserves associated with reproduction (Mann- Whitney U-test; $U_{8,10}=12.1$; $P>0.05$; Table 2). Liver weight and deposits of lipid on the intestine, as assessed from a fat index scale (Wright, 1989), also did not decline in relation to ovary development ($P>0.05$), suggesting that these potential energy reserves are not utilised during reproduction. Thus it appears that females obtain all their energy resources for reproduction from current food resources rather than stored energy reserves.

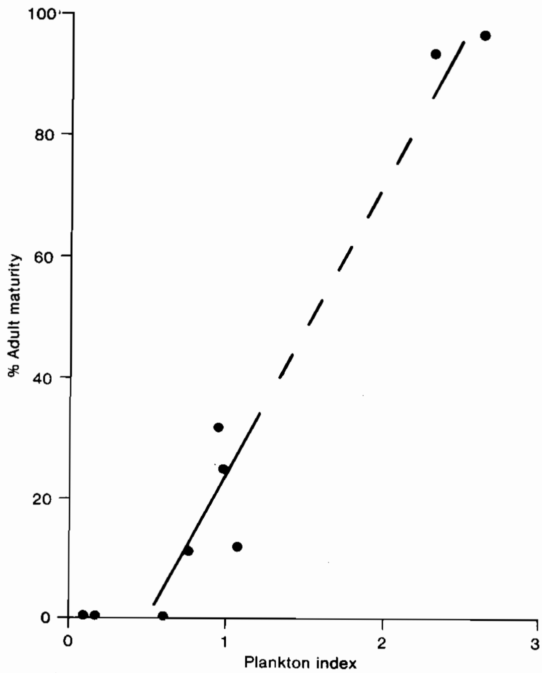

Figure 2. Relationship between the percentage of mature adult *Stolephorus heterolobus* within monthly samples with prevailing prey abundance index.
Mature refers to adults with mature or later stage gonads (see Wright, 1989). See methods for calculation of prey abundance index.

Spawning activity and food availability

The percentage of adults with mature gonads within monthly samples was positively correlated with the prevailing mean density of copepods (the major prey item of *S. heterolobus* in this region; $r_s=0.77$; $p<0.05$) and the abundance index of all prey species ($r_s=0.98$; $P<0.01$; Fig. 2) although the data sets were clustered around either low or high prey abundance.

A comparison between prey abundance index and spawning frequency in months in which the incidence of females in samples was sufficient to estimate inter-spawning interval, suggested that mean inter-spawning interval was inversely correlated with prey abundance ($r_s=0.94$; $p<0.05$; Fig. 3). Thus prey availability may influence the number of adults breeding and the number of broods a female can produce.

Discussion

Reproductive traits and larval survivorship

In a habitat where the factors influencing larval growth and mortality do not recur regularly there may be no advantage to larval survivorship in spawning at a particular time. Evidence from both plankton surveys and the entry of post-larvae and juveniles into the exploited stock suggests that such is the case for *S. heterolobus* inhabiting the Jepara region. Willoughby (pers. comm.) found that the density and distribution of both larval prey species and planktonic predators did not vary in a regular pattern or in relation to adult prey, indicating that there is no predictable variation in either prey or predator abundance. Furthermore the incidence of post-larvae and juveniles in samples during this study did not vary cyclically or in relation to particular sea conditions (Wright, 1989).

This apparent lack of seasonality of larval mortality in *S. heterolobus* would explain why the current study found no evidence for a seasonal peak in spawning activity. As the time of ovulation is the only stage of reproductive development that may be coordinated in *S. heterolobus* (Muller, 1976; Wright, 1989), photoperiod is likely to be the only extrinsic factor to act as a cue for reproductive development in this species. Comparisons of the proportion of maturing individuals with prevailing abiotic conditions support this view.

Aseasonal larval survivorship would be expected to favour selection for traits that mitigate the effects of chance larval extinction. Asynchronous spawning, as observed in the Jepara population, is believed to reduce the effect that short-term larval extinctions can have on annual recruitment by effectively increasing the number of days over which eggs are released (Bye, 1984). Further, Giesel (1974) has demonstrated, from a theoretical analysis of reproductive strategies, that a given water mass and prey density can support a greater number of reproducing adults in populations with several breeding units than in populations with a single unit. Thus by maximising the spatial and temporal dispersal of eggs, adults may reduce their risk of total reproductive failure.

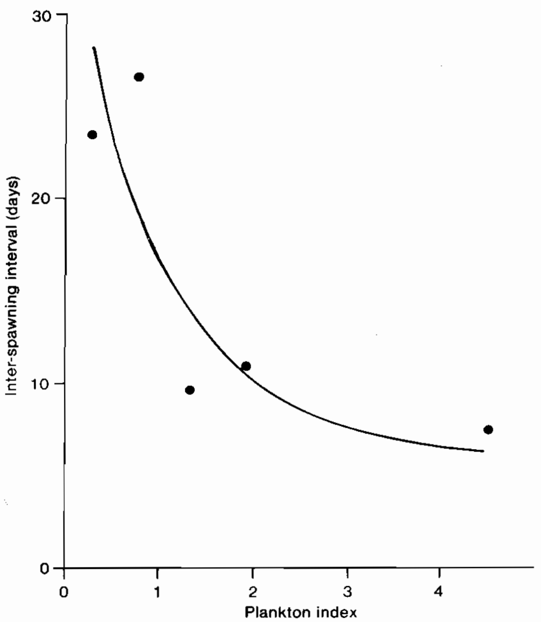

Figure 3. Relation between mean monthly inter-spawning interval and prevailing prey abundance index.
Mature refers to adults with mature or later stage gonads (see Wright, 1989). Inter-spawning interval was estimated from the incidence of females with phase 1 post-ovulatory follicles. See methods for calculation of prey abundance index.

The influence of food availability on reproductive investment.

It is evident from a comparison of relative condition and biochemical composition of pre- and post-spawned females that the energy allocated to oocyte development must be largely derived from immediate intake rather than stored energy resources. The faster growth rates and higher relative condition of females with mature and partially spawned ovaries suggests that females only allocate energy resources to reproduction when food availability is sufficient to support both somatic growth and gonadal development. Further the apparent cessation of breeding in fish with low condition suggests that females may cease gonadal investment when conditions for growth are unfavourable.

The reliance on current prey availability for reproductive investment would explain why the proportion of the population investing in reproduction increased and the mean inter-spawning interval decreased in relation to prey abundance in the Jepara fishing grounds. Thus it would seem that spawning within the population of *S. heterolobus* inhabiting the Jepara region is dependent on the fishes' ability to find sufficient forage to sustain the energetic costs of repeated gonad maturation.

Implications to fisheries management

As reproductive investment in this population is dependent on current prey density and distribution, the size of the spawning stock and the number of eggs it produces would be expected to vary in relation to the fishes' ability to find prey. Fluctuations in egg abundance will add to the many other causes of recruitment variability (Lasker, 1981). Perhaps more significantly, periods of low food availability may reduce the number of breeding fish and thereby effectively reduce the length of the spawning period. Several investigations of the causes of stock collapse in clupeoid populations have indicated that the resilience of populations is related to the length of the spawning season and the area over which eggs are released (Murphy, 1977; Lasker, 1981). Future studies are needed to quantify the effects of variations in prey density and distribution on spawning biomass and subsequent larval survivorship. Meanwhile any future attempts to estimate sustainable yields from this fishery should consider the possible indirect effects of variations in the density and distribution of adult prey species on recruitment.

Conclusions

Adults did not spawn in synchrony within a population of *S. heterolobus* inhabiting the Java Sea. Spawning was solely dependent on the availability of forage to sustain repeated gonad maturation. The lack of synchronisation in the timing of spawning could be explained by a lack of seasonality in larval mortality. A timed reproductive cycle would therefore have no adaptive value. By spawning asynchronously *S. heterolobus* may reduce the risk of reproductive failure due to short-term or localised larval extinction, and also increase the chance that some larvae will find suitable forage.

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Reproductive Biology of *Spratelloides delicatulus, S. gracilis* and *Stolephorus heterolobus* from Solomon Islands and Maldives

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Abstract

The reproductive biology of three major tuna baitfish species: *Spratelloides delicatulus, S. gracilis* and *Stolephorus heterolobus* was compared between Solomon Islands and Maldives. *Spratelloides gracilis* and *Stolephorus heterolobus* matured at a smaller size in Solomon Islands than Maldives or other parts of their range. All species had protracted spawning seasons in both countries. In Solomon Islands, fish spawned continuously throughout the year with one or two periods of peak activity. *S. gracilis* and *S. heterolobus* from Maldives had a single spawning season within the atolls and their reproductive cycle may be linked with the monsoons and prevailing winds. Length–weight relationships were compared between sites in Solomon Islands, Maldives and with other studies. *Spratelloides* species from Tulagi, Solomon Islands weighed much less than fish from other areas. Overall, the results did not indicate fish from continental islands were in poorer condition than fish from coral atolls. Sex-ratios of *S. delicatulus* and *S. heterolobus* from Solomon Islands and Maldives showed a male bias among small length classes with the proportion of females increasing with length. This pattern was reversed in *S. gracilis*, which had an excess of females in most length classes. The temporal pattern of sex-ratio of *S. delicatulus* and *S. heterolobus* were also male biased and reflected the length ranges examined. The male bias was consistent among samples of fish collected by several methods and indicates that there is either, a strong segregation of the sexes from an early age, or the sex-ratio of these species is not 1:1. There was little intraspecific variation in fecundity for any of the species in this study, except *Stolephorus heterolobus* from Vona Vona, which had more, smaller eggs than fish from other sites, including Maldives. Other baitfish fecundity studies showed some variation and may indicate that baitfish can vary their fecundity in relation to egg size. In Solomon Islands, there was no difference in batch fecundity between the three species which suggests that their relative abundance may depend on the frequency of spawning and hence, total egg production or recruitment success.

THE tuna baitfisheries in Solomon Islands and Maldives are the largest in the Pacific and Indian Oceans respectively, with annual catches of over 2000 tonnes (Anon. 1988; Anderson and Hafiz 1988). The single most important species in the Maldives is *Spratelloides gracilis* (Anderson and Hafiz 1988). In Solomon Islands, *Stolephorus* species are the dominant baitfish, although *Spratelloides delicatulus* and *S. gracilis* are also important. *Stolephorus heterolobus,* a major baitfish species in Solomon Islands is also important in southern Maldives and elsewhere in the Indo-Pacific (Dalzell and Wankowski 1980; Conand 1988).

Aspects of the reproductive biology of *Spratelloides delicatulus, S. gracilis* and *Stolephorus heterolobus,* have been studied both in Solomon Islands (Evans and Nichols 1984; Milton and Blaber, In prep.) and elsewhere (Dalzell and Wankowski 1980; Conand 1988; Dalzell 1985; McCarthy 1985; Mohan and Kunhikoya 1986;

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Ozawa et al. 1989). These studies indicate that there is variability in spawning seasonality, sexual maturity, sex-ratio and fecundity, both temporally and spatially on local and regional scales. Some study sites were continental 'high' islands (eg. Papua New Guinea: Dalzell and Wankowski 1980; Dalzell 1985) others were coral atolls (Kiribati: McCarthy 1985). Differences in physical structure, depth and the different current patterns and hence, nutrient regimes of these lagoons may affect some or all aspects of the reproductive biology of baitfish. The aims of this study were: (1) to examine the length at sexual maturity, spawning seasonality, sex-ratio and fecundity of *Spratelloides delicatulus, S. gracilis* and *Stolephorus heterolobus* sampled over the same periods in Solomon Islands and Maldives, and (2) compare and contrast their biology from the two habitats with the published literature in an attempt to explain the variability in their reproductive cycles.

Methods and Materials

Solomon Islands

Samples of up to 100 *Spratelloides gracilis, S. delicatulus* and *Stolephorus heterolobus* were collected each month between March 1987 and May 1989, from three sites in Solomon Islands. Two sites (Munda and Tulagi) were heavily exploited by the commercial fishery and the other site, Vona Vona, was located near Munda in the Western Province. This site was not commercially exploited and was used as a control site. All sites consisted of a deep lagoon (up to 40m deep), surrounded by fringing coral reefs. Details of site locations are given in Blaber et al. (1990). Fish collected at the exploited sites were obtained from the commercial fishery, and those at Vona Vona using a smaller bouke-ami net, of similar design to that used by the commercial fishery. All sampling took place at night (1900–2400 hrs) with the exception of some additional samples of *Spratelloides delicatulus* collected in shallow reef areas during the day.

Maldives

Baitfish were collected monthly from the artisinal fishery at one of two sites in Maldives between April 1986 and June 1989. Fish were caught by attracting schools of tuna baits and enclosing them in a small lift net. All fish were caught during the early morning (0700–1000 hrs).

Laboratory analysis

Fish length (S.L. mm), weight (± 0.001 g), sex and gonad weight were recorded for at least 100 fish of each species from each site every month during the study. A random subsample of females and any other female examined macroscopically, which had enlarged ovaries, were examined histologically to verify reproductive stage. Details of the analysis and criteria used to verify ovarian development stages are given in Milton and Blaber (Unpubl. ms). The ovaries of fish which were in spawning condition (from the histological analysis), were dissected and the number and diameter of eggs in the most advanced modal group were recorded. Length-weight relationships were determined for each species from all fish samples to see if there were differences in growth form which may be related to their nutritional condition (Ricker 1975).

Results

A total of 13 064 fish of the three species from Solomon Islands and 3191 from Maldives were examined for reproductive condition. All data for each species from Solomon Islands were grouped as there were insufficient numbers caught in Maldives for specific site comparisons.

Maturation

The length at sexual maturity of *Spratelloides delicatulus, S. gracilis* and *Stolephorus heterolobus* from throughout the Indo-Pacific region (Table 1) showed that there is considerable variation between sites for *S. gracilis* and *Stolephorus heterolobus*. *Spratelloides delicatulus* varied little in length at maturity over the entire geographic region. *S. gracilis* matured at a smaller size in Solomon Islands than other areas. Maximum length also varied between sites for *S. gracilis* and *S. heterolobus*. Fish from higher latitudes (Table 1) grew longer than more tropical populations.

Spawning seasons

Spratelloides delicatulus

The pattern of spawning by *S. delicatulus* at the three sites in Solomon Islands (Fig. 1a) revealed almost continuous spawing during the study with 10–20% of the population spawning all the time at one of the sites. There was a minor peak in spawning activity during April in all three years samples.

Spratelloides gracilis

The seasonal distribution of spawning female *S. gracilis* (Fig. 1b,c) showed a similar pattern for both the Solomon Islands and Maldives. In the Maldives, there is a protracted spawning season

Table 1. Length at sexual maturity (standard length mm) and maximum length (mm) of *Spratelloides delicatulus*, *Spratelloides gracilis* and *Stolephorus heterolobus* in various parts of the Indo-Pacific.

Species	Country	Sexual Maturity (SL mm)	Maximum Length (mm)
S. delicatulus	Solomon Islands	37.0	70.0
	Maldives	38.0	55.0
	Fiji	35.0	75.0[a]
	Kiribati	40.0	68.0[b]
	New Caledonia	40.0	70.0[c]
	India	42.0	59.0[d]
S. gracilis	Solomon Islands	35.0	69.0
	Maldives	42.0	78.0
	Papua New Guinea	40.0	70.0[e]
	New Caledonia	45.0	80.0[c]
	India	44.0	62.0[d]
S. heterolobus	Solomon Islands	42.0	78.0
	Maldives	45.0	92.0
	Papua New Guinea	43.0	75.0[e]
	Philippines	60.0	95.0[f]
	New Caledonia	48.0	90.0[c]

a = Lewis et al. (1983); b = McCarthy (1985); c = Conand (1988); d = Mohan and Kunhikoya (1986); e = Dalzell and Wankowski (1980); f = Tiews et al. (1971).

from May to January when up to 35% of the population may be spawning at any time (Fig. 1). In comparison, there was little spawning activity detected during 1987 in Solomon Islands, and yet spawning occurred in most months during 1988 (May-January).

Stolephorus heterolobus

The spawning seasonality of *S. heterolobus* varied considerably between countries (Fig. 2). Fish from Solomon Islands showed little similarity in spawning activity, either between sites at the same time, or within sites from year to year. However, at least 10% of the fish samples were spawning at any time in Solomon Islands. Fish from Maldives (Fig. 2b) spawned later in the year during 1986 and 1987, but in 1988, fish were spawning from June to August.

Sex-ratios

Seasonal variation

Spratelloides delicatulus — The variation in sex-ratio of *S. delicatulus* from Solomon Islands (Fig. 3a) showed an excess of males in samples taken during many (12 of 27) of the monthly samples. There was a significant excess of females only during April 1987 and 1988, when spawning also peaked.

Spratelloides gracilis — Monthly differences in sex-ratios of *S. gracilis* from Solomon Islands and Maldives (Fig. 3b,c) showed considerable variation between samples. Most samples from the Solomon Islands were biased towards females (Fig. 3b) but did not relate to the proportion of females spawning ($P>0.5$). In comparison, samples from the Maldives fluctuated about a 1:1 sex-ratio, except during the spawning seasons, (Figs 1c, 3c) when there were more males.

Stolephorus heterolobus — Variations in sex-ratios of *S. heterolobus* showed that at all sites (Fig. 4) there was a significant bias towards males ($P<0.01$). There was no relationship between sex-ratio and the proportion spawning, at any site ($P>0.50$), nor was there any similarity in sex-ratios between sites ($P>0.70$).

Ontogenetic variation

The change in sex-ratio with length, of the three species, (Fig. 5), showed a consistent pattern for each species in Solomon Islands and Maldives. For *Spratelloides delicatulus* and *Stolephorus heterolobus* the smaller length classes were male biased and only among the largest fish did females predominate (Fig. 5c-f). This pattern was highly correlated among Solomon Island fish ($r^2=0.92$; $P<0.01$; $N=8$) and between *S. delicatulus* from the Solomon Islands and Maldives ($r^2=0.79$; $P<0.05$; $N=5$).

Ontogenetic change in the sex-ratio of *S. gracilis* differed from the pattern of the other species (Fig. 5a,b) with females more common among both the smaller and larger length classes. The trend was similar for both Solomon Islands and Maldives. Sex-ratios of Maldivian *S. gracilis* and *S. delicatulus*, however, were negatively correlated ($r^2=-0.84$; $P<0.05$; $N=5$).

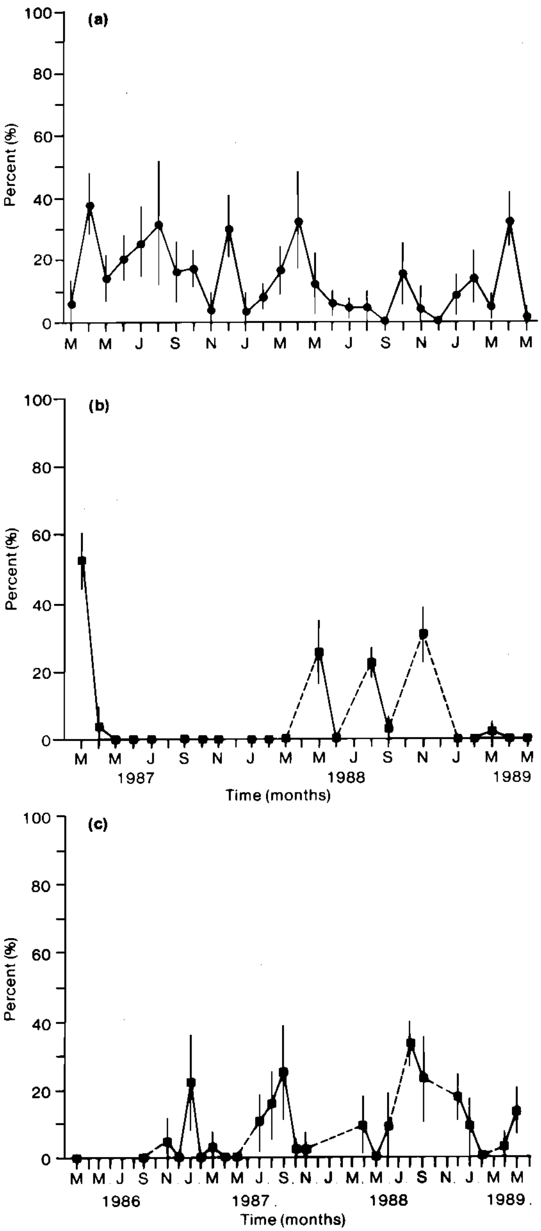

Figure 1. Monthly variation in the percentage of (a) female *S. delicatulus*, (b) *S. gracilis* spawning (± 95% confidence limits) from March 1987 to May 1989 in Solomon Islands and (c) Maldives from May 1986 to May 1989.

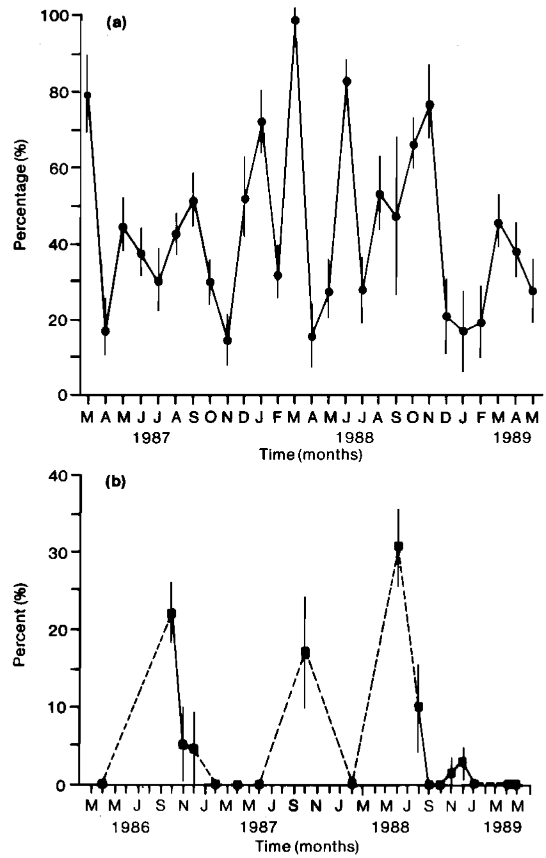

Figure 2. Monthly variation in the percentage of female *S. heterolobus* spawning (± 95% confidence limits) in (a) Solomon islands from March 1987 to May 1989 and (b) Maldives from April 1986 to May 1989.

Length-weight relationships

Spratelloides delicatulus — Within Solomon Islands, *S. delicatulus* from Munda weighed more at any length than other sites ($P<0.05$) and fish from Tulagi weighed least ($P<0.05$). *S. delicatulus* from Maldives had a length-weight relationship which was not significantly different from Tulagi in Solomon Islands (Table 2). New Caledonian and Kiribati fish weighed significantly more than Solomon Islands or Maldives ($P<0.01$).

Spratelloides gracilis — The length-weight relationships of *S. gracilis* (Table 2) showed little variation between sites within Solomon Islands or between regions ($P<0.50$) except for Tulagi in Solomon Islands, where the *S. gracilis* were in much poorer condition than fish from all other sites ($P<0.001$).

Stolephorus heterolobus — The length-weight relationships of *S. heterolobus* (Table 2) showed that fish from Papua New Guinea and Maldives were significantly heavier ($P<0.01$) than Solomon Islands fish. Within the Solomon Islands, Tulagi fish were heavier than Munda fish

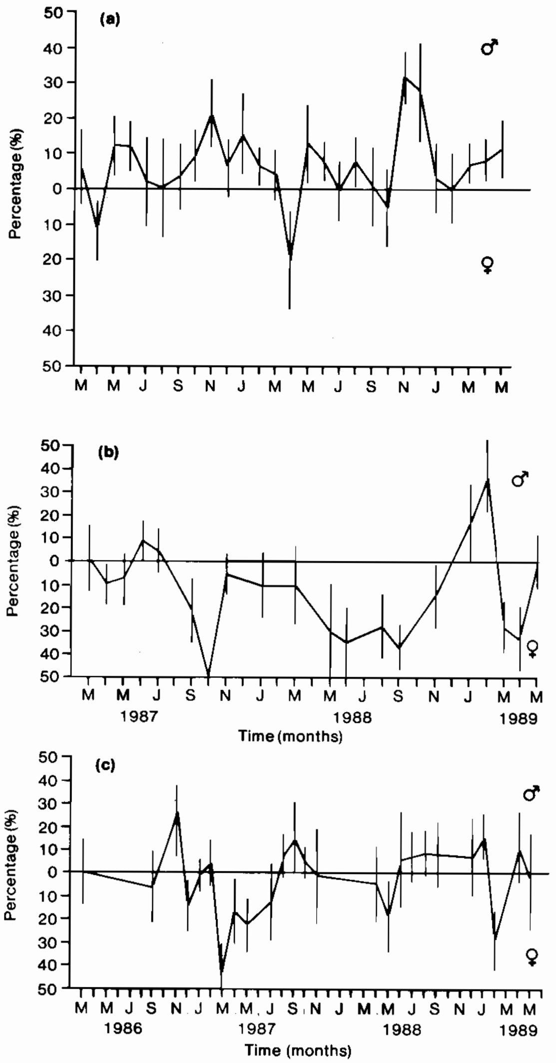

Figure 3. Monthly variation in sex-ratio (± 95% confidence limits) of (a) *S. delicatulus* and (b) *S. gracilis* from Solomon Islands from March 1987 to May 1989 and (c) *S. gracilis* from Maldives from April 1986 to May 1989. Values are expressed as percentage deviation from 1 : 1 sex-ratio.

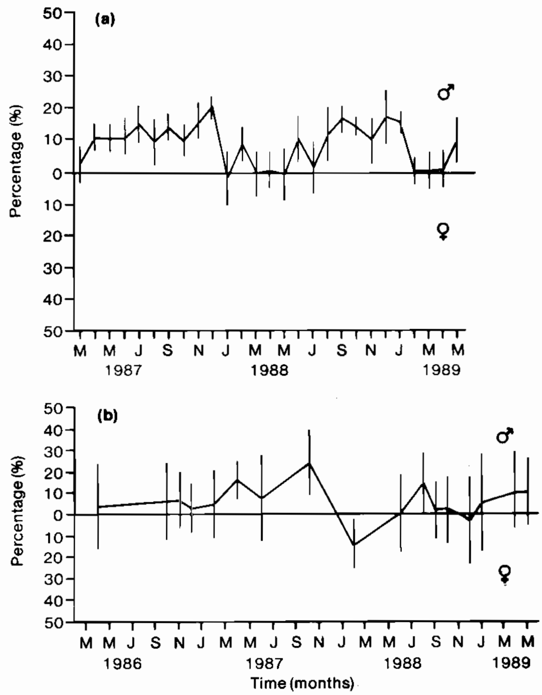

Figure 4. Monthly variation in sex-ratio (± 95% confidence limits) of *S. heterolobus* in (a) Solomon Islands from March 1987 to May 1989 and (b) Maldives from April 1986 to May 1989. Values are expressed as percentage deviation from 1 : 1 sex-ratio.

($P<0.05$) and Vona Vona fish were similar to both.

Fecundity studies

The relative fecundity (eggs per g body weight) of the two *Spratelloides* species showed little variation between sites, within Solomon Islands or compared with Maldives (Table 3). In contrast, fecundity of *S. heterolobus* was significantly greater at Vona Vona than other sites ($P<0.05$). Comparison with other studies showed that *S. delicatulus* had higher relative fecundity in New Caledonia and *S. gracilis* higher relative fecundity in Papua New Guinea, than found in this study ($P<0.01$). The relative fecundities of *S. heterolobus* from Papua New Guinea and Palau were less than in Solomon Islands fish (Table 3; $P<0.05$).

Spratelloides gracilis and *S. heterolobus* in Maldives were longer at first spawning compared to fish from Solomon Islands. Within Solomon Islands, *S. delicatulus* from Vona Vona did not spawn until they attained a greater length than at other sites (Table 3). For *S. heterolobus,* fish spawned at a smaller size at Vona Vona. Studies from Papua New Guinea showed similar patterns.

Egg diameter did not vary significantly between sites for *S. delicatulus* (Table 4), although there was a significant positive relationship between mean egg diameter and fish length ($r^2=0.35$; $P<0.01$). *S. gracilis* from Vona Vona had larger eggs than Maldivian fish ($P<0.001$). Egg diameter varied between *S. heterolobus* populations. Maldivian fish had much smaller eggs than other

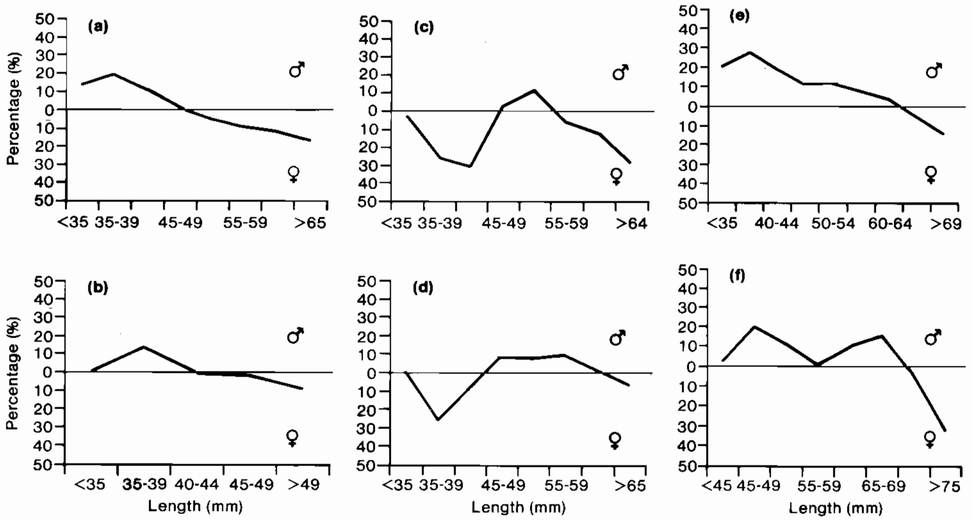

Figure 5. Ontogenic change in sex-ratio (± 95% confidence limits) of *S. delicatulus* (a,b), *S. gracilis* (c,d) and *S. heterolobus* (e,f) from Solomon Islands and Maldives respectively. Values are expressed as percentage deviation from 1 : 1 sex-ratio.

Table 2. Length-weight relationships of *Spratelloides delicatulus, S. gracilis* and *Stolephorus heterolobus* from three sites in Solomon Islands (S.I.) and Maldives. All data are from the current study except where indicated (P.N.G. = Papua New Guinea; r^2 = regression coefficient; N = sample size).

Species	Country	Site	Equation	r^2	N
Spratelloides delicatulus	S.I.	Munda	$W = 1.19 \times 10^{-5}L^{3.0}$	0.86	1820
		Vona Vona	$W = 1.91 \times 10^{-5}L^{2.86}$	0.70	1764
		Tulagi	$W = 2.87 \times 10^{-5}L^{2.77}$	0.82	775
	Maldives	Alifushi	$W = 2.61 \times 10^{-5}L^{2.76}$	0.91	291
	Kiribati	Tarawa	$W = 5.79 \times 10^{-6}L^{3.16}$	0.90	813[a]
	New Caledonia	Noumea	$W = 2.14 \times 10^{-6}L^{3.29}$	0.99	138[b]
Spratelloides gracilis	S.I.	Munda	$W = 5.14 \times 10^{-5}L^{3.01}$	0.76	32
		Vona Vona	$W = 1.0 \times 10^{-5}L^{3.01}$	0.95	168
		Tulagi	$W = 6.81 \times 10^{-5}L^{2.44}$	0.79	220
	Maldives	Thinadhoo	$W = 8.4 \times 10^{-6}L^{2.98}$	0.92	1611
	P.N.G.	Ysabel	$W = 9.5 \times 10^{-6}L^{3.0}$	0.99	868[c]
	New Caledonia	Noumea	$W = 2.3 \times 10^{-6}L^{3.23}$	0.99	140[b]
	India	Minicoy	$W = 3.6 \times 10^{-2}L^{3.09}$	0.82	88[d]
Stolephorus heterolobus	S.I.	Munda	$W = 1.88 \times 10^{-5}L^{2.82}$	0.79	3419
		Vona Vona	$W = 1.48 \times 10^{-5}L^{2.89}$	0.83	2464
		Tulagi	$W = 9.98 \times 10^{-6}L^{2.96}$	0.78	2399
	Maldives	Thinadhoo	$W = 2.09 \times 10^{-6}L^{3.36}$	0.92	1289
	P.N.G.	Ysabel	$W = 2.4 \times 10^{-6}L^{3.35}$	0.98	737[e]
	Singapore	Singapore	$W = 3.71 \times 10^{-6}L^{3.59}$	—	—[f]
	Palau	Palau	$W = 7.61 \times 10^{-6}L^{3.09}$	—	—[g]
	New Caledonia	Noumea	$W = 1.2 \times 10^{-6}L^{3.38}$	0.99	140[b]

a = McCarthy (1985); b = Conand (1988); c = Dalzell (1985); d = Mohan and Kunhikoya (1986); e = Dalzell and Wankowski (1980); f = Tham (1966); g = Muller (1976).

sites ($P<0.001$) and fish from Vona Vona also had smaller eggs than the other two sites in Solomon Islands ($P<0.001$).

There was a significant relationship between absolute fecundity and length for the three baitfish species (Table 5). An exponential equation described the best fit for the relationship between fecundity and length among all species in Solomon Islands. Comparison with the same equation for *S. gracilis* from Papua New Guinea showed that fecundity increased more rapidly with length than for Solomon Islands fish. There was no significant relationship between fecundity and length or weight for *S. heterolobus* from Maldives (Table 5), although as in Papua New Guinea, length was a better predictor of fecundity.

Table 3. The minimum standard length at first spawning (Min. SL), mean relative fecundity (eggs/g body weight) ± se of baitfish from three sites in Solomon Islands, Maldives and other published studies. (Min SL = minimum standard length; N = sample size; PNG = Papua New Guinea).

Sites	*S. delicatulus*			*S. gracilis*			*S. heterolobus*		
	Min SL	Fecundity	N	Min SL	Fecundity	N	Min SL	Fecundity	N
Munda	35	554 ± 25	39	—		—	45	652 ± 36	28
Vona Vona	41	717 ± 45	28	30	882 ± 68	13	43	901 ± 54	34
Tulagi	38	567 ± 49	28	—		—	48	695 ± 37	48
Maldives	—		—	46	1011 ± 78	21	59	653 ± 63	5
PNG	—		—	40	1690 ± 96	18[a]	40	536 ± 29	26[b]
Palau	—		—	—		—	54	450 ± 52	9[c]
New Caledonia	42	883 ± 14	20	—		—	—		—[d]
India	—		—	45	962 ± 53	15	—		—[e]

a = Dalzell (1985); b = Dalzell and Wankowski (1980); c = Muller (1976); d = Conand (1988); e = Mohan and Kunhikoya (1986).

Table 4. Mean egg diameter (mm) ± se for *Spratelloides delicatulus, S. gracilis* and *Stolephorus heterolobus* from Solomon Islands and Maldives (N = sample size)

Sites	*S. delicatulus*		*S. gracilis*		*S. heterolobus*	
	$\bar{x}$ ± se	N	$\bar{x}$ ± se	N	$\bar{x}$ ± se	N
Munda	0.59 ± 0.003	288	—	—	0.79 ± 0.006	544
Vona Vona	0.58 ± 0.006	40	0.58 ± 0.004	90	0.67 ± 0.004	820
Tulagi	0.60 ± 0.006	386	—	—	0.81 ± 0.003	1513
Maldives	—	—	0.51 ± 0.004	263	0.33 ± 0.004	105

Table 5. Regression equations of best fit of absolute fecundity (F) against total body weight (wt) or length (L) of *Spratelloides delicatulus, S. gracilis* and *Stolephorus heterolobus* from three sites in Solomon Islands (S.I.), Maldives, New Caledonia (N.C.), Papua New Guinea (PNG) and India. All equations are of the form $F = aX^b$ where X = weight or length except for species from Maldives, *S.delicatulus* from New Caledonia and *S. heterolobus* from Papua New Guinea where F = a + bX.

Species	Country	Variable	a ± se	b ± se	r^2	N	Significance
S. delicatulus	S.I.	length	0.004 ± 0.001	3.14 ± 0.41	0.39	95	P<0.001
	N.C.	weight	−375 ± −	883 ± −	0.94	20	P<0.001[a]
	India	length	0.013 ± 0.005	2.74 ± 0.40	0.79	15	P<0.001[b]
S. gracilis	S.I.	length	$2.5 \times 10^{-5} \pm 8.5 \times 10^{-6}$	4.62 ± 1.0	0.66	13	P<0.001
	Maldives	weight	−846.7 ± 413	1547 ± 229	0.71	21	P<0.001
	PNG	length	6.7×10^{-4} ± −	3.76 ± −	0.81	18	P<0.001[c]
	India	length	$1.4 \times 10^{-4} \pm 2.1 \times 10^{-5}$	3.89 ± 0.33	0.91	15	P<0.001[b]
S. heterolobus	S.I.	length	$7.2 \times 10^{-5} \pm 1.4 \times 10^{-5}$	4.13 ± 0.45	0.42	121	P<0.001
	Maldives	length	−2820 ± 2772	72.5 ± 39	0.53	5	n.s.
	PNG	length	−2355 ± −	61 ± −	0.95	27	P<0.001[d]

a = Conand (1988); b = Mohan and Kunhikoya (1986); c = Dalzell (1985); d = Dalzell and Wankowski (1980).

Discussion

The major baitfish species in Solomon Islands and Maldives, including those examined here, have similar reproductive strategies. All mature at a small size, spawn throughout the year (Dalzell and Wankowski 1980; Dalzell 1985; McCarthy 1985; Milton and Blaber, In prep., these Proceedings), during which each female produces several (Wright 1989) relatively small batches (Conand 1988; Dalzell 1985) of quite large eggs. In more temperate waters off Japan, *S. gracilis* reduce their reproductive season to the three months over summer (Ozawa et al. 1989). In Maldives (Fig. 1) spawning was greatest during the southeast monsoon from March to September. Although spawning was protracted for all species, especially in Solomon Islands, there were certain periods when a greater proportion of the population was involved. Milton and Blaber (In prep.) have suggested that these small pelagic species increase spawning in response to local conditions that will maximize their reproductive success. The local proximal stimuli which appeared to be linked to spawning of *Stolephorus* and *Spratelloides* in Solomon Islands varied between sites, although the baitfish species at each site spawned in response to the same stimuli (Milton and Blaber, In prep.).

When all spawning data from the three sites are combined (Figs 1 and 2) it becomes apparent that for each species in Solomon Islands, a significant proportion of the population (minimum 10%) are spawning at any time. This has important implications for the management of the fishery. Local heavy fishing, even during peak spawning, should not seriously affect the overall fishery, as there will be some recruitment to the fishery from fish spawning at other sites.

The ontogenetic change in sex-ratio of the three species were consistent in Solomon Islands, Maldives and other parts of their range (Lewis et al. 1974; Lewis et al. 1983; Conand 1988; McCarthy 1985). *Stolephorus heterolobus* and *Spratelloides delicatulus* have an excess of males among the smaller length classes which change as length increases until the largest length classes contain only females (Conand 1988; McCarthy 1985, these Proceedings). This pattern of ontogenetic change in sex-ratio is most often seen among protogynous hemaphrodites (eg. *Lates calcarifer;* Moore 1979; Davis 1982) or among fish whose sexes grow at different rates (eg. some labrids; Jones 1980). However, there is no difference in growth rate of the sexes of either species (Milton et al., these Proceedings). The sex of an individual is determined genetically, but has been found to be environmentally influenced through temperature in some vertebrate groups e.g. crocodiles (Ferguson and Joanen 1982), turtles (Bull and Vogt 1979) and one species of fish (Conover and Kynard 1981). If temperature during the egg or larval stages was influencing the sex-ratios of these species then this could have a significant impact on the number of females reproducing at any particular time. Another possibility is that there is differential attraction of males and females to the baitlights leading to bias towards males in the length classes sampled. This is unlikely, however, as our sampling in the Maldives using a different technique, showed similar results (Fig. 5).

The ontogenetic change in sex-ratio of *S. gracilis* showed a different pattern to the other species. Smaller as well as larger length classes were dominated by females. In all species, though, females survive longer than males. This has selective advantage as larger females lay more eggs (Table 5). Males may die earlier due to their higher reproductive effort than females (Gunderson and Dygert 1988) — gonosomatic indices of males are higher at peak times than females — who spread their investment over several broods and trade-off their future survival against the increase in reproductive potential.

These ontogenetic changes in sex-ratio may account for the temporal fluctuations in sex-ratio found in this and other studies of baitfish (Tiews et al. 1971; Mohan and Kunhikoya 1986; Ozawa et al. 1989; Figs 3 and 4). If the sex-ratio is not 1:1 in all length classes, and younger fish are dominated by one sex, then the male bias among samples of *S. heterolobus* and *S. delicatulus* may just reflect the size of the fish in the sample. Conversely, most samples of *S. gracilis* from Solomon Islands, Maldives and Japan (Ozawa et al. 1989) were biased towards females which were more common in most length classes. Klingbeil (1978) found sex-ratios of samples of Northern anchovy *Engraulis mordax* were biased towards females and suggested that there may be spatial segregation of the sexes. If baitfish species form schools of fish of one sex and baitlighting attracted more male schools, this would suggest that female schools occurred in different habitats, either in the shallows or outside the lagoon, which is not the case.

Length-weight data are often used to study fish condition and assume heavier fish of a given length are in better condition (Bolger and Connolly 1989). Data on baitfish (Table 3) showed considerable variation both locally and regionally. In Solomon Islands, both *Spratelloides* species weighed significantly less at Tulagi than other sites, and may indicate that conditions were less favourable at this site. There is no indication from these relationships that there are any consistent differences in fish condition between high island lagoons (eg. Solomon Islands, New Caledonia, Papua New Guinea) and coral atoll lagoons (Maldives, Kiribati, Palau). Rather it may reflect the quantity and quality of food as available at each site.

Fish condition did not appear to affect the relative fecundity of any of the species in this study. Populations with higher length-weight regression slopes did not have higher relative fecundities. Rather, variation in fecundity among fish sampled during this study reflected the trade-off between egg size and fecundity (Tables 3 and 4). Populations with higher fecundity had smaller eggs (eg. *S. heterolobus* from Vona Vona). Regional differences in relative fecundity may also be related to egg size differences between countries, or to the different length ranges examined in each study.

Absolute fecundity ranged from 200–3000 among the various populations of baitfish examined (Table 5). Fecundity was positively related to length and weight for all species at all sites where sample sizes were sufficient. There was no difference in the slope of the fecundity-length equations between the two *Spratelloides* species or *S. heterolobus* from Solomon Islands. *S. gracilis* in Papua New Guinea and India appear to have higher fecundity than in Solomon Islands. These data suggest that total egg producion by these species in a particular area may depend on spawning frequency and their ability to develop a new batch of eggs after each spawning. We have no data on interspawning interval for any species, although Wright (1989) found that female *S. heterolobus* in Indonesia can spawn as frequently as every second day. If this species spawned at the same frequency in Solomon Islands, it may account for its greater abundance in baitfish catches (Rawlinson, these Proceedings).

Conclusions

The reproductive biology of three major baitfish species was compared between Solomon Islands and Maldives. All species mature early and have a protracted spawning season in both countries. Fish in Solomon Islands spawn throughout the year, with one or two more intense spawning periods. In Maldives *S. heterolobus* and *S. gracilis* appear to have a single spawning season within the atoll and this may coincide with the monsoon. Length-weight relationships varied between sites within Solomon Islands more than between countries. This and the results of other published studies do not indicate differences in condition between baitfish populations from high islands and coral atolls.

The sex-ratio of all species showed a bias among small length classes towards one sex. The sex-ratios of *S. heterolobus* and *S. delicatulus* were biased towards males among small length classes. The proportion of females increased as length increased. Large length classes were almost all female. *S. gracilis* differed from the other species in that the sex-ratio of smaller length classes were biased towards females. These results were consistent with other studies of baitfish sex-ratios. They may explain the temporal pattern of sex-ratios in this study and the bias towards males in most samples of *S. heterolobus* and *S. delicatulus*.

Fecundity of baitfish from Solomon Islands and Maldives showed little intraspecific variation, except for *S. heterolobus* from Vona Vona, which had more, smaller eggs than fish from other sites, including Maldives. Fecundity studies of these species from other areas showed some variation and these species may vary their fecundity in relation to egg size. In Solomon Islands, there was no difference in fecundity between the three species examined which suggests that differences in their population densities may depend on spawning frequency or recruitment success, rather than egg batch size.

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III Population Dynamics and Aging

Biology and Population Dynamics of Tuna Baitfish in Papua New Guinea

P. Dalzell*

Abstract

Pole-and-line tuna fishing commenced in Papua New Guinea during 1970 and persisted until the mid 1980s. Various stock assessment sampling programs were carried out on live bait stocks over this period on exploited and unexploited populations. The pole-and-line fishery was dependent for live bait mainly on populations of anchovies of the genus *Stolephorus* and sprats of the genus *Spratelloides*. Growth and mortality parameters were computed for these species, mostly from length frequency data. Total mortality rates of the principal species were found to be proportional to fishing pressure in the country's main bait grounds, which in turn permitted computation of natural mortality rates.

The relationship between annual catch and fishing effort was best described by a straight line rather than a curvilinear function at the Ysabel Passage and the country's other major baitground, Cape Lambert. Estimates of MSY were computed for the stolephorid anchovies from simple production models. Rainfall was also shown to markedly affect abundance yield of stolephorid anchovies, probably through influence on recruitment. Estimates of overall MSY for PNG's baitfishery ranged from 1 to 2 t/km^2/yr based on biomass and natural mortality rates of the major species.

FROM 1970 until 1981 a fleet of Japanese pole-and-line tuna vessels was based in Papua New Guinea (PNG) catching skipjack and yellowfin tuna for canning overseas. The fishery stopped in 1981 for a variety of socio-economic reasons, then recommenced at a much reduced level during 1985. Fishing was again discontinued after 1985, and the pole-and-line fishery remains closed. During the twelve successive years of the tuna fishery the pole-and-line fleet represented the largest live bait fishery in the South Pacific region with annual catches ranging between 75 and 1900 tonnes and a mean of 1125 tonnes. This has since been superseded by the bait catch of the Solomon Islands pole-and-line tuna fleet which is now the biggest and most important pole-and-line tuna fishery in the South Pacific.

Research on PNG's baitfish stocks initially took the form of identifying species and areas of baitfish abundance. The coralline coasts of PNG were initially surveyed for baitfish during the late 1960s by vessels from the Japanese Far Seas Fisheries Research Laboratory (Anon 1969). These early records tended to simply record the presence or absence of different species at many different locations around the PNG coast. Later surveys organised within PNG also made studies of various aspects of the biology and taxonomy of baitfish species, especially the anchovies *Stolephorus heterolobus* and *S. devisi,*[1] and the sprats *Spratelloides gracilis* and *S. delicatulus* (Kearney et al. 1972; Lewis et al. 1974)

Monitoring of baitfish stocks other than survey work commenced in the early 1970s when sample collection began from commercial bait catches in the north of PNG and from unexploited populations in the vicinity of Port Moresby. A more intense research effort started in northern PNG in

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[1] The genus *Stolephorus* was split by Nelson (1983) into *Encrasicholina* and *Stolephorus sensu stricto.* I have maintained the original classification to avoid confusion.

1976 with the objective of intensively sampling bait catches from the major baitfishing grounds. This sampling effort ran continuously from 1976 to 1981 and was revived in 1985 when the pole-and-line fishery was briefly in operation again.

The data collected from the different sampling and monitoring programs mentioned above have been summarised and analysed by Tierney (1979), Dalzell and Wankowski (1980), Wankowski (1980), Dalzell (1983, 1984 a and b, 1985, 1986 a, and b, 1987 a, and b), Dalzell and Lewis (1988, in press). Data concerning a short lived baitfishery on the southern coast of PNG was given by Cooper and Wankowski (1980). In this paper a synthesis is made of these various studies to illustrate aspects of the biology and population dynamics of baitfish species in PNG relevant to exploitation and fisheries management.

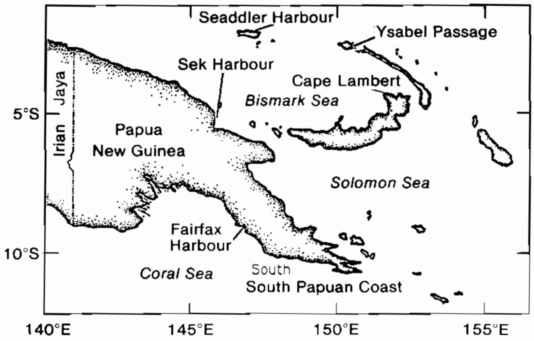

Figure 1. Map of Papua New Guinea showing the locations of the baitgrounds mentioned in the text.

Fishing Methods and Fishing Operations

Baitfish were caught in PNG by the use of a stick held lift net (bouke-ami), assembled and mounted on the pole-and-line vessel. The baitfish were aggregated at night around submersible lamps of 1 to 1.5 kW that are used after dusk. Besides lamps suspended from the vessel itself, other catching stations were deployed using generators and lamps mounted on small skiffs.

During setting and hauling of the net, the lights were dimmed and raised to near the surface. After the net was hauled, the mass of baitfish was concentrated in one corner of the net to be brailed into buckets and then emptied into baitwells set in the hull of the pole-and-line vessel. This method of catching baitfish is used throughout the tropical western Pacific wherever pole-and-line fishing has been established. The method is described in greater detail in Ben-Yami (1976).

Pole-and-line tuna fishing in PNG was always a fleet operation supported by mother ships. Fishing vessels would fish for tuna during the day then return to the motherships at night to offload their catch. The motherships were anchored on the baitgrounds and would supply ice, fuel, water and victuals to the fishing vessels. Towards the late 1970s pole-and-line vessels with cooling coils in their fish holds began fishing in PNG. These vessels could spend longer at sea but the day boat style of operation centred around a mothership was still maintained.

Lewis (1977) gives an account of the early years of pole-and-line fishing in PNG when there were major fleet operations catching live bait at the Ysabel Passage (New Ireland), Cape Lambert (East New Britain) and Sek Harbour near Madang on the mainland (Fig. 1). Apart from these sites there were about 20 other sites where fishing occurred intermittently because of declines in production at the main baitgrounds or were used when winds blew from the north towards year's end. The number of companies fishing for tuna declined from three in the early 1970s to one by 1979, with a corresponding reduction in fleet numbers and size. This plus other socio-political factors reduced the number of sites where baitfish were caught and fishing for bait became more or less concentrated on the Ysabel passage and Cape Lambert baitgrounds.

Sampling Areas and Methods

A detailed account of sampling areas and sampling methods for baitfish in PNG is given by Dalzell and Wankowski (1980) and Dalzell (1984b). The Ysabel Passage was PNG's main baitground supporting up to 30 vessels during some years, and was thus the most intensively studied of the various baiting sites. Catches at this site ranged from 75 to 980 t/yr with a mean of 480 t/yr. Cape Lambert was the second most important site and from 1971 to 1981 regularly supported fleets of up to 20 pole-and-line vessels. Annual catches at this baitground ranged between 55 and 600 t/yr with a mean of 305 t/yr.

During the early 1970s regular catches of baitfish were also made in Fairfax Harbour, adjacent to Port Moresby, by PNG Fisheries Department personnel. Unlike the other sites in the country Fairfax Harbour was never used as a commercial baitground so samples from this location were from unexploited populations. Sampling of the baitfish in this area occurred on average one day every two weeks. Sampling of the commercial fisheries was much more intensive with sampling intervals of three to five days.

Bait samples were normally separated by species to determine numerical and weight (to the nearest 0.1g) composition. The fork lengths of the major species were then measured to the nearest 0.1cm. Maturation of gonads was examined both by macroscopic examination and by computation of the gonad index: GI=(Gonad weight/Total fish weight)/100. The length frequencies and species composition data were initially summarised in 10 day intervals (Dalzell and Wankowski 1980) but were later compiled by calendar month, in common with the gonad data.

Aging studies were also carried out on PNG baitfish using otolith microstructure or daily growth increments (Panella 1971). A full account of the methods employed to determine ages for PNG baitfish is given by Dalzell (1984b, 1987). Aging of the juvenile and adult stages of the sprats *S. gracilis* (Dalzell 1984b) and *S. lewisi* (Dalzell 1987a) was accomplished by this method. Some estimates were also made of the ages of stolephorid anchovy larvae (Tierney 1979) but the otoliths of the adult fishes were difficult to read given the simple techniques being employed.

Species Composition

The composition of baitfish hauls from the Ysabel Passage and Cape Lambert is given in Table 1 (see also Lewis 1977). Similar data were not available from Fairfax Harbour where composition was recorded in terms of dominant and sub-dominant species. The bulk of the catch from Fairfax Harbour was *S. devisi,* with *Stolephorus waitei.* Stolephorid anchovies formed the bulk of the catch at both the two major baitgrounds but at the Ysabel Passage the sprat *S. gracilis* made an important contribution to baitfish catches, in some years accounting for over half the total catch by volume.

The sprats were not very abundant at the Cape Lambert site but at this location in certain years the oceanic anchovy *Stolephorus punctifer* would make significant contributions to the catch. By contrast *S. punctifer* was virtually absent from the Ysabel Passage bait catches apart from the beginning months of the revived fishery in 1985 (Dalzell 1986a). At both bait grounds a wide variety of less common small pelagic fishes such as sardines, herrings, fusiliers, silversides, scads and mackerels comprised the other species in the catch. Also included in this grouping were juvenile reef fishes such as post-acronurus surgeonfishes, juvenile goatfishes and juvenile rabbitfishes.

The 'other species' grouping appears to have comprised a major proportion of the Cape Lambert bait catches since the inception of the fishery (Table 1). At the Ysabel Passage the other species component appears to have amounted to between two to three percent of the catch during the early years of the fishery. As fishing persisted, however, the other species component gradually increased to around 30% of the catch whilst the anchovies as a group and *S. gracilis* oscillated in a more or less antagonistic fashion. The relative abundance of the anchovies is inversely correlated with that of the sprat (Dalzell 1984b) but this is not a particularly meaningful relationship when the percent composition is reduced to only three variables. A more relevant comparison is that of the annual biomasses of the different bait stocks and this is examined further below.

Age and Growth

Growth of baitfish species in PNG was assumed to conform to the von Bertalanffy growth function (VBGF) which takes the form for length of:

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

where L_t is length at time t, L_∞ is asymptotic length, K is a growth constant and t_0 is the curve origin. Tierney (1979) and Dalzell and Wankowski (1980) attempted to determine growth rates for *S. heterolobus, S. devisi,* and *S.*

Table 1. Annual mean percent species composition (in numbers) of bait hauls at the Ysabel Passage and Cape Lambert bait grounds.

Species	Ysabel Passage[a]	Cape Lambert[b]	South Papuan Coast[c]
Stolephorus heterolobus	34.1	48.6	53.1
S. devisi	16.3	20.8	20.8
S. punctifer	0.7	5.8	4.4
Spratelloides gracilis	34.4	0.2	0.0
S. lewisi	2.2	4.3	0.0
S. delicatulus	2.5	0.9	0.1
Other spp.	9.8	19.4	21.6[d]

[a]Data collected from 1972–73, 1976–81 & 1985.
[b]Data collected from 1972–73, 1977 & 1980–81.
[c]Data collected from 1978–79.
[d]Contains 16% unidentified juvenile stolephorid anchovies.

gracilis from modal progression analysis of length frequency data. The results from these initial attempts gave rather poor estimates of the VBGF with upwardly biased estimates of both K and L_∞. These problems resulted from the subjectivity of the methods employed and the time taken to prepare the data and perform the necessary calculations by hand.

The advent of the ELEFAN suite of computer programs (Pauly 1987) meant that a more objective approach could be taken to the analysis of baitfish length frequency data. Moreover, it was also possible to see that there were regular progressions of cohorts through each year and that this was repeated year after year, where long time series were available. The estimates of growth parameters in exploited and unexploited baitfish stocks are given in Table 2. Growth of the various baitfish species is rapid and life spans short, particularly for the sprats which live for $\leq$ 0.5 years. The life spans of the stolephorid anchovies ranged between 1.0 and 1.5 years.

Good correspondence was found between the growth as determined from length frequency data and from otoliths for *S. gracilis* from the Ysabel Passage (Dalzell 1984b). Muller (1976) also found a similar correspondence for *S. heterolobus* from Palau. The maximum life span of *S. heterolobus* in Palau was estimated to lie between 1.25 and 1.7 years. A few specimens of *S. heterolobus,* from Manila Bay, Philippines, have also been aged through the use of daily growth increments (B. Morales-Nin, Instituto de Ciencas del Mar, Barcelona, Spain pers. comm.). Specimens of about 7.0 cm in length were just over one year old.

Mortality Rates

The annual total mortality rates (Z) of PNG baitfish were determined from a variant of the Beverton and Holt mean length equation proposed by Pauly (1980a) after Ssentongo and Larkin (1973). The equation takes the form:

$$Z = \frac{K}{\dfrac{\ln (L_\infty - L')}{\ln (L_\infty - L_m)}}$$

where K and L_∞ are the parameters of the von Bertalanffy equation, L′ is the recruitment length and L_m is the mean length above L′. The estimates of Z for each bait species in PNG are given in Table 3 by location and year.

Table 2. Age and growth parameters for different stocks of bait fishes in Papua New Guinea.

Species	Location	K	L_∞ (cm)	L_{max} (cm)	t_{max} (yrs)
Stolephorus heterolobus	YP[a]	2.6	7.9	7.2	1.0
S. heterolobus	CL[b]	2.4	8.7	8.2	1.2
S. devisi	YP	2.1	7.4	7.2	1.5
S. devisi	CL	2.4	7.4	7.2	1.3
S. devisi	FH[c]	2.0	7.8	7.2	1.3
S. waitei	FH	1.7	10.9	9.9	1.5
Spratelloides gracilis	YP	4.3	7.6	7.0	0.5
S. lewisi	YP	5.4	5.5	4.9	0.4
S. lewisi	CL	5.4	7.0	6.2	0.4

[a]Ysabel Passage
[b]Cape Lambert
[c]Fairfax Harbour

Table 3. Mean annual mortality rates and exploitation rates for stocks of baitfish in Papua New Guinea.

Species	Location	Z	M	F	E	Range of E estimates
Stolephorus heterolobus	YP[a]	10.2	5.2	5.0	0.49	0.29–0.63
S. heterolobus	CL[b]	9.4	6.2	3.2	0.34	0.23–0.43
S. devisi	YP	9.2	5.7	3.5	0.38	0.11–0.50
S. devisi	CL	9.8	7.4	2.4	0.25	0.20–0.32
S. devisi	FH[c]	6.9	6.9	0.0	0.00	0.00–0.00
S. waitei	FH	3.8	3.8[d]	0.0	0.00	0.00–0.00
S. gracilis	YP	14.4	11.3	3.1	0.22	0.10–0.27
S. lewisi	YP	13.6	8.9	4.7	0.35	0.29–0.40
S. lewisi	YP	14.8	8.4	6.4	0.43	0.43–0.44

[a]Ysabel Passage
[b]Cape Lambert
[c]Fairfax Harbour
[d]M estimated from Pauly's mean length equation.

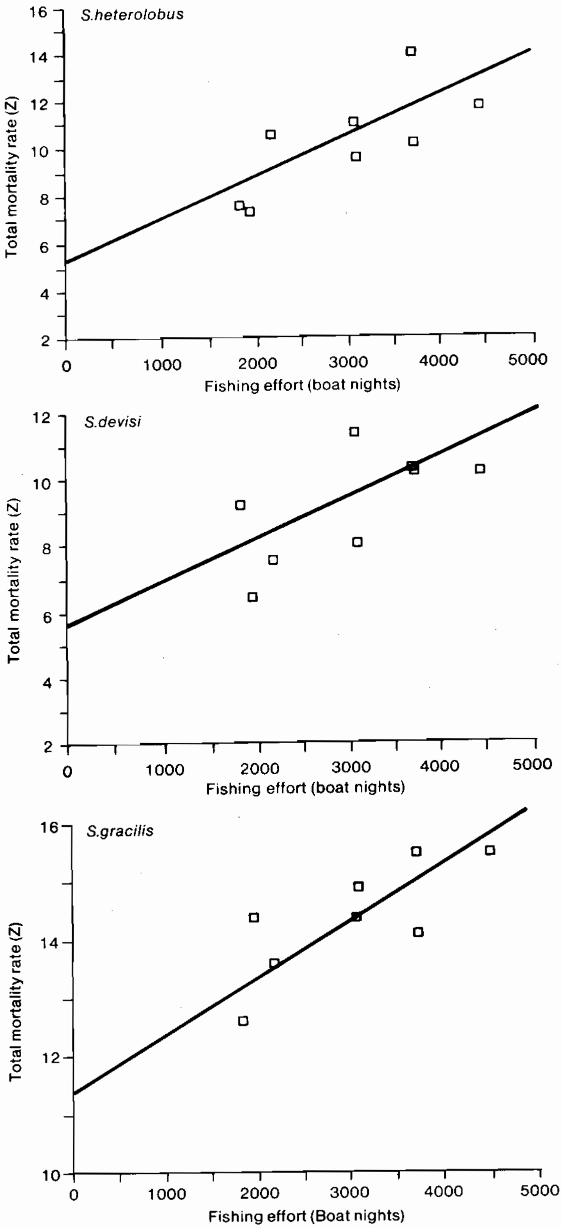

Figure 2. Total mortality rates versus fishing effort for exploited baitfish stocks at the Ysabel Passage, Papua New Guinea.

Dalzell (1984b) showed that there was a linear relationship between total mortality rate and annual fishing effort (f) for baitfish from the Ysabel Passage. The plots of Z on f for the three baitfish species from the Ysabel Passage are shown in Figure 2. These have been updated by the addition of the points from the 1985 fishing season and the regressions recalculated. Assuming that the relationship between fishing effort and fishing mortality (F) or catchability coefficient (q) is constant then the regression equation takes the form:

$$Z = qf + M$$

where q is the slope of the line and the intercept is the natural mortality rate, M.

In the case of the populations of *S. devisi,* and *S. waitei* at Fairfax Harbour the estimates of Z should conform to the natural mortality rate, given that this location was not used as a commercial bait ground. At Cape Lambert the data set is insufficient to compute a linear regression of Z on f. Instead the data for 1972 and 1973, where fishing effort increased markedly, were used to construct simultaneous equations which could then be solved for q and M (Gulland 1983). This method was also used for the sprat *S. lewisi* at the Ysabel Passage by Dalzell (1987a), although in this case the estimates of Z were obtained from length converted catch curves.

As might be expected from such short lived fishes the mortality rates are very high and are probably best expressed on a monthly rather than annual basis. Monthly survival rates ranged from 30 to 70%, depending on the degree of exploitation. The ratio of fishing mortality to total mortality or exploitation rate (E) can be used as a measure of the exploitation of a fish stock. Gulland (1971) suggested that in a stock that is optimally exploited, fishing mortality should be about equal to natural mortality or $F_{opt}=M$ and $E_{opt}=0.5$. Recently Pauly (1984), based on Beddington and Cooke (1983), proposed a more conservative definition of optimum fishing mortality where $F_{opt}=0.4M$ and $E_{opt}=0.3$. The estimates of mean E values for the exploited stocks of baitfish in PNG (Table 3) lie between the two suggested optima though for some species such as *S. heterolobus* at the Ysabel Passage the annual values of E tended to approach or exceed 0.5 during most years when sampling occurred.

Catch and Fishing Effort

The relationship between catch of baitfish and fishing effort in PNG has been investigated by Dalzell and Wankowski (1980), Dalzell (1983, 1984b, 1986b) and Dalzell and Lewis (1988, in press). Total annual bait catch is shown plotted against fishing effort for the Ysabel Passage and Cape Lambert bait grounds in Figure 3 The scatters demonstrate strong linearity with no evidence of declining catch rates as effort increases. Attempts to fit conventional surplus production

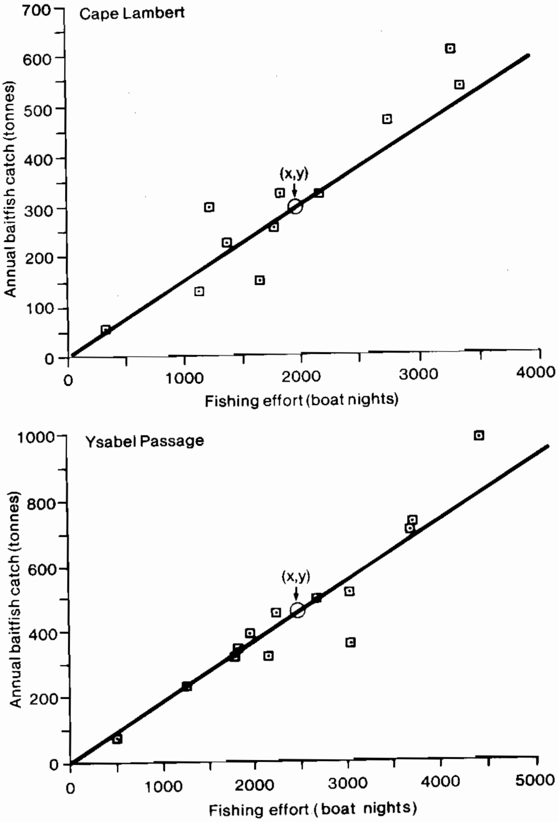

Figure 3. Catch versus fishing effort for PNG's two major bait grounds, the Ysabel Passage and Cape Lambert. Scatters are fitted with a line through the mean and the origin.

models of the Schaefer (1954) and Fox (1970) types were thus unsuccessful and, during the lifetime of the PNG fisheries limitation of fishing effort, particularly in the Ysabel Passage, was largely a matter of intuition.

Periodic collapses of baitfish production did occur on a monthly basis during both 1978 and 1979 at the Ysabel Passage and at Cape Lambert during 1980. In each instance the majority of the pole-and-line fleet relocated elsewhere. The temporary collapses of fishing at the Ysabel Passage during 1978 and 1979 led to the introduction of fleet size limits at this bait ground during 1980 and 1981. Very high levels of fishing effort did not occur again during the remainder of the fishery.

The relationships between catch and fishing effort for individual components of the bait catch at 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 *S.*

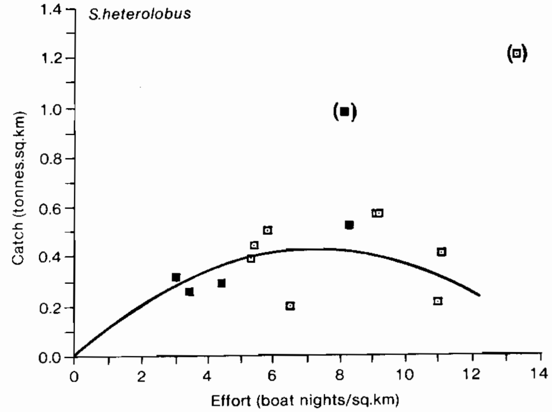

Figure 4. Catch/km^2 versus effort/km^2 for *S. heterolobus* catches for Ysabel Passage (□) and Cape Lambert (■) bait grounds. Points in parentheses were omitted from regression (see text).

heterolobus and *S. 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 as the areas fished by the pole-and-line vessels could be accurately defined from the fishing vessel catch reports. Attempts to fit a surplus production model to the catch data for the sprats at the Ysabel Passage and Cape Lambert were unsuccessful.

An analysis of the *S. heterolobus* data alone (Fig. 4) gave a predicted MSY of 0.44 t/km^2/yr, similar to an estimate of 0.48 t/km^2/yr for the same species in Palau (Muller 1976). Actual yields of *S. heterolobus* ranged from 0.29 to 0.67 t/km^2/yr (mean=0.44 t/km^2/yr) in Palau and 0.20 to 1.20 t/km^2/yr (mean=0.49 t/km^2/yr) in PNG. The MSY for combined catches of *S. heterolobus* and *S. devisi* from the Ysabel Passage and Cape Lambert was about 0.65 t/km^2/yr (Fig. 5). The actual yields of both anchovies combined ranged from 0.25 to 1.60 t/km^2/yr with a mean of 0.75 t/km^2/yr.

Despite the reasonable correspondence of these estimates certain assumptions concerning the surplus production model were violated. It is doubtful if either Ysabel Passage or the Cape Lambert fisheries were in equilibrium condition given the large inter-annual variations in fishing effort. Thus data points which were not included in the fitting of the curves (Figs 4, 5) may represent 'fishing up' of the stock as effort increased prior to a decline in catch per unit effort (CPUE) with continued fishing effort. Further, no surplus production model could be fitted to the data for *S.*

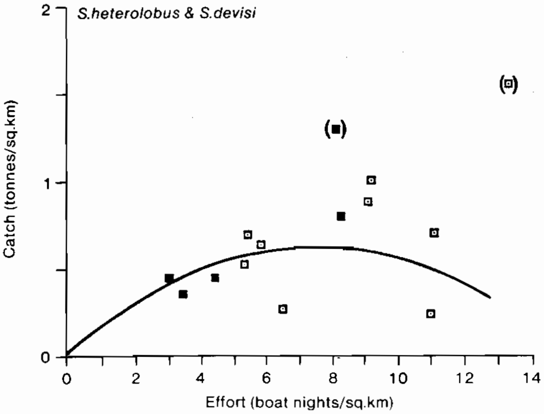

Figure 5. Catch/km^2 versus effort/km^2 for combined catches of *S. heterolobus* and *S. devisi* from the Ysabel Passage (□) and Cape Lambert bait (■) grounds. Points in parentheses were omitted from the regression (see text).

gracilis or any other species component of the bait catch. However, Dalzell (1984b) suggested that, based on the anchovy data alone, optimum fishing effort levels at the Ysabel Passage and Cape Lambert should be in the region of 3000 boat nights. This translates to a fleet at each bait ground of between 10 and 12 fishing boats or approximately 1 vessel per 30 km^2 of fishing ground per year.

Environmental Effects on Production

The analyses discussed in the previous section do not take into account the effects of the environment on the productivity of baitfish stocks and ascribe changes in abundance directly to the variations in fishing effort and thus fishing mortality. Csirke (1988) has pointed out that small schooling pelagic fishes are likely to be susceptible to climatic effects on the aquatic environment due to their habitat being close to the air-water interface. There is some evidence to suggest that production of tropical clupeoids is indeed strongly influenced by environmental effects, particularly wind and rainfall. Several authors have demonstrated that there is a relationship between rainfall (and resultant freshwater influx) and production of several tropical clupeoid fisheries (Tham 1953, Ben-Tuvia 1960, Antony-Raja 1972, Wetherall 1977, Ianelli 1988).

In the South Pacific region, the generally nutrient-poor waters around coral reefs can be enriched by runoff resulting from 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 stolephorid anchovies at the Ysabel Passage (mean rainfall = 3300 mm/yr) and Cape Lambert (mean rainfall = 2160 mm/yr). Catches at Cape Lambert contain *Stolephorus punctifer,* a stenohaline species. Not surprisingly the annual abundance of this species as expressed by mean CPUE declines with increasing rainfall (Fig. 6).

For both *S. devisi* and *S. heterolobus,* Dalzell (1984a) concluded that the catch rates of these might be modelled with a simple parabolic function of the form: $y=a+bx+cx^2$. The catch rates were standardised by area in the same manner as the catch and fishing effort. In both species, the optimum rainfall for maximum CPUE is about 3000 mm/year. Note that the additional points for 1985 for the Ysabel Passage, which fit rather well, were added without recalculating the curves (see Fig. 6).

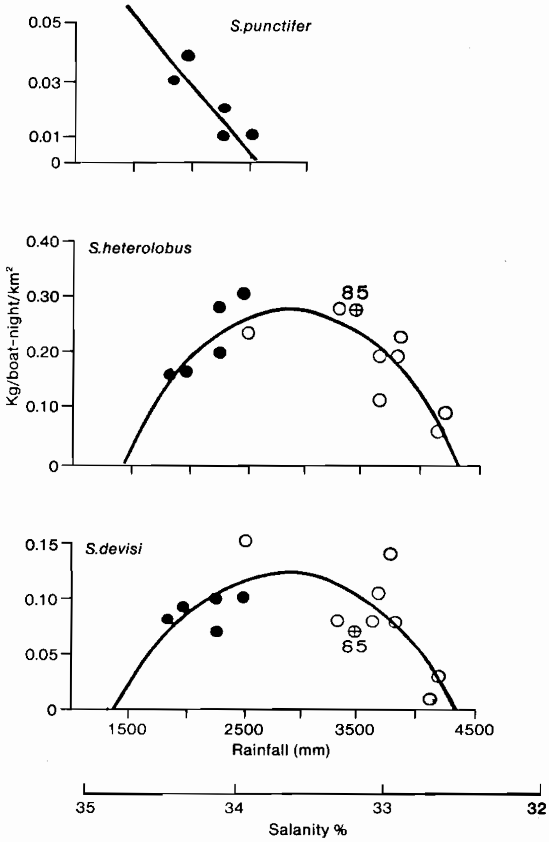

Figure 6. Mean annual yield of *S. punctifer, S. heterolobus* and *S. devisi* versus rainfall for two Papua New Guinea baitfisheries. Circles = Ysabel Passage; dots = Cape Lambert. Circles with crosses are the 1985 data points for *S. heterolobus* and *S. devisi* at the Ysabel Passage.

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 the Ysabel Passage catches of *S. heterolobus,* and *S. 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 baitfish catches have been made in Fiji (Ellway and Kearney 1981) and Kiribati (Ianelli 1988). Ellway and Kearney suggested that rainfall did not markedly affect baitcatches 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 *Spratelloides delicatulus* and rainfall. Dalzell (1984a) found no correlation between rainfall and catch rates of the con-gener *S. gracilis* from the northern PNG baitfisheries.

Reproduction and Recruitment

The reproductive biology of baitfish has been discussed in detail by Dalzell and Wankowski (1980) and Dalzell (1985, 1987a,b) based on observations from 1976 to 1985. The spawning of the stolephorid anchovies at the Ysabel Passage was shown to be highly seasonal, with a major peak of reproductive activity during May-June and a smaller one in November. These peaks in spawning activity were also coincident with seasonal peaks in CPUE of *S. heterolobus* and *S. devisi.* The spawning activity of *S. gracilis* was extremely variable from year to year without the clearly defined peaks observed in the anchovies.

Dalzell (1988) suggested that the spawning intensity of the stolephorid anchovies in the Ysabel Passage was related to peaks in zooplankton production which occurred between May-June and during October. These periods mark the transition from northwest monsoon to southeast trades in May-June and vice versa in October-November. Spawning data for stolephorid anchovies at Cape Lambert are rather sparse but suggest a peak in reproductive activity during the middle of the year. Although mature individuals of both *S. devisi* and *S. waitei* were observed at Fairfax Harbour from 1972 to 1974 no ripe or spawning specimens were observed in the samples.

Table 4. Mean relative batch fecundities of PNG baitfish.

Species	Relative fecundity (eggs/g. body weight)	Standard deviation
Stolephorus heterolobus	592	133
S. devisi	1039	176
S. punctifer	875	301
S. waitei	224	21
Spratelloides gracilis	1689	405

The relative batch fecundities of the different baitfish stocks are shown in Table 4. The highest fecundities on a unit body weight basis were found in the sprat *S. gracilis* and the lowest in the larger stolephorid anchovy *S. waitei.* Although the two anchovies *S. heterolobus* and *S. devisi* are closely related the relative fecundities of these two species are quite different, with mature *S. devisi* containing on average about 40% more eggs in each spawning batch. Spawning frequency was not investigated for PNG baitfish although it was initially thought that these fish matured, spawned once, then because of the high mortality rates did not accomplish further spawnings (Dalzell 1985). Recent studies on anchovy spawning periodicity, however, showed that *Stolephorus purpureus* (Clarke 1987) and *Engraulis mordax* (Parrish et al. 1986) have spawning intervals ranging from 2 to 7 days respectively.

The relationship between stock and recruitment for baitfish species in the Ysabel Passage was investigated by Dalzell (1984b) following the method of Pauly (1980a, 1982). This method uses the yield per recruit formulation of Beverton and Holt (1957) to generate estimates of recruit numbers and size of the adult standing stock biomass and is a modification of an earlier method of Hempel and Sarhage (1959). The stock and recruitment curves generated from this method were near linear for *S. heterolobus, S. devisi* and *S. gracilis.* Cushing (1971) has argued that relatively primitive fish such as clupeoids have strongly linear stock recruitment relationships as opposed to more developed species such as gadoids where strongly density dependent mechanisms have developed. It should be pointed out, however, that the methodology to generate the stock recruitment data as outlined above, has been criticised by Garcia (1983) for possibly producing a strong positive correlation purely as a statistical artefact.

Muller (1976) fitted a Ricker type stock-recruitment function to data for *S. heterolobus* 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 material from runoff. Longhurst and Pauly (1987) have suggested that the parabolic rainfall-CPUE model discussed earlier for the stolephorid anchovies at the Ysabel Passage is essentially a recruitment model, where recruitment strength as measured by CPUE is dependent on annual rainfall.

Biomass and Potential Yield

Given a knowledge of annual catches and fishing mortality rates it is possible to compute the annual standing stock biomass of individual catch components in the PNG bait fisheries (Tables 5, 6). When these are expressed on an area basis annual standing stocks range from 0.19 to 0.38 t/km^2 at Cape Lambert and 0.2 to 0.66 t/km^2 at Ysabel Passage with an overall weighted mean of 0.43 t/km^2. The standing stock biomass of small pelagic bait fish (primarily anchovies, sprats and sardines) in the bays and lagoons of New Caledonia has been estimated by Petit and Philippes (1983) to range between 0.04 and 1.84 t/km with a weighted mean of 0.47 t/km^2. The estimates of Petit and Philippes were made from hydroacoustic data rather than from catch data but are interesting since they suggest that around the high islands of the tropical western South Pacific biomass densities of small pelagic fishes may be similar.

The annual biomass estimates for the individual catch components at the Ysabel Passage for the sampling years between 1972 and 1985 are shown in Figure 7. These estimates support what was observed in the species composition data,

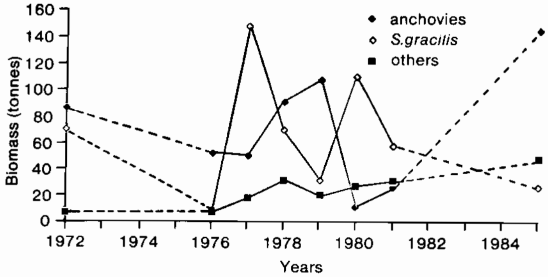

Figure 7. Changes in biomass of component baitfish stocks at Ysabel Passage from 1972 to 1985.

Table 5. Annual biomass estimates (tonnes) of baitfish populations at the Ysabel Passage bait ground.

Year	*S. heterolobus*	*S. devisi*	*S. gracilis*	Other spp.[a]	Total
1972	60.8	25.7	70.0	7.1	163.6
1976	32.9	18.9	8.1	7.1	67.0
1977	27.6	22.7	148.2	18.3	216.8
1978	62.2	28.0	69.5	31.8	191.5
1979	43.6	63.5	31.7	20.6	159.4
1980	8.2	2.8	110.0	27.3	148.3
1981	12.5	13.9	57.4	31.3	115.1
1985	80.0	65.7	26.1	48.5	220.3
Mean	41.0	30.2	65.1	24.0	160.4

[a]Other species standing stock estimated using mean F values for three bait species. 86% of other species composed of Clupeidae (41.8%), Apogonidae (15.5%), Caesionidae (13.7%), Atherinidae (8.9%), Carangidae (6.4%) (Anon 1984).

Table 6. Annual biomass estimates (tonnes) of baitfish populations at Cape Lambert bait ground.

Year	*S. heterolobus*	*S. devisi*	Other spp.[a]	Total
1972	61.1	37.2	23.2	121.5
1973	67.7	32.9	53.3	153.9
1981	28.7	16.7	33.4	78.8
Mean	52.5	28.9	36.6	118.1

[a]Other species standing stock estimated using mean F values for anchovy species. 89% of other species composed of Caesionidae (65.2%), Clupeidae (13.6%) and Scombridae (10.2%) (Anon 1984).

that anchovy abundance oscillated in an antagonistic manner to that of the sprat and that there was a gradual increase in the abundance of the 'other species' component. These limited data would suggest that there may be some form of interaction between the sprat and the anchovies although the exact nature of this remains a matter for speculation. Similarly the reasons for the increase in the abundance of the other species component during the life of the fishery remain unknown.

The annual yield of baitfish at the Ysabel Passage ranged from 0.223 to 2.929 t/km^2 with a mean of 1.360 t/km^2 and at Cape Lambert from 0.135 to 1.484 t/km^2 with a mean of 0.749 t/km^2. Attempts to estimate optimum yields from either fishery using surplus production models applied only to the stolephorid anchovies, and made use of a limited time series of catch and effort data. Where initial or virgin biomass (B_∞) estimates are available then maximum sustainable yield (MSY) can be computed from the empirical method of Gulland (1971) where:

$$MSY = 0.5 \times M \times B_\infty$$

and is derived from the surplus production model. Virgin biomass estimates were not available for the Ysabel Passage since no attempts were made to determine the standing stock biomass in the unexploited state. This baitground was not fished from 1981 to 1985 and this period may have been sufficient to allow recovery of the stocks to levels approaching the virgin biomass. Using the 1985 biomass data the MSY was computed for the stolephorid anchovies and the sprat separately. A weighted mean value of $M = 6.2$ was used with the other species category, and together the total MSY was 682 tonnes or 2 t/km^2/yr. If all stocks are considered together then using the mean natural mortality rate in the equation gives an MSY of 710 tonnes or a yield of 2.1 t/km^2/yr.

During the years 1970 to 1976 annual catches at the Ysabel Passage fishery ranged between 75 and 498 t/yr, with a mean of 327 tonnes. From 1977 to 1981 catches ranged between 319 and 984 t/yr, with a mean of 652 tonnes. During the latter years of the fishery, catches tended to be at or beyond the MSY as computed from the above equation. Although total standing stock biomass was low in 1976 and increased markedly in 1977, there was a steady decline in biomass from 1977 to 1981, with a corresponding decline in CPUE. Given an MSY of about 700 tonnes this corresponds to a level of fishing effort of 3700 boatnights or a fleet of 12 fishing vessels. This is similar to suggested levels of fishing effort and fleet size determined from an analysis of the anchovy data alone.

There is much less data available for the Cape Lambert fishery and there was never a hiatus in the fishery. Fishing at Cape Lambert did not commence seriously until 1972. During this and the following year the standing stock biomass at Cape Lambert was 122.5 and 153.9 tonnes respectively. Assuming that these values are close to the unexploited virgin biomass then the mean may give a reasonable approximation of B_∞. Using a mean value of 6.8 from the stolephorid anchovies (Table 3) then the predicted MSY is 468 tonnes, corresponding to a yield of 1.15 t/km^2/yr. If the MSY is computed on the basis of the individual catch components then the MSY is 459 tonnes or a yield of 1.13 t/km^2/yr. This corresponds to an annual fishing effort of about 2900 boatnights or a fleet size at Cape Lambert of 10 vessels.

Stock Interactions

From the viewpoint of management it was assumed that the baitfish stocks at different locations in PNG represented discrete populations. It was not possible to test this hypothesis using conventional tagging techniques since the baitfish species are prone to high mortality rates if handled incorrectly and because tagged individuals could easily be overlooked in the catch given the small size of the bait species.

For these reasons, Daly and Richardson (1980) used electrophoretic analysis of tissue enzymes to determine the degree of stock separation at three PNG bait grounds, Ysabel Passage, Cape Lambert and Seaddler Harbour at Manus Island (Fig. 1). The authors concluded that stocks of anchovies at these sites were effectively discrete populations. The samples of sprats from Seaddler Harbour and Cape Lambert were too small to make comparisons with the results from the Ysabel Passage. The analysis of the material from the Ysabel Passage samples of *S. gracilis,* however, was instrumental in the later description of a new species, *S. lewisi,* by Wongratana (1983).

The degree of localised population mixing between the Ysabel Passage stocks and those of other contiguous smaller bait grounds separated by mainly coastal waters remains unknown. Also unknown is the degree which different populations of the oceanic species *S. punctifer* interact, since this species is not confined to a coastal neritic habitat, unlike the other stolephorid anchovies, and may range over wide areas of ocean (Hida 1973).

Discussion

The objective of carrying out the type of investigations discussed here is to rationally manage and conserve the live baitfish resource. However it is important to recognise the limitations of the data, particularly now since the PNG baitfishery is likely to be only of historical interest. Apart from the surplus production model, Dalzell (1984b) used the yield per recruit formulation of Beverton and Holt (1957) and the catch-mortality method of Csirke and Caddy (1983) to try to estimate optimal fishing effort and MSY. The plots of yield per recruit vs fishing mortality for PNG bait fish demonstrated little curvature and maximised at E = 1.0 or F = ∞. According to Murphy (1977) this is not an uncommon feature of clupeoid stocks with short life spans and has led in the past to the false conclusion that overfishing was impossible. The Csirke and Caddy approach was used with time series of catch and total mortality data for baitfish from the Ysabel Passage. The results, however, were equivocal and in some instances produced unrealistic estimates of virgin biomass, MSY and optimal fishing mortality. As with the surplus production models the small data sets for individual stocks limited the application of the Csirke and Caddy method.

Gulland's 1971 empirical method which does not rely on a time series of catch and fishing effort may thus be the most appropriate approach for estimating MSY given the limitations of the PNG data for production modelling and the yield per recruit formulation with short lived species. Mortality rates were also related to fishing effort at Ysabel Passage and Cape Lambert thus it was possible to compute natural mortality rates. The relatively wide scatter of points of Z vs f for *S. devisi* at the Ysabel Passage may be a consequence of this species existing over a broader range of habitats than *S. heterolobus* and *S. gracilis* (Lewis 1977, Lewis pers. comm.). This species may periodically enter very shallow water, beyond the range of the pole-and-line boats. The area of operations of the baitfishery are generally the limits of *S. heterolobus* and *S. gracilis* habitat area and thus samples from fishing may be more representative of the size frequencies in the populations. This problem has also been discussed for estimating total mortality rate from samples of the gold spot herring, *Herklotsichthys quadrimaculatus*, from the Fijian baitfishery by Dalzell et al. (1987).

Whatever estimates are made of MSY and/or optimal fishing effort, the data from the northern PNG *Stolephorus* stocks suggests that environmental parameters such as rainfall can have marked effects on production and yield. Setting total allowable catches and a MSY limit may not be feasible when yields fluctuate markedly with environmental changes. The most practical management response is the limitation of effort and the movement of fishing vessels away from fishing grounds that show severe declines in production.

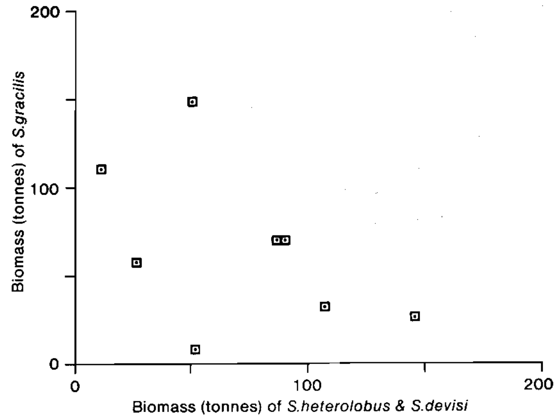

Figure 8. Annual biomass of *S. gracilis* versus biomass of combined stocks of *S. heterolobus* and *S. devisi* at the Ysabel Passage between 1972 to 1985.

This was the general strategy in PNG particularly after 1978 when the fleets concentrated at Ysabel Passage and Cape Lambert. Ancillary bait grounds were still available to the fleets in times of poor fishing at the two main baitgrounds. Thus the rapid relocation of the fleets during these times is probably a contributing factor to the near linear total catch and effort relationships for the Ysabel Passage and Cape Lambert grounds.

There is evidence that the abundance of *S. gracilis* in Ysabel Passage is inversely proportional to that of the stolephorid anchovies (Fig. 8) but this is not statistically significant given the small data set. Little is known about the ecological interactions of the stolephorid anchovy and sprat populations at Ysabel Passage and Cape Lambert. At Ysabel Passage sprats, particularly *S. gracilis*, were a major feature of the catch. At Cape Lambert all species of sprats combined formed less than 5% of the catch. Chapau (1983) made a study of the feeding habits of *S. heterolobus, S. devisi* and *S. gracilis* at Ysabel Passage and Cape Lambert and noted that there were marked differences in the diets between the anchovies and the sprat. Whilst the two anchovy species fed mainly on copepods and other invertebrate zooplankton, *S. gracilis* included a significant proportion of fish eggs and larvae in its diet, particularly at Ysabel Passage where ichthyoplankton accounted for about 80% of the total diet. What the effect of high sprat stock abundances are on anchovy egg and larval mortality are unknown, but may be an interesting area of investigation with respect to changes in adult stock densities.

Tuna baitfisheries by their very nature are supportive fisheries with little economic value compared to tuna catches. Pole-and-line fishermen will always want to maximise bait catches, either to take advantage of good tuna fishing or to catch as much as possible when tuna catches are poor. The data presented here suggests that the MSY for bait catches in PNG ranges between 1 and 2 t/km^2/yr or at a density of between 1 boat per 30 to 40 km^2 of bait ground. These estimates probably only refer to the bait fisheries of northern PNG where lagoons and productive coastal waters are limited. However, the fact that environmental factors can be limiting to production of at least part of the bait catch is relevant to other bait-fisheries on similar species and management policies must take account of this.

Acknowledgments

These studies were the result of a long term commitment by the Papua New Guinea Government to understanding the biology of exploited baitfish populations. I thank the numerous assistants who helped me with the routines of sampling and data processing and colleagues who gave advice on various aspects of the work. I am grateful to ICLARM and Drs Daniel Pauly and John Munro who in 1982 extended an invitation to analyse the bait-fish data using an early version of the ELEFAN programs. Finally, I thank my colleagues at the South Pacific Commission, Dr Tony Lewis, Mr Kevin Bailey and Mr Garry Preston for their helpful comments and criticisms of the manuscript, and Mr John-Paul Gaudechoux for his help with the various figures and drawings.

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Length-frequency Analysis of Major Baitfish Species in Solomon Islands

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Abstract

The engraulid anchovies *Stolephorus heterolobus* and *S. devisi* are the dominant species in the Solomon Islands tuna baitfishery. The sprat, *Spratelloides delicatulus,* also constitutes a significant proportion of the bait catch.

Length-frequency data were collected on a monthly basis between March 1987 and May 1989 from two heavily baitfished areas and one non-baitfished area in Solomon Islands. Analyses were performed on yearly data sets for each species at each site, using the compleat ELEFAN suite of programs. Values of asymptotic length (L_∞) and growth coefficient (K) were derived using ELEFAN I, length converted catch curves were constructed using ELEFAN II from which total mortality (Z), fishing mortality (F), exploitation rate (F/Z) and recruitment patterns were estimated. An empirical method was used to estimate natural mortality (M).

The results indicate that both anchovies are lightly to moderately fished at both the baitfished sites. The sprat experiences somewhat higher mortalities. The growth rates for both anchovy species were higher at the baitfished sites when compared to the non-baitfished site. K and L_∞ values were relatively constant between years at each site.

The results are discussed in the light of similar work in other bait fisheries and in regard to management implications.

THE domestic commercial tuna fishing industry in Solomon Islands began in 1973, following the success of a survey carried out during 1971–72 by Taiyo Gyogyo of Japan to determine the feasibility of pole-and-line fishing. An abundance of skipjack (*Katsuwonis pelamis*) and the requisite baitfish resources were clearly indicated by the survey. The pole-and-line industry has grown steadily over the years and in 1988, the local fleet consisted of 34 vessels which caught a total of 33 052 tonnes of tuna (92% skipjack, 7% yellowfin tuna (*Thunnus albacares*)). Exports of tuna and tuna products were worth approximately S.I.$78.4 million in foreign export earnings for that year (SIG, 1988). Baitfish catches taken by the pole-and-line fleet have risen to around 2498t, composed primarily of the engraulid anchovies *Stolephorus heterolobus* and *S. devisi.* The sprat, *Spratelloides delicatulus,* also contributes a significant part of the baitcatch at certain times of the year (see Rawlinson, these Proceedings).

The Fisheries Department of the Solomon Islands Government started a sampling program in 1982 to begin collection of biological data which would ultimately provide an insight into the fisheries dynamics and biology of the important bait species (Nichols, 1988). This program was expanded in 1986 with the implementation of a three year collaborative research program between the Fisheries Department and the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia to investigate in more detail the biology and population dynamics of the major baitfish species. Funding for this Baitfish Research Project (BRP) was provided by the Australian Centre for International Agricultural Research (ACIAR 1986).

The biology of the baitfish species that dominate the baitcatch in Solomon Islands has been

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investigated by others, most notably in Papua New Guinea (Dalzell, 1984; Dalzell and Wankowski, 1980; Lewis et al., 1974) and elsewhere (Tham, 1967, Masuda et al., 1975, Burhannudin et al., 1975, Muller, 1977; Bachman, 1963, McCarthy, 1985; Tiews et al., 1970, 1974).

Prior to the commencement of the BRP, no estimates had been made of the parameters relating to growth, recruitment or mortality for the important baitfish species. This paper presents the results of analysis of the length frequency data collected for the major baitfish species during the course of the 3-year collaborative BRP program from two baitfished and one non-baitfished sites, using computer-based length frequency analytical software.

Materials and Methods

Baitfishing

The pole-and-line fishing technique requires a nightly supply of suitable live baitfish (see Nichols and Rawlinson, these Proceedings). Baitfish are small pelagic species which are used to 'chum' or attract schools of skipjack to the pole-and-line vessels (or catcher boats as they are called in Solomon Islands) before fish can be poled onboard.

The catching of the baitfish is a separate fishery in time, location and method. Fishing takes place at night from designated baitfishing grounds (mainly lagoonal areas) using the 'bouke-ami' technique: bamboo-held lift nets of 4mm square mesh are used to capture the baitfish which are attracted by 2.0kW underwater lights. The Solomon Islands baitfishery is dominated by the engraulid anchovies, in particular *Stolephorus heterolobus* and *S. devisi* (Evans and Nichols, 1984). Clupeid species, such as *Spratelloides delicatulus* and *Herklotsichthys quadrimaculatus* are important at certain times of the year (Rawlinson, these Proceedings).

Sampling

When the pole-and-line fishery started, data collection was limited to catch reports made by the captains of the fishing vessels. The whole system was reviewed as complaints were received from the baitground owners on different aspects of the baitfishery. In 1981 a logbook system was introduced to obtain more detailed catch and effort statistics and an observers program was initiated so that biological specimens from the catch could be collected for later analysis in the laboratory (Nichols and Rawlinson, these Proceedings).

Observers were put on board commercial vessels and would collect samples of bait from wherever fishing may have taken place each night. This system had the disadvantage that vessels would concentrate their fishing effort at different sites during the year and this meant samples collected were not producing a good time series from any one site. This problem was overcome with the commencement of the bailfish research project (BRP). Collection of baitfish samples during this study was carried out at Munda baitground in the Roviana Lagoon, which is heavily exploited by catcher-boats after unloading at the tuna shore-base at Noro; Tulagi baitground, which is close to the tuna shore-base on the island of Tulagi, Florida Islands, and at Vona Vona Lagoon, a non-baitfished control site, to the north-west of Munda (Fig. 1).

The majority of samples taken at Munda and Tulagi were taken directly from the catches of the pole-and-line vessels. As buckets of bait are being taken from the net and transferred to the baitwells onboard either the whole bucket, or a part of the contents of the bucket, is collected in a very fine meshed net. Samples were then preserved in a solution of formalin for later analysis in the laboratory. Prior to the initiation of the collaborative research program it had not been possible to collect samples throughout the year as there has always been a closed season to fishing for two to three months, starting in either November or December. This closed season is a holiday period for commercial fishermen, and has not been enforced as a management measure or due to any seasonality of tuna abundance. Samples were collected during the holiday period at Munda and Tulagi (and on all sampling occasions at Vona Vona) by using a 1.0 or 0.5kW underwater light powered by a 2.5 kVA portable generator in a canoe. As the mesh size of the net used was the same as used by commercial vessels (4 mm square), and the power of the underwater lights was similar, the samples were considered to be representative of samples that would be taken from the catcher- boats.

In the laboratory, samples were sorted by species and the fork length of each fish measured to the nearest millimetre. Species were identified using the guide of Lewis et al. (1983). For the analysis of this data the individual fish lengths were summed into five millimetre length classes.

Estimation of population parameters

Length-frequency time series data for *Stolephorus heterolobus* and *S. devisi* were analysed by year for each sampling area. Data for *Spratelloides delicatulus* from all sites showed no clear progression of modes in the length frequencies. However, when

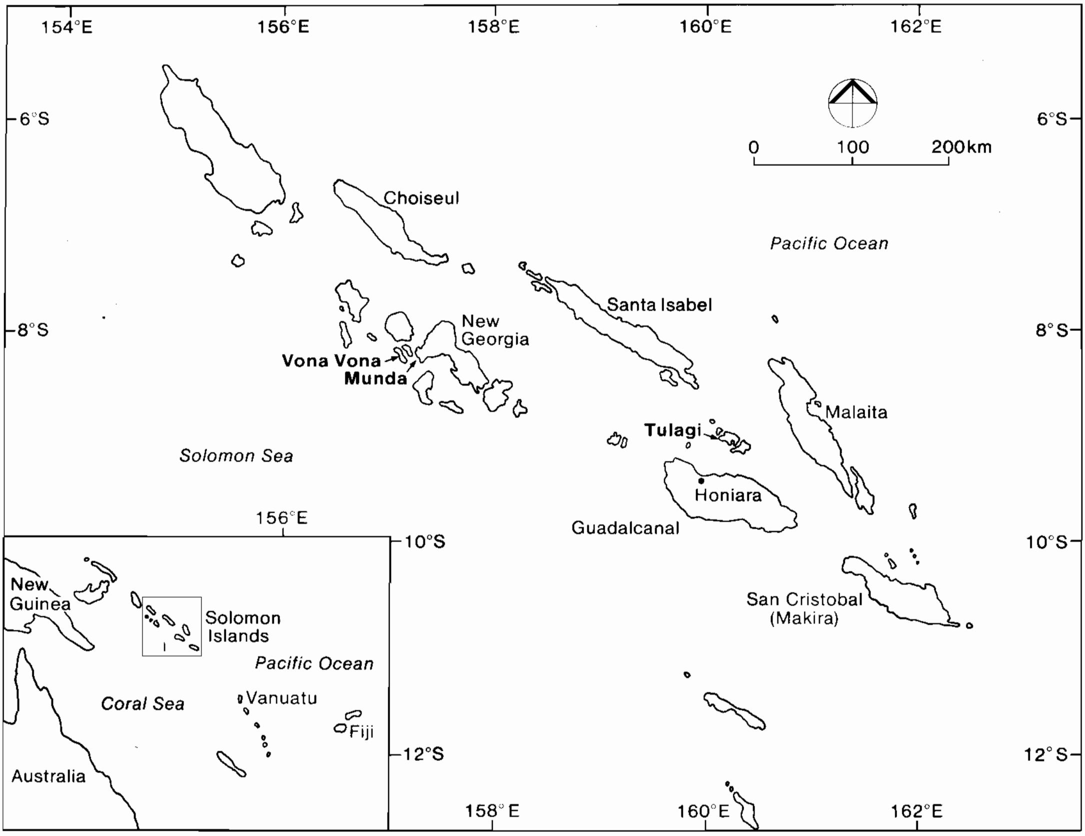


Figure 1. Map of Solomon Islands, showing sampling sites.

samples from Vona Vona and Munda, which are geographically close together a have similar geophysical characteristics, was pooled, and better progression of modal lengths were apparent; these data proved more amenable to analysis.

The length-frequency data were analysed using the Compleat ELEFAN suite of computer programs: ELEFAN is an acronym meaning Electronic LEngth Frequency ANalysis (Gayanilo, et al. 1988). Growth parameter estimates were estimated using ELEFAN I: this program is an iterative routine that fits a von Bertalanffy growth function (VBGF) to the length frequency data, arranged chronologically along a time axis. The curve has the general form:

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

In ELEFAN I, a seasonally oscillating version of the general VBGF is used (Pauly and David, 1981) of the form:

$$L_t = L_\infty (1 - e^{-[KD(t-t_0) + C\frac{KD}{2\pi} \sin 2\pi(t-t_s)]})^{1/D}$$

Where:

L_t = predicted length at age t,
L_∞ = asymptotic length
K = catabolic growth coefficient (or 'stress factor' in Pauly 1981)
D = another growth constant ('surface factor' in Pauly, 1981)
C = a factor which expresses the amplitude of the growth oscillations (Gayanilo et al., 1988).
t_o = time at which fish length is zero
t_s = sets the beginning of sinumsoidal growth oscillation with respect to t = 0 (Pauly and Gaschutz, 1979).

ELEFAN I estimates the constants L_∞ and K of the growth curve, using 'seed' input values determined by the user. Also required for the seasonally oscillating growth curve is a value relating to the 'winter point' (WP), which corresponds to the time of the year at which growth is slowest. The growth curve is fixed to the time axis by t(o) i.e. the age of the fish at zero length assuming that the fish has always grown in the manner described by the curve. Values of t(o) calculated by Dalzell (1984) for *Stolephorus heterolobus* and *S. devisi* in PNG were used in the present study. These were −0.0356/yr for *S. heterolobus* and −0.0739/yr for *S. devisi*. A t_0 of −0.023/yr was used for *Spratelloides delicatulus,* based on sagittal increment data for this species in Fiji (Dalzell et al. 1987).

ELEFAN I was run as many times as necessary on each data set until a satisfactory fit to the data was achieved. The program, in trying to pass the growth curve through as many of the length modes as possible, generates an Rn value as an indication of the goodness of fit (equivalent to ESP/ASP ratio in earlier versions of ELEFAN).

Values of Ø′, a dimensionless parameter used to compare the growth performance of fish and invertebrates when their growth is adequately described by the VBGF, were calculated for all species at each sampling site using the best fit values of L_∞ and K obtained from ELEFAN I (Pauly and Munro, 1984). Ø′ is calculated by:

$$Ø' = \log(10)\ K + 2\ \log(10)\ L_\infty$$

Ø′ values for the datasets in the present study were compared with values calculated for L_∞ and K values estimated by other authors.

Estimation of mortality rates

ELEFAN II estimates total annual mortality from a length converted catch curve, where the slope of the right-hand, descending limb of the catch curve equates to total mortality, Z. The selection of points for a catch curve also permitted the calculation of the mortality from the following:

$$Z = \frac{K}{\text{Log}(e)\dfrac{[L_\infty - L']}{[L_\infty - L(\text{mean})]}}$$

where:

Z = total annual mortality
K and L_∞ = parameters of von Bertalanffy growth curve
L′ = length at full recruitment, and
L(mean) = mean length above full recruitment.

This mean length equation, incorporated in ELEFAN II, was found to give more realistic estimates of Z when compared to estimates derived from the catch curve, where in some instances only two or three points lie on the descending limb. The same situation has been reported from PNG (Dalzell, 1984). A second, independent estimate of Z was obtained by multiplying the value of Z/K derived from a Wetherall Plot (Wetherall, 1986 as modified by Pauly, 1986) by K estimated from ELEFAN I.

Natural mortality (M) was calculated from Pauly's empirical formula:

$$\log(10)\ M = 0.0066 - 2.279\ \log(10)\ L_\infty + 0.6543\ \log(10)\ K + 0.4643\ \log(10)\ T$$

where T = mean annual environmental temperature in degrees Centigrade.

Pauly (1980) derived this formula from a multiple regression analysis of the growth and mortality parameters of 175 stocks of fish. Mean ambient water temperatures and annual temperature ranges for each year at the three sites are given in Table 1. Temperature readings were taken each time a monthly baitfish sample was collected.

Recruitment patterns were also calculated for *Stolephorus heterolobus, S. devisi* and *Spratelloides delicatulus* from ELEFAN II: each length frequency data set was analysed on a yearly basis because of the effects that the closed season may have on recruitment patterns from year to year.

Procedure for data analysis

The analytical procedure was as follows:

1. Length-frequency data were entered into yearly files for each site and species using ELEFAN 0.

2. A first estimate of L_∞ was made using ELEFAN II and the method of Wetherall (1986), as modified by Pauly (1986). Where a L_∞ value appeared unreasonable (in cases where the L_∞ estimate has been less than the maximum length class of the sampled fish), a 'seed' input value for L_∞ was derived using the relationship:

$$L_\infty \text{ approx.} = L(\max)/0.95$$

The seed value for L_∞ was then used in ELEFAN I search routine. Seed values for K were derived by

Table 1. Mean annual water temperature and range (degrees Celsius) for each sampling site, by year.

	1987		1988		1989	
Site	mean	range	mean	range	mean	range
Munda	29.5	28.0–30.2	30.9	29.2–31.5	30.0	29.5–30.8
Vona	29.9	27.5–31.2	31.0	30.0–32.5	30.4	29.8–31.8
Tulagi	28.7	27.5–30.5	29.5	28.5–31.5	29.2	28.0–30.0

reference to published literature, and through trial and error using the curve fitting by eye routine of ELEFAN I.

3. ELEFAN I was used to obtain estimates of $L\infty$, K, C and WP. For each species, the best yearly data set was used to obtain first estimates of the growth parameters. First estimates were then corrected using probability of capture data from ELEFAN II which was used to correct the original data for incomplete recruitment to the fishery. The corrected data was then run through ELEFAN I to give final estimates of growth parameters. It should be noted that K values using corrected data did not increase as should be expected because the mesh size of the bait net is such that the smallest size classes of fish are caught so selection effects are negligible. The final results were then used as guide for the runs using the other years' data.

4. After growth parameters had been obtained ELEFAN II was run using the catch curve routine to produce mortality estimates from length-converted catch curves, and recruitment patterns (for complete-year data, i.e. 1987 and 1988) using the recruitment pattern routine.

Results

The number of fish sampled each month for each of the three major species is given in Table 2. Initial estimates of L_{∞} derived from the Wetherall plot routine using ELEFAN II are given in Table 3, along with Z/K values derived from the plot.

Growth

Stolephorus heterolobus

ELEFAN I generated von Bertalanffy growth curves for Munda 1987–1989 data sets are given in Figures 2a–2c, respectively. Two growth curves are presented (solid and dotted lines), suggesting

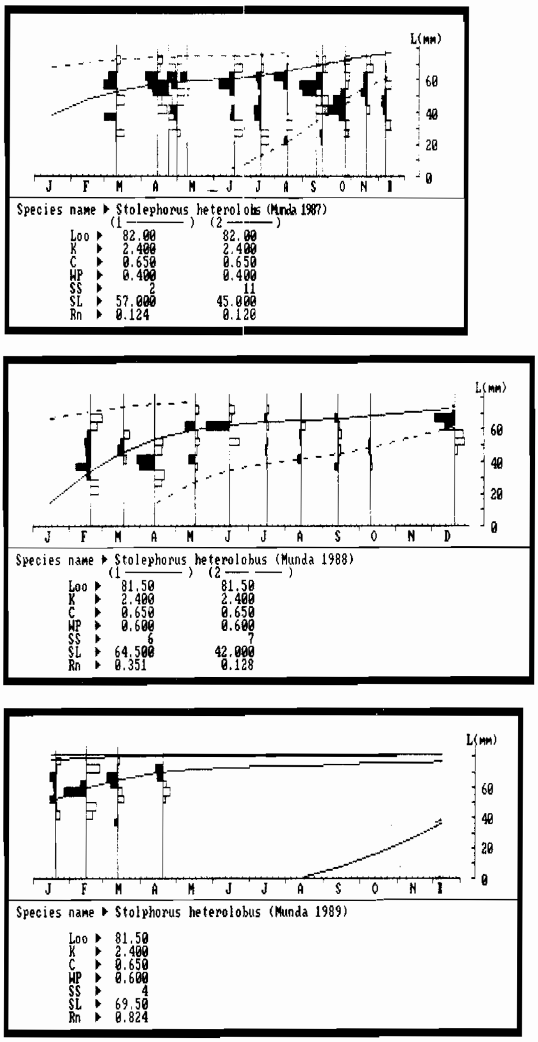
Table 2. Number of specimens of *Stolephorus heterolobus*, *S. devisi* and *Spratelloides delicatulus* collected each month, by year and site.

Site/year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
						S. heterolobus							
Munda:													
1987	—	—	434	949	9	965	1 563	756	1 808	2 630	575	75	9 764
1988	—	812	33	26	89	279	13	28	21	84	—	113	1 498
1989	141	299	384	171	—	—	—	—	—	—	—	—	995
Vona Vona:													
1987	—	—	120	—	86	59	43	108	27	12	90	24	569
1988	87	13	14	—	—	77	—	42	96	9	82	—	420
1989	69	40	68	52	412	—	—	—	—	—	—	—	641
Tulagi:													
1987	—	—	—	317	392	178	378	886	22	571	84	—	2 828
1988	—	465	—	106	268	69	—	170	44	313	—	13	1 448
1989	—	325	—	—	35	—	—	—	—	—	—	—	360
						S. devisi							
Munda:													
1987	—	—	73	206	10	331	428	147	128	682	447	460	2 912
1988	48	87	—	—	560	49	120	532	28	239	132	235	2 030
1989	1 159	1 153	699	115	350	—	—	—	—	—	—	—	3 476
Vona Vona:													
1987	—	—	187	191	192	556	234	132	752	309	225	187	2 965
1988	98	625	292	161	9	69	13	68	154	59	268	22	1 838
1989	278	265	229	857	—	—	—	—	—	—	—	—	1 629
Tulagi:													
1987	—	—	—	55	200	525	334	876	63	53	—	318	2 424
1988	—	433	303	100	365	523	564	339	636	55	106	146	3 570
1989	—	815	21	68	66	—	—	—	—	—	—	—	970
						Spratelloides delicatulus							
Munda:													
1987	—	—	—	258	189	466	14	17	691	602	279	261	2 770
1988	131	186	363	390	1 222	325	556	232	401	401	302	666	5 175
1989	573	127	369	216	175	—	—	—	—	—	—	—	1 460
Vona Vona:													
1987	—	—	187	191	192	556	234	132	752	309	225	187	2 965
1988	98	625	292	161	9	69	13	j68	154	59	268	22	1 838
1989	278	265	229	857	—	—	—	—	—	—	—	—	1 629

Table 3. Values of L∞ and Z/K obtained using the method of Wetherall (1986).

	Munda		Vona Vona		Tulagi	
	L_∞	Z/K	L_∞	Z/K	L_∞	Z/K
Stolephorus heterolobus						
1987	75.0	3.010	81.0	3.313	83.0	3.355
1988	np	np	80.1	4.260	80.5	1.824
1989	82.3	2.448	np	np	np	np
Stolephorus devisi						
1987	65.8	2.478	79.6	5.151	77.6	4.335
1988	64.6	2.546	69.0	3.301	74.2	2.818
1989	72.9	3.203	np	np	74.9	2.354
Spratelloides delicatulus						
	Munda and Vona Vona (combined)					
1987	np	np				
1988	68.3	4.472				
1989	78.0	6.454				

np = not possible, due to poor fit of data.

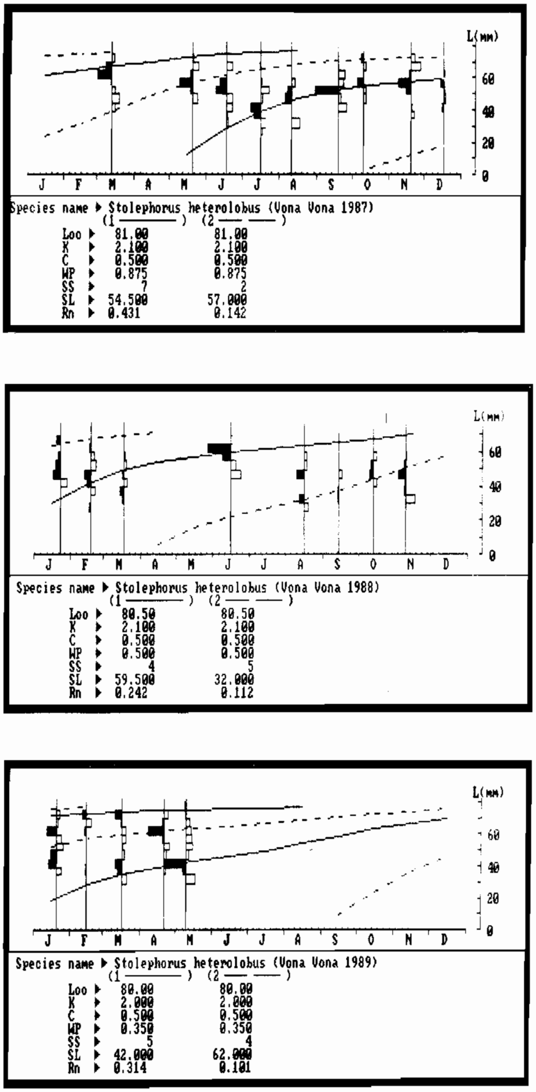


the progression of two major cohorts through the time series each year. The parameters of each pair of curves in each year's data set were very similar between years at each site. The growth curves in each case are drawn against the restructured data, which tends to emphasise modal peaks. Similar plots for *S. heterolobus* for Vona Vona and Tulagi data sets are given in Figures 3a–3c and 4a–4c, respectively. The growth parameters obtained are summarised for these data in Table 4, along with L_∞ and K values estimated for *S. heterolobus* by other authors for comparison. An indication of the comparability of the growth parameters estimated with those of other authors is indicated by the Ø' values calculated after the method of Pauly and Munro (1984).

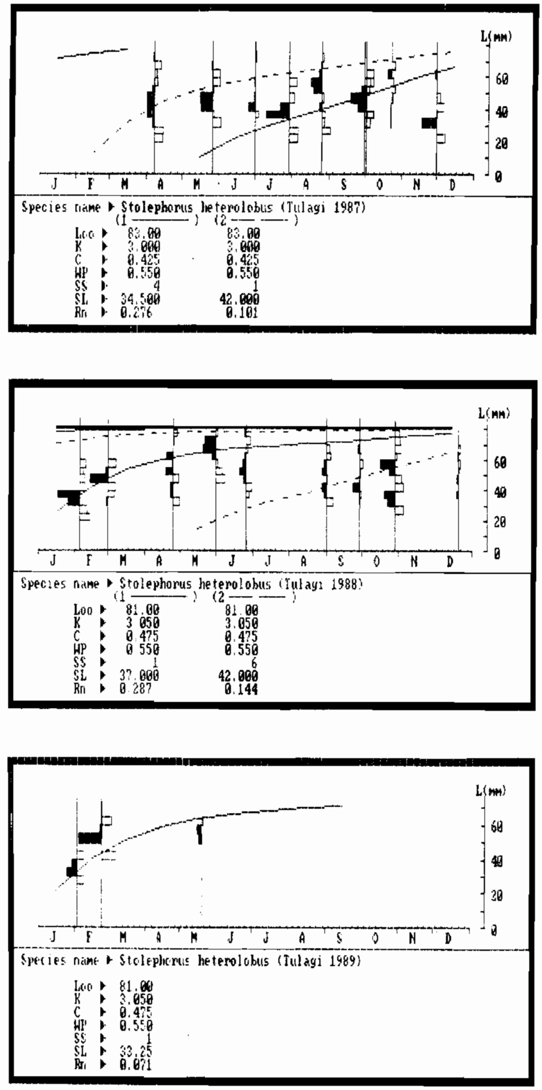
It is apparent that the L_∞ and K values for *S. heterolobus* vary little between years within a site; this has been reported for this species in Papua New Guinea (Dalzell, 1984). Estimated values of K for this species at the non-baitfished Vona Vona Lagoon ranged between 2.0–2.1. These K values are considerably lower than at either of the bait-fished sites, perhaps due to reduced competition at the baitfished areas for food resources, resulting in greater growth rates. Rawlinson (1988), used ELEFAN I to estimate L_∞ and K values at 82.0 mm and 2.4 respectively for *S. heterolobus* from length frequency data collected at Munda during 1985 and 1986.

The growth estimates obtained in the present study are consistent with those of Dalzell (1984) in Papua New Guinea for *S. heterolobus.* Dalzell did not, however, consider growth oscillation due

Figures 2a–2c. ELEFAN I generated von Bertalanffy growth curves for *Stolephorus heterolobus* from Munda, by year (1987–1989).



Figures 3a–3c. ELEFAN I generated von Bertalanffy growth curves for *Stolephorus heterolobus* from Vona Vona, by year (1987–1989).



Figures 4a–4c. ELEFAN I generated von Bertalanffy growth curves for *Stolephorus heterolobus* from Tulagi, by year (1987–1989).

to water temperature fluctuations, which has been included in this analysis. The results show that growth oscillation is important and might reasonably be expected with temperature fluctuations of between 3–4°C during the year (Table 1).

The results obtained here from ELEFAN I are also similar to those of Muller (1977), who worked on *S. heterolobus* in Palau. Wright (1989) estimated growth for this species from Java, Indonesia, based on otolith increment counts. His estimate for K was 0.0057mm/day (or 2.1/yr) which is close to the results obtained in this study and also the work of Muller (1977) in Palau and Tham (1967). Wright found, however, wide discrepancies between growth rates estimated from otolithic aging, modal progression and ELEFAN I; an inability to follow the progression of size modes through the time series data compounded Wright's problems in applying length-based methodologies.

Table 4. Growth parameters estimated for *Stolephorus heterolobus* using ELEFAN I. Also given are ϕ' values calculated using the method of Pauly and Munro (1984).

Year	L_∞	K	C	WP	Rn	ϕ'
			Munda			
1987	82.0	2.4	0.65	0.40	0.124	4.21
	82.0	2.4	0.65	0.40	0.120	4.21
1988	81.5	2.4	0.65	0.60	0.351	4.20
	81.5	2.4	0.65	0.60	0.128	4.20
1989	81.5	2.4	0.65	0.60	0.824	4.20
			Vona Vona			
1987	81.0	2.1	0.50	0.875	0.431	4.13
	81.0	2.1	0.50	0.875	0.142	4.13
1988	80.5	2.1	0.50	0.50	0.242	4.13
	80.5	2.1	0.50	0.50	0.112	4.13
1989	80.0	2.0	0.50	0.35	0.314	4.11
	80.0	2.0	0.50	0.35	0.101	4.11
			Tulagi			
1987	83.0	3.0	0.425	0.55	0.276	4.32
	83.0	3.0	0.425	0.55	0.101	4.32
1988	81.0	3.1	0.475	0.55	0.287	4.30
	81.0	3.1	0.475	0.55	0.144	4.30
1989	81.0	3.1	0.475	0.55	0.071	4.11

Growth parameters from other authors:

Reference:	L_∞	K	Location	Method	ϕ'
Rawlinson, 1988	82.0	2.4	Munda, Solomons	ELEFAN I	4.21
Dalzell, 1984	79.0	2.6	Ysabel Pass., PNG	ELEFAN I	4.21
	87.0	2.4	Cape Lambert, PNG	ELEFAN I	4.26
Muller, 1977	85.0	2.2	Palau	NORMSEP	4.20

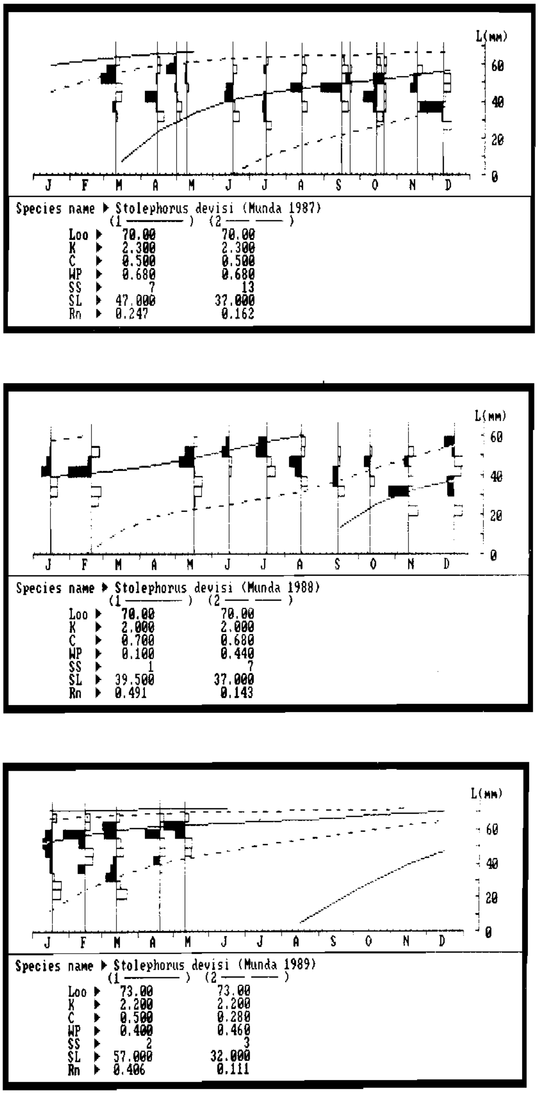
Stolephorus devisi

ELEFAN I output growth curves for S. devisi for Munda 1987–1989 data sets are given in Figures 5a–5c, respectively. Similarly plots for *S. devisi* for Vona Vona and Tulagi data sets are given in Figures 6a–6c and 7a–7c, respectively. The growth parameters obtained are summarised for these data in Table 5. As in the case of *S. heterolobus,* the L_∞ and K values estimated at each site vary little between years. *S. devisi* has a lower asymptotic length when compared to its cogener, *S. heterolobus,* and a slightly slower growth constant. The result from this study are also consistent with those of Dalzell (1984) in PNG for this species. It is perhaps noteworthy that Dalzell's estimate of K for a non-baitfished site, Fairfax Harbour, was lower than K values derived for the two baitfished sites examined, Ysabel Passage and Cape Lambert. In the present study, K values for *S. devisi* were generally between 2.2/yr and 2.3/yr for Tulagi and Munda, and 2.0/yr for fish at the non-baitfished site, Vona Vona.

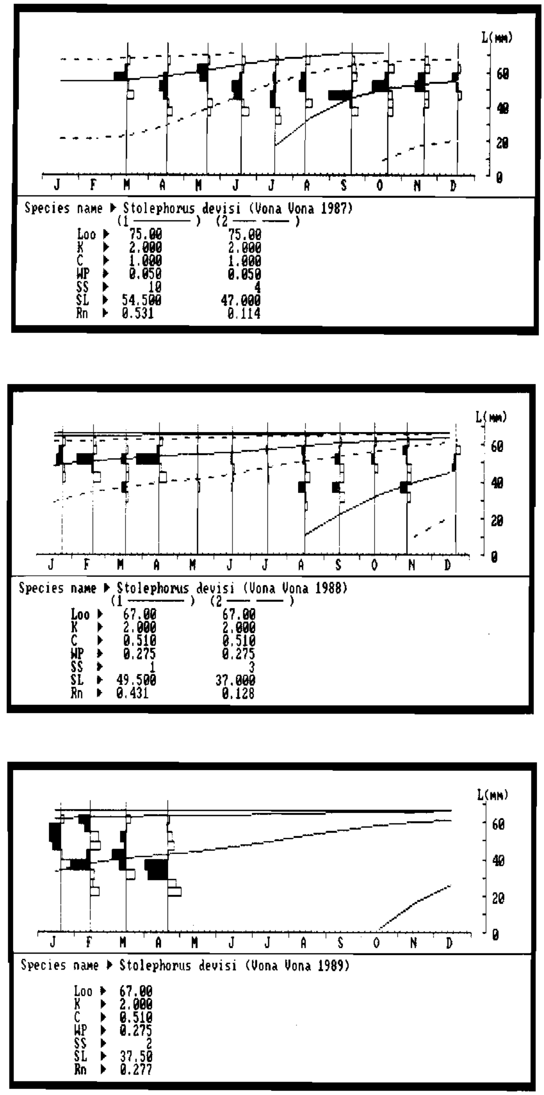
Spratelloides delicatulus

The ELEFAN I output for combined data sets from Vona Vona and Munda for the years 1987–1989 are given in Figures 8a– 8c respectively. A clear progression of modes was apparent in the 1987 combined data set, which gave an estimate of L_∞ at 68 mm and K of 4.5/yr. These growth parameters also afforded the best 'explanation' of the modes in the 1989 combined data set. Combination of the Tulagi data set with the combined length frequency data of Munda and Vona Vona resulted in a confused picture, where no clear progression of modes could be discerned. This is not surprising, considering the more 'oceanic' physical nature of the Tulagi baitground, whereas both Vona Vona and Munda are much more enclosed systems, with a true, shallow lagoon and fringing reef (see Leqata et al., these Proceedings). The generally lower temperature data for Tulagi (Table 1) also indicates the more open nature of this baitground, and this factor probably results in a different growth rate for *S. delicatulus* at Tulagi when compared with the other two sites.

These results are consistent with published data for this species in other areas: Dalzell et al. (1987) estimated L_∞ at 73mm and K at 4.38 for this species in Fiji using ELEFAN I and L_∞ at 73 mm and K at 4.74 using otolithic analysis. Munch-Petersen (1983), using modal progressive analysis, again in Fiji, obtained an L_∞ of 75.0mm and K of 4.4. Table 6 summarises growth parameters and other ELEFAN output parameters for *S. delicatulus.*



Figures 5a–5c. ELEFAN I generated von Bertalanffy growth curves for *Stolephorus devisi* from Munda, by year (1987–1989).



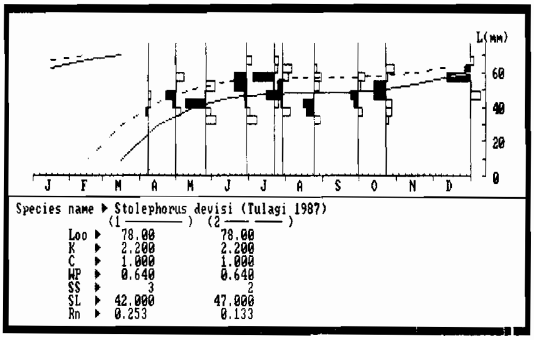
Figures 6a–6c. ELEFAN I generated von Bertalanffy growth curves for *Stolephorus devisi* from Vona Vona, by year (1987–1989).

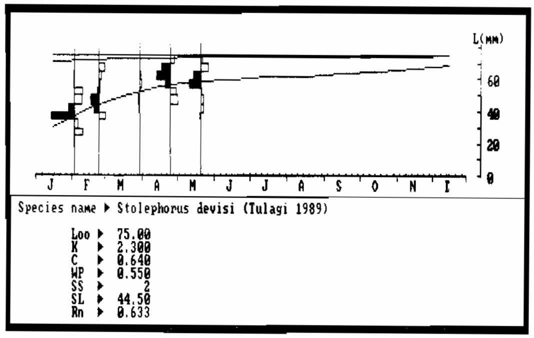
The sprats are a fast growing, short lived group of fishes; the life expectancy of *S. delicatulus* is around six months (Dalzell et al., 1987). Other species of sprat have been shown to have very high growth coefficients: Dalzell and Wankowski (1980) estimated L_∞ and K values for *Spratelloides gracilis,* a dominant species in the Papua New Guinea baitfishery, at 83 mm and 4.38 respectively using modal progression analysis, and Dalzell (1984) made estimates of 76 mm and 4.38 for this species using ELEFAN I. Dalzell (1987) calculated K values for *Spratelloides lewisi* in Papua New Guinea at around 5.44/yr.

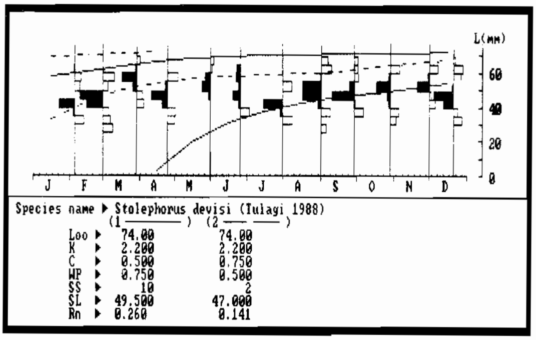
Mortality

Stolephorus heterolobus

Mortality rates estimated for this species were generally high as would be expected for such a short lived fish. Figures 9a–9c (left panels) are length-converted catch curves produced from







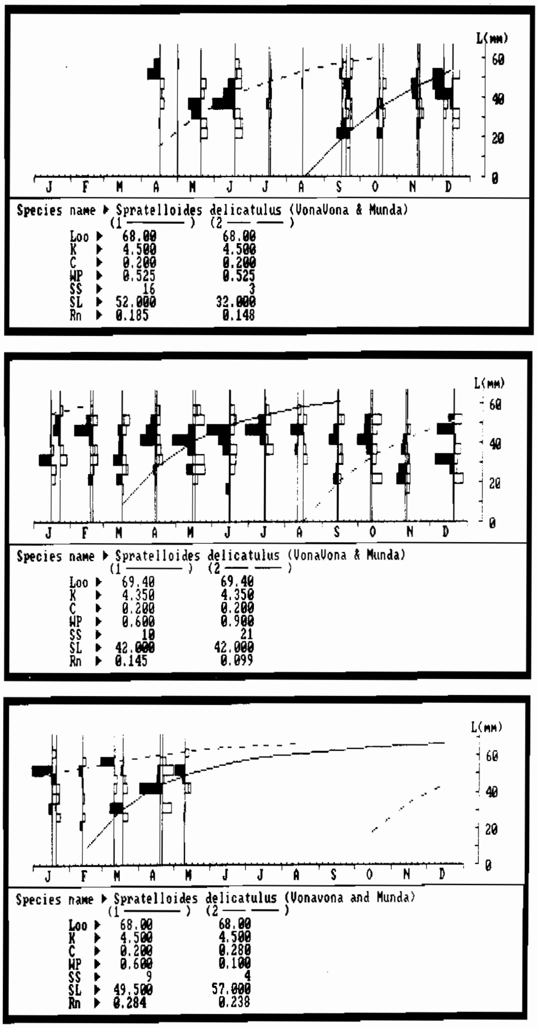
Figures 7a–7c. ELEFAN I generated von Bertalanffy growth curves for *Stolephorus devisi* from Tulagi, by year (1987–1989).

Table 5. Growth parameters estimated for *Stolephorus devisi* using ELEFAN I. Also given are ϕ' values calculated using the method of Pauly and Munro (1984).

Year	L_∞	K	C	WP	Rn	ϕ'
			Munda			
1987	70.0	2.3	0.50	0.68	0.247	4.05
	70.0	2.3	0.50	0.68	0.162	4.05
1988	70.0	2.0	0.70	0.10	0.491	3.99
	70.0	2.0	0.68	0.44	0.143	3.99
1989	73.0	2.2	0.50	0.40	0.406	4.07
	73.0	2.2	0.28	0.46	0.111	4.07
			Vona Vona			
1987	75.0	2.0	1.00	0.050	0.531	4.05
	75.0	2.0	1.00	0.050	0.114	4.05
1988	67.0	2.0	0.51	0.275	0.431	3.95
	67.0	2.0	0.51	0.275	0.128	3.95
1989	67.0	2.0	0.51	0.275	0.279	3.95
			Tulagi			
1987	78.0	2.2	1.00	0.64	0.253	4.13
	78.0	2.2	1.00	0.64	0.133	4.13
1988	74.0	2.2	0.50	0.75	0.260	4.08
	74.0	2.2	0.75	0.50	0.141	4.08
1989	75.0	2.3	0.64	0.55	0.633	4.11

Growth parameters from other authors:

Reference:	L_∞	K	Location	Method	ϕ'
Dalzell, 1984 (PNG)	78.0	2.0	Fairfax Harbour	ELEFAN I	4.10
	75.0	2.4	Cape Lambert	ELEFAN I	4.13
	74.0	2.1	Ysabel Passage	ELEFAN I	4.06



Figures 8a–8c. ELEFAN I generated von Bertalanffy growth curves for combined data from Vona Vona and Munda for *Spratelloides delicatulus*, by year (1987–1989).

ELEFAN II; the right hand panels are the recruitment patterns calculated by the recruitment pattern routine for this species for the 1987 and 1988 data sets. Mortality estimates for this species are summarised in Table 7; total mortality values calculated from the length converted catch curves for 1988 and 1989 are shown rather than Z values calculated from mean length, as the former was found to fit the data better for these years at Munda.

Similar data for Vona Vona and Tulagi for 1987–1989 are given in Figures 10a–10c and 11a–11b, respectively.

The mortality rates calculated lie in the same range as the longer time-series of yearly mortality rates for this species in Papua New Guinea on two heavily baitfished areas: Dalzell (1984) estimated natural mortality (M) for *S. heterolobus* from Pauly's empirical formula to range from 4.4–5.6 for the two baitfished sites under study. These results are very similar to M values calculated for Munda and Tulagi.

Exploitation rates (E) are in the low to medium range. The indication is therefore, that even on a heavily baitfished ground such as Munda, this species, which forms the dominant part of the catch over the year (see Rawlinson, these Proceedings), is only light to moderately exploited by the pole- and-line fleet.

Stolephorus devisi

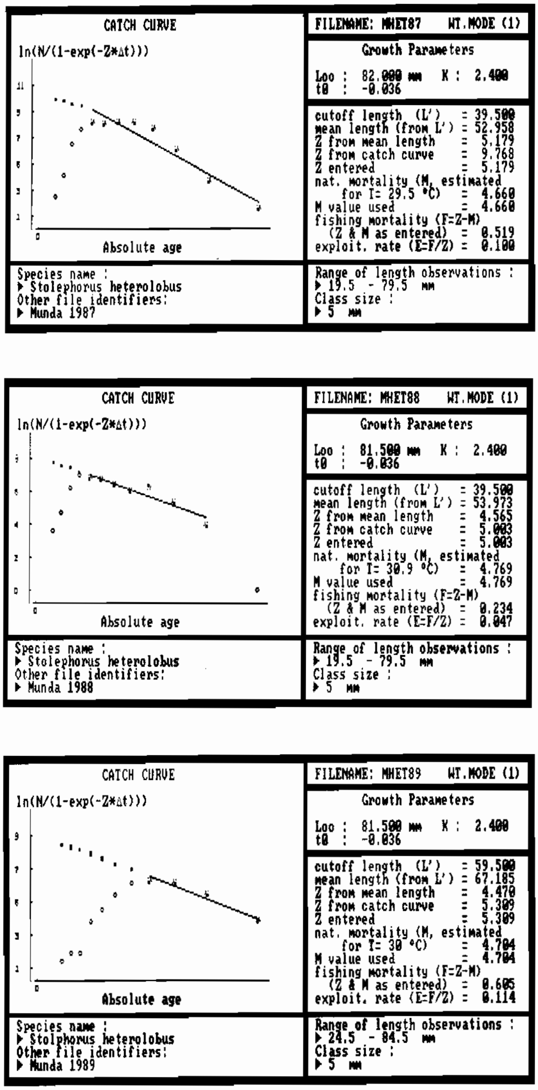
Table 8 summarises mortality estimates for this species for each data set by year and site. Figures 12a–c, 13a–c and 14a–c show catch curves and recruitment patterns for Munda, Vona Vona and Tulagi, respectively, by year. Natural mortality, M, was fairly consistent between sites and between years. Total mortality, Z, varied more for the baitfishing areas, Tulagi and Munda, as might be expected in the face of varying fishing mortality each year. Exploitation rate, E, however, again

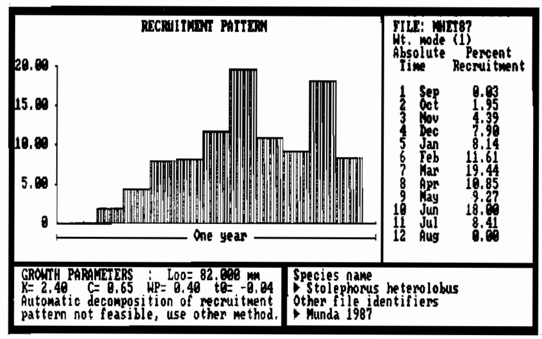
Table 6. Growth parameters estimated for *Spratelloides delicatulus* using ELEFAN I on pooled samples from Munda and Von Vona. Also given are ϕ' values calculated using the method of Pauly and Munro (1984).

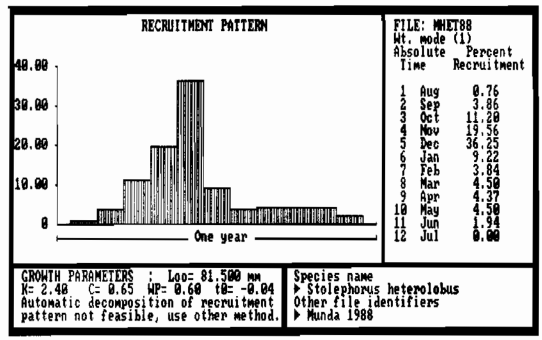
Year	L_∞	K	C	WP	Rn	ϕ'
1987	68.0	4.5	0.20	0.525	0.185	4.31
	68.0	4.5	0.20	0.525	0.148	4.31
1988	69.4	4.35	0.20	0.60	0.145	3.95
	69.4	4.35	0.20	0.60	0.099	3.95
1989	68.0	4.5	0.20	0.60	0.284	4.31
	68.0	4.5	0.28	0.10	0.238	4.31

Growth parameters from other authors:

Reference:	L_∞	K	Location	Method	ϕ'
Munch-Petersen (1983)	75.0	4.4	Fiji	Modal Progression Analysis	4.39
Dalzell et al. (1987)	73.0	4.38	Fiji	ELEFAN I	4.36







Figures 9a–9c. ELEFAN II generated length-converted catch curves (left panels) and recruitment patterns (right panels) for *Stolephorus heterolobus*, by year (1987–1989) for Munda baitground. Recruitment patterns for the incomplete 1989 data set are not included.

indicated that this species is only lightly exploited at each of the baitfishing grounds.

Estimated M values for this species were fairly consistent in the range 4.4–4.7/yr for all three sites. Dalzell (1984) reports much higher M values for *S. devisi* in the range 7.2–7.5/yr for the three sites he investigated, with the highest value, 7.5/yr, applying to the non-baitfished site, Fairfax Harbour.

Spratelloides delicatulus

Table 9 summarises mortality estimates obtained for this species by combining the Vona Vona and Munda length frequency data sets by year. ELEFAN II generated length-converted catch curves for Vona Vona and Munda combined data sets are shown in Figures 15a–15c (left panels), and recruitment patterns (right panels) by year, 1987–1989.

Both total and natural mortalities for *S. delicatulus* were considerably higher than for either of the anchovies, which is consistent with findings for this species in Fiji (Dalzell et al., 1987; Munch-Petersen, 1983), and what might be expected from such a short-lived, fast growing species. The relatively high fishing mortalities, especially for 1988, indicates that when this species is present in a baitground, it suffers very high mortality.

Table 7. Mortality estimates for *Stolephorus heterolobus* using ELEFAN II. Z(1) values were calculated by multiplying Z/K estimates in Table 5 by K value obtained from ELEFAN I; Z(2) values are estimated from mean length given by descending limb of the length-converted catch curve, unless indicated otherwise. Also indicated is exploitation ratio (E = F/Z).

Year	Z(1)	Z(2)	M	F	E = F/Z
Munda					
1987	7.224	5.179	4.660	0.519	0.100
1988	np	5.003*	4.769	0.234	0.047
1989	5.875	5.309*	4.704	0.605	0.114
Vona Vona					
1987	6.957	5.416	4.311	0.000	0.000
1988	8.946	4.033	4.385	0.000	0.000
1989	np	6.882	4.223	0.000	0.000
Tulagi					
1987	10.065	8.805	5.306	3.499	0.397
1988	5.563	5.760	5.469	0.291	0.051
1989	np	np	np	np	—

Mortality rates calculated by other authors:

Reference:	Z/yr	M/yr	Location	Method
Dalzell (1984)	9.6–14.0	6.2	PNG	ELEFAN II
Dalzell (1984)	9.3–10.8	6.2	PNG	ELEFAN II
Muller (1977)	12.8	4.4	Palau	GULLAND, 1969

* Values calculated from catch curve, where catch curve appeared to adequately represent exploited population.
np = not possible, due to poor fit of data.

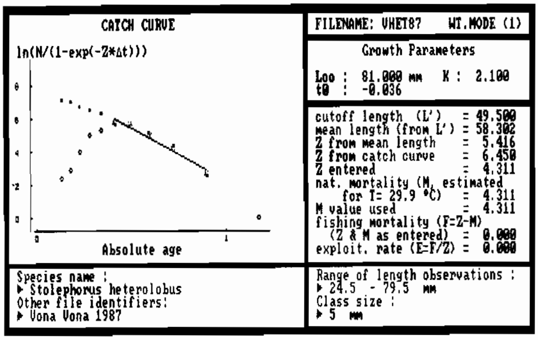
Discussion

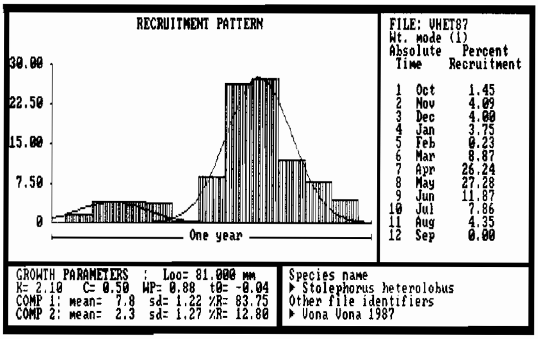
At present, there is no formal control enforced by government on baitfishing activities in Solomon Islands: pole-and-line vessels are free to baitfish on any of the 87 registered baitgrounds in the country and capture as much bait as is necessary for the next day's tuna fishing (Nichols and Rawlinson, these Proceedings). The primary concern of rural fishermen regarding possible adverse effects of baitfishing in Solomon Islands through a reduction of prey items for reef-fish which are important in the rural diet and form a source of food for rural communities is assessed by Blaber et al. (these Proceedings). There is no direct interaction between the baitfishery and the subsistence fisherman, as baitfish are not food items in the diet of Solomon Islanders.

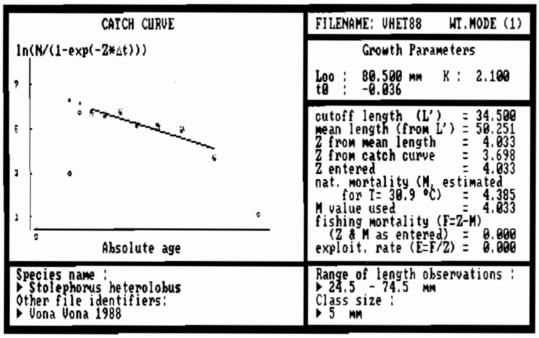
From the results of the present study, the indication is that even on the heavily fished baitgrounds such as Munda and Tulagi, which are close to the tuna shore-bases and therefore favoured by the pole-and-line vessel captains, exploitation of the major species is low to moderate. Table 10 shows that catch by major species at Munda and Tulagi for 1987 and 1988. Munda baitground underwent a decline in use during 1988 with the opening of a new baitground close to the shore base at Noro (and with easier access); hence, the catch of *S. heterolobus* declined from 210.9t in 1987 to 13.8t in 1988. Similarly, the catch of *S. devisi* declined from 63.5t in 1987 to 20.0t in 1988. This decline in catch for the two major species is reflected in the reduced fishing mortality estimate (F) for *S. heterolobus* at Munda in 1988 (Table 7). A similar reduction in F, and hence exploitation rate, is seen for *S. devisi* at Munda in 1988 (Table 8). The length-based estimates of mortality for these two species presented here tie in well with the actual catch statistics, at least for Munda.

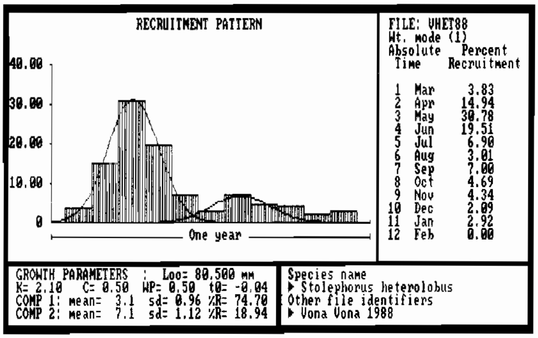
Tulagi baitground appears to be a much less 'stable' site (see Rawlinson and Nichols, these Proceedings). Massive species composition fluctuations and a greater variation in catch per haul both within and between years is common for this baitground. Increasing baitfishing effort in the Tulagi area, which would come about through raising the number of vessels based at Tulagi should be considered with extreme caution.

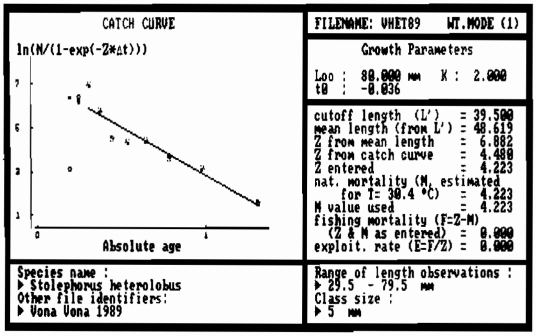
For the baitfishery as a whole, Rawlinson and Nichols present evidence that catch per unit effort, in terms of number of buckets of bait taken for each haul, is relatively constant, even for the most heavily fished baitgrounds, although wide fluctuations in species composition may occur where baitfishing effort is high. It appears, therefore, that the baitfish resource in Solomon Islands is at present well able to sustain the level of fishing effort expended by the national pole-and-line fleet, assuming no increase in deleterious environmental or pollution effects.



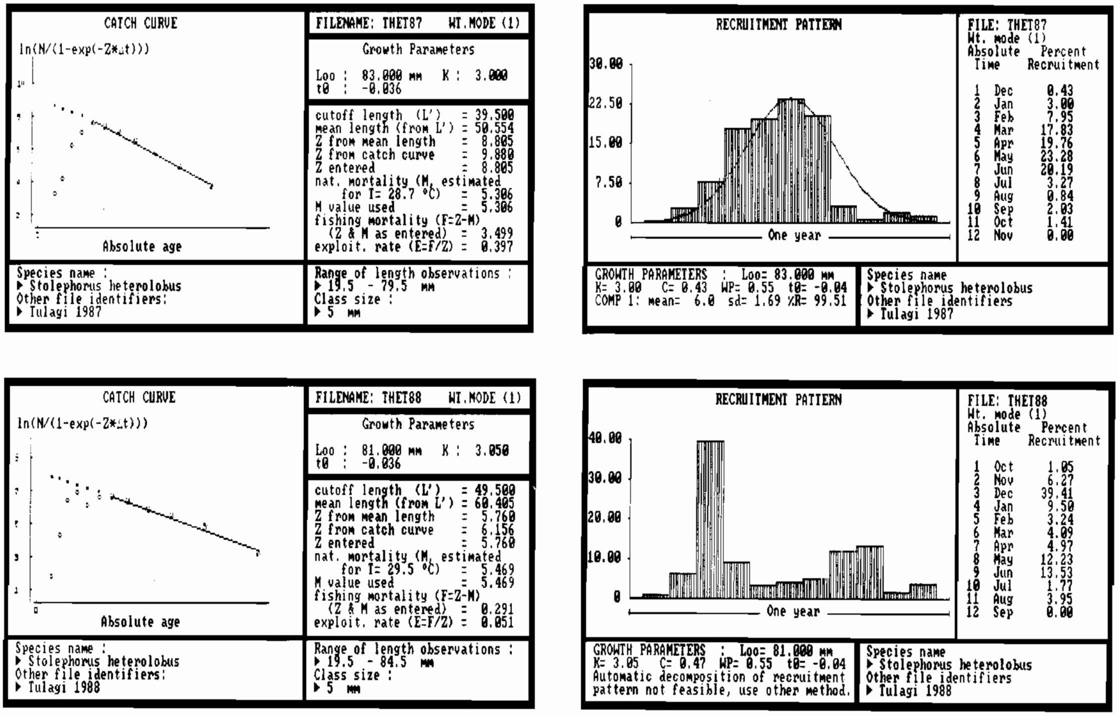








Figures 10a–10c. ELEFAN II generated length-converted catch curves (left panels) and recruitment patterns (right panels) for *Stolephorus heterolobus*, by year (1987–1989) for Vona Vona Lagoon. Recruitment patterns for the incomplete 1989 data set are not included.



Figures 11a–11b. ELEFAN II generated length-converted catch curves (left panels) and recruitment patterns (right panels) for *Stolephorus heterolobus*, by year (1987–1988) for Tulagi baitground. Recruitment patterns for the incomplete 1989 data set are not included.

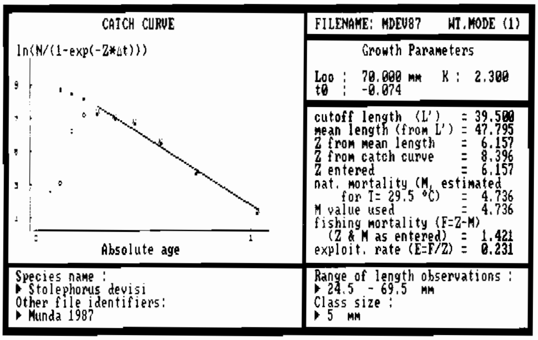
Table 8. Mortality estimates for *Stolephorus devisi* using ELEFAN II. Z(1) values were calculated by multiplying Z/K estimates in Table 5 by K value obtained from ELEFAN I; Z(2) values are estimated from mean length given by descending limb of the length-converted catch curve. Also indicated is exploitation ratio (E = F/Z).

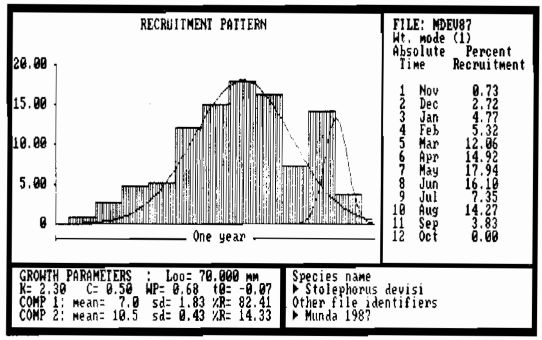
Year	Z(1)	Z(2)	M	F	E = F/Z
Munda					
1987	5.699	6.152	4.736	1.421	0.231
1988	5.092	5.208	4.416	0.792	0.152
1989	7.046	7.043	4.582	2.461	0.349
Vona Vona					
1987	10.302	5.187	4.266	0.000	0.000
1988	6.602	5.791	4.470	0.000	0.000
1989	np	4.613	4.437	0.000	0.000
Tulagi					
1987	9.537	6.171	4.407	1.764	0.286
1988	6.199	6.142	4.530	1.612	0.262
1989	5.414	5.729	4.624	1.105	0.193

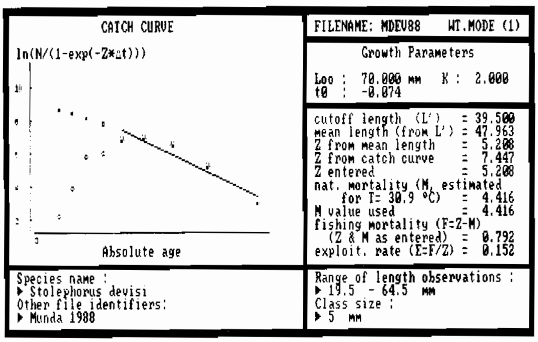
Mortality rates calculated by other authors:

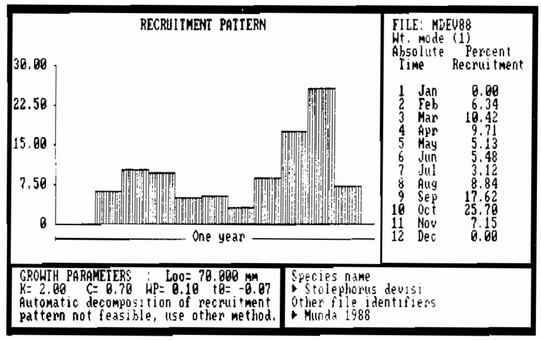
Reference:	Z/yr	M/yr	Location	Method
Dalzell (1984–PNG)	7.5–11.4	7.2	Ysabel Passage	ELEFAN II
Dalzell (1984–PNG)	9.2–10.9	7.4	Cape Lambert	ELEFAN II
Dalzell (1984–PNG)	7.5	7.5	Fairfax Harbour	ELEFAN II

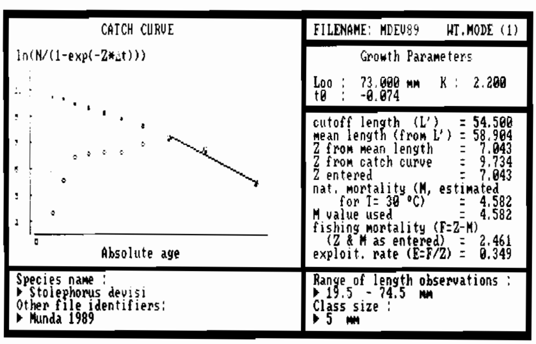
np = not possible, due to poor fit of data.











Figures 12a–12c. ELEFAN II generated length-covered catch curves (left panels) and recruitment patterns (right panels) for *Stolephorus devisi*, by year (1987–1989) for Munda baitground. Recruitment patterns for the incomplete 1989 data set are not included.

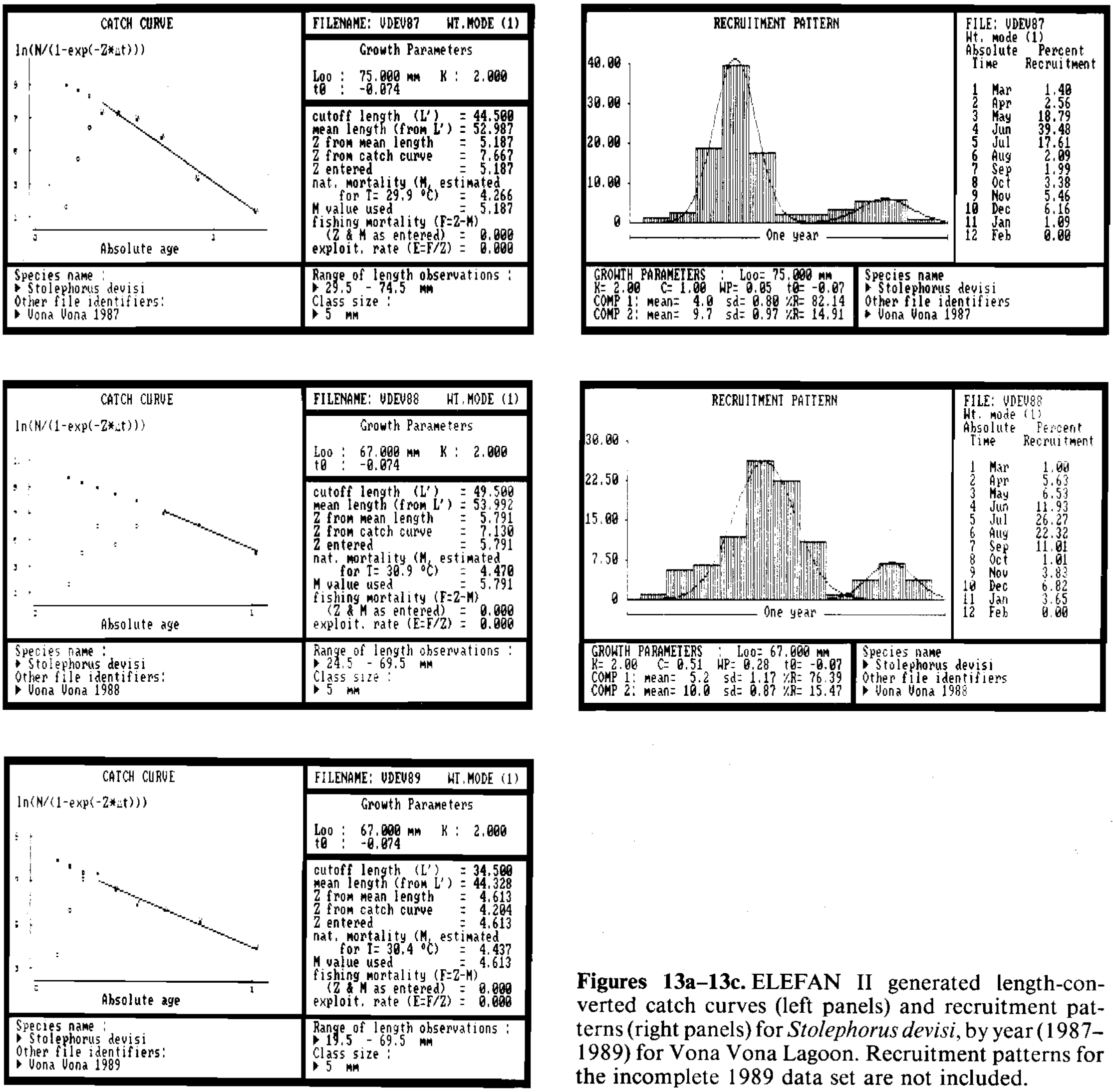
Table 9. Mortality estimates for *Spratelloides delicatulus* using ELEFAN II on combined sample data from Munda and Vona Vona. Z(1) values were calculated by multiplying Z/K estimates in Table 5 by K value obtained from ELEFAN I; Z(2) values were estimated from mean length given by descending limb of the length-converted catch curve. Also indicated is exploitation ratio (E = F/Z).

Year	Z(1)	Z(2)	M	F	E = F/Z
1987	np	11.240	7.430	3.810	0.339
1988	20.124	15.210	7.360	7.850	0.516
1989	29.043	11.117	7.488	3.629	0.326

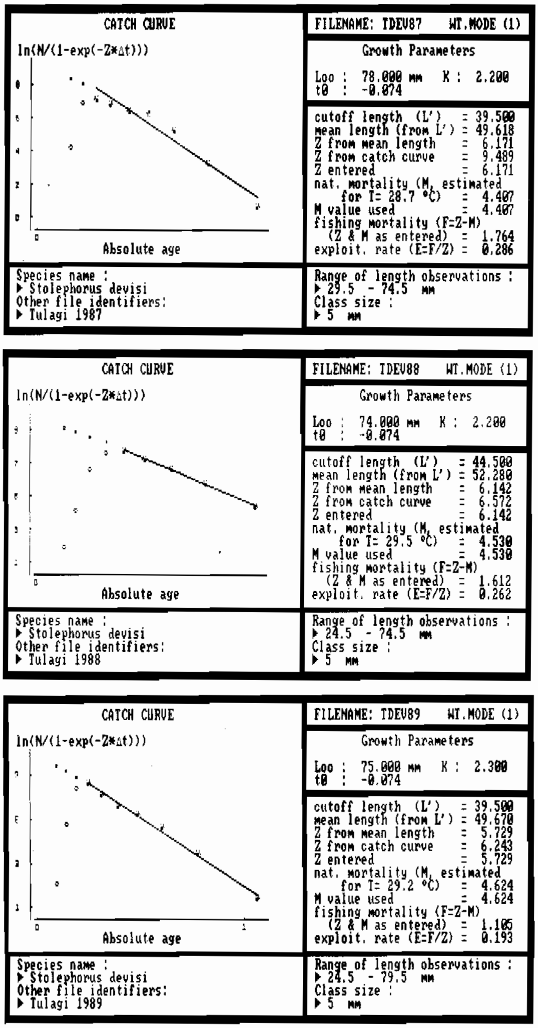
Mortality rates calculated by other authors:

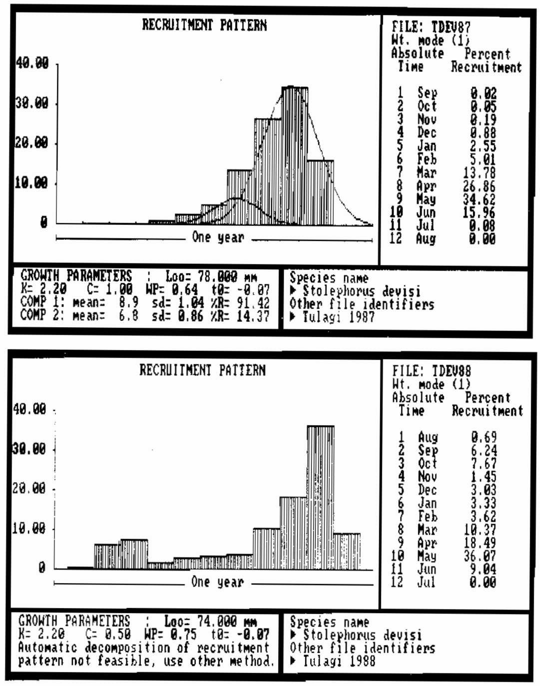
Reference:	Z/yr	M/yr	Location	Method
Dalzell et al. (1987)	9.9	6.9	Fiji	ELEFAN II
Munch-Petersen (1983)	10.3		Fiji	Not known

np = not possible, due to poor fit of data.



Figures 13a–13c. ELEFAN II generated length-converted catch curves (left panels) and recruitment patterns (right panels) for *Stolephorus devisi*, by year (1987–1989) for Vona Vona Lagoon. Recruitment patterns for the incomplete 1989 data set are not included.





Figures 14a–14c. ELEGFAN II generated length-converted catch curves (left panels) and recruitment patterns (right panels) for *Stolephorus devisi*, by year (1987–1989) for Tulagi baitground. Recruitment patterns for the incomplete 1989 data set are not included.

Table 10. Catch and effort data for baitfishing operations at Munda and Tulagi baitgrounds during 1987 and 1988. Composition of total weight by major bait species is indicated.

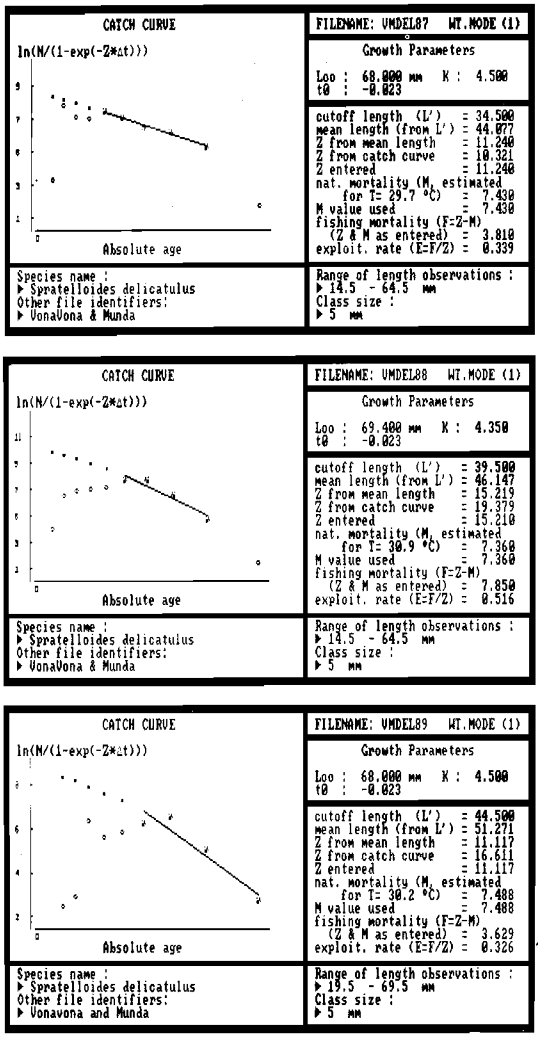
	Catch (t):	
	1987	1988
Munda baitground		
Stolephorus heterolobus	210.9	13.8
Stolephorus devisi	63.5	20.0
Spratelloides delicatulus	10.6	8.3
Total catch (all species)	441.1	75.0
Total effort (hauls)	5 815	792
Tulagi baitground		
Stolephorus heterolobus	38.8	43.7
Stolephorus devisi	34.6	120.4
Spratelloides delicatulus	5.6	2.3
Total catch (all species)	181.4	285.4
Total effort (hauls)	3 173	3 588

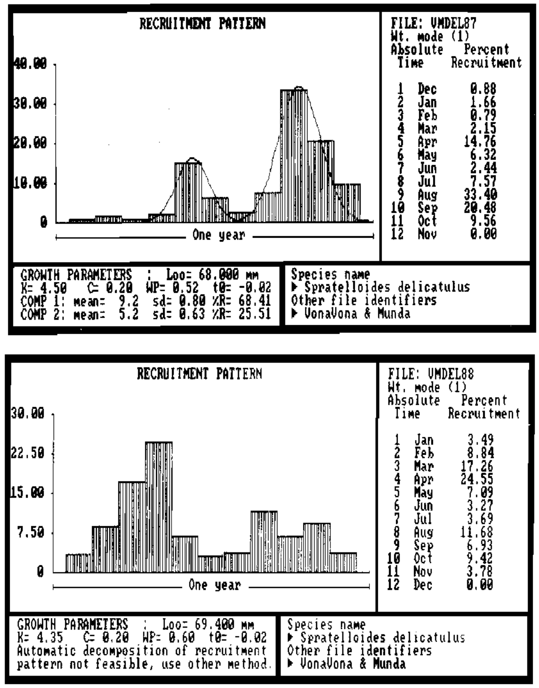
Unless baitfishing effort increases substantially in the country, it is not likely that formal management options, such as restricted effort, will be necessary, except possibly in the case of individual baitgrounds upon which baitfishing effort is significantly higher than the national average.

Further work to estimate sustainable yields for the major species at the important baitfishing grounds in Solomon Islands would be a useful exercise.

Acknowledgments

We would like to thank the communities of Vona Vona, Munda and Tulagi for their help and participation in this study. Special thanks are due to the members of the Collenson, Hitu and Hiva





Figures 15a–15c. ELEFAN II generated length-converted catch curves (left panels) and recruitment patterns (right panels) for combined data from Vona Vona Lagoon and Munda baitground for *Spratelloides delicatulus*, by year (1987–1989). Recruitment patterns for the incomplete 1989 data set are not included.

families, to Aleke Meloty, Fisheries Officer for Tulagi, Solomon Taiyo Ltd. and National Fisheries Developments Ltd. for their help, hospitality and logistical support.

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Age and Growth of Major Baitfish Species in Solomon Islands and Maldives

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Abstract

Otoliths of the major baitfish species in Solomon Islands and Maldives were examined and the number of increments counted. The number of increments in the otoliths were related to length in all species. Several experiments were undertaken to validate that increments were deposited daily. The results of these experiments are discussed, in relation to the growth curves of each species derived from counts of otolith increments. For *Stolephorus* species, these curves were not consistent with those inferred from length–frequency analysis. Possible reasons for these differences are discussed. Growth increments in *Spratelloides delicatulus* have been previously validated as daily. Growth in this species and other *Spratelloides* species was rapid and fish do not live more than five months. There was good agreement between the inferred growth curves from length–frequency analysis and those derived from daily aging. Growth varied between sites and countries for these, and other baitfish species. However, these differences were not related to the intensity of baitfishing, but probably reflected differences in the local environment at each site.

To effectively manage any fishery, it is essential that the status of the stock being exploited is well known. Knowledge of the age structure and growth pattern in the population is necessary before a stock assessment study is undertaken. Most fisheries management relies on estimates of population parameters, including growth, derived from the analysis of length-frequency data (e.g. Ricker 1975). Growth parameters are inferred from the change in the modal length over a series of samples. This approach is relatively cheap and does not require expensive or complicated equipment, but suffers from inadequacies due to potential sampling errors, and subjectivity during analysis of the data.

An alternative method for smaller species involves examining fish hard parts, including otoliths, in which regular increments are deposited (Panella 1971) and assumed to be laid down daily. This has the advantage that it is a direct measure of the age of a fish and a growth curve can be generated from a small sample of fish over the length range of the species. However, the results are only reliable if the rate of increment deposition has been validated. There have been few studies of the otoliths of baitfish (*Stolephorus* species and *Spratelloides* species) (Dalzell and Wankowski 1980; Conand 1988; Wright 1989) and daily increments have only been validated in *Spratelloides delicatulus.* All previous stock assessment of tuna baitfisheries have been based on analysis of length–frequency data. The aims of this study were to: (1) examine the otoliths of three major baitfish species — *Stolephorus heterolobus, Spratelloides delicatulus* and *S. gracilis* — from several sites in Solomon Islands and Maldives and count the increments; (2) to validate the daily increments in the otoliths of these fish; and (3) to compare the growth curves generated from

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counts of otolithic increments with those inferred from analysis of length-frequency data.

Materials and Methods

Sampling

Samples of up to 100 of each of *Stolephorus heterolobus, Spratelloides delicatulus* and *S. gracilis* from Solomon Islands (three sites), and Maldives (up to two sites) and *Spratelloides delicatulus* from Tarawa lagoon, Kiribati were collected monthly from the commercial baitfisheries. Sampling methods have been described elsewhere (Rawlinson and Nichols and also Maniku et al., these Proceedings). Samples were preserved in 70% ethanol and returned to the laboratory for otolith examination.

Analysis

In the laboratory, fish were measured (S.L. mm), sexed and both sagittae and lapillae were removed, cleaned of excess tissue and mounted in immersion oil on microscope slides. Otoliths from each fish were assigned a sequential code for identification. Otoliths were then allowed to clear in oil for at least two days before counts of internal bands were made. The internal structure of the otoliths were examined using a video camera and monitor mounted on a compound microscope. A polarising filter was also used to enhance the image. Bands were counted at 400× magnification. For each otolith counted, the axis which was counted, and areas of the otolith where possible errors in counting may have occurred, were noted. A random subsample (approximately 30%) were re-counted after at least two days to validate counts. Any otoliths which varied by more than 5% between counts, were re-counted a third time and the median value taken.

Validation Experiments

To validate whether bands observed within baitfish otoliths were laid daily, three techniques were used. Firstly, a sequential series of samples were taken from Munda during October 1987. A single modal length class of juvenile *Stolephorus* was identified and otoliths of fish from this presumed single cohort were removed from fish sampled over ten days. The change in the modal number of increments was compared to the number of days between samples. Secondly, at least 50 *Spratelloides delicatulus* were collected and maintained in aerated aquaria and fed on wild caught zooplankton for three days. They were then immersed in tetracycline treated seawater for 12 hours (250mg l^{-1}; Schmitt 1984). This compound is incorporated at sites of calcium deposition, such as otolith margins (Pitcher 1988) and can be detected as it fluoresces under ultraviolet light. Fish were then maintained for a further two weeks and a subsample of fish were removed every two days and preserved in 70% ethanol. Tetracycline marked otoliths were then prepared in a similar way to other otoliths but were examined under a UV-microscope. The final validation experiment involved:

(1) maintaining at least 250 of each of *Stolephorus devisi* and *S. heterolobus* in large sea cages and feeding them skipjack tuna eggs that had been soaked in strontium chloride (0.5g/l) for 24 hours prior to feeding. The fish were then maintained for a further two weeks on twice daily rations of untreated eggs.

(2) 300–400 juvenile *Spratelloides gracilis* and *Stolephorus* species were held in a 1.5×1×1m tank and immersed in strontium treated seawater (0.5g/l) for 24 hours. All water was then replaced and the tank flushed to remove any contamination. Fish were then fed skipjack eggs to excess twice daily for 11 days before preservation in 70% alcohol. Any fish which died during the experiment were also preserved in alcohol. Strontium has a stronger affinity for bases than calcium and replaces it at deposition sites. Otoliths of fish immersed in strontium were cleaned, embedded in polyester resin and ground using successively finer grade wet/dry sandpaper to expose the primordial axis. The surface of the otolith was then polished using aluminium oxide pastes (8 and 1μ). Otoliths were coated in carbon prior to x-ray microscopy to determine strontium distribution and density. After x-ray microscopy, otoliths were etched with 1% (V/V) hydrochloric acid and recoated with carbon prior to using scanning electromicroscopy to examine internal bands. The number of bands between the zone of maximum strontium activity and the outer edge of the otolith were compared to the number of days of the experiment. Published data for Papua New Guinea, New Caledonia, Kiribati and India were compared with the results reported here.

Results

Otoliths of 2 026 fish of the three species from three countries were removed and the number of increments counted. The relationship between fish length and presumed age (in days) (Table 1; Figs 1–3) showed considerable variation within and between species. Exponential curves of the form $Length = a * Age^b$ adequately described the form of the growth curve for most species at most sites.

Stolephorus heterolobus

There was considerable variation in growth between sites. *S. heterolobus* grew faster at Munda ($P<0.001$) than at other sites. Maldivian *S. heterolobus* grew at a slower rate than fish from Solomon Islands ($P<0.005$) although the length range of the specimens examined from the Maldives was restricted (Fig. 1). There was also a wide discrepancy between the growth curves from the otolithic increment data and the growth curve generated from analysis of length–frequency data (Tiroba et al., these Proceedings; Fig. 1).

Spratelloides

Of the species examined, *S. delicatulus* was the most widely sampled and growth rates varied

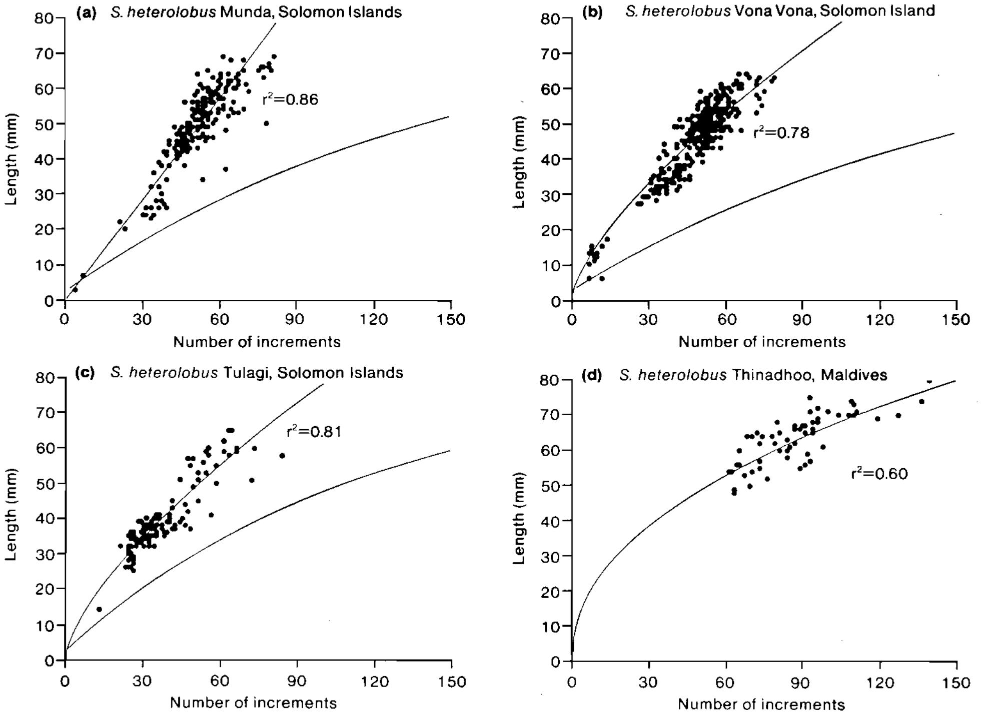


Figure 1. The plot of length versus the number of otolith increments in four populations of *Stolephorus heterolobus* from Solomon Islands (a-c) and Maldives. The von Bertalanffy growth curves derived from the analysis of length-frequency data (Tiroba et al., these Proceedings) are also shown for the three sites from Solomon Islands (a-c).

Table 1. Growth equations for the best fit of length (L) and age (A) based on daily aging of otoliths (S.I. = Solomon Islands; Corr. = correlation coefficient; N = sample size).

Species	Country	Site	Length range (mm)	Equation	Corr.	N
Stolephorus heterolobus	S.I.	Munda	3–69	$L=0.92A^{1.01}$	$r^2=0.86$	203
		Vona Vona	6–64	$L=3.03A^{0.70}$	$r^2=0.78$	302
		Tulagi	14–65	$L=3.43A^{0.68}$	$r^2=0.81$	125
	Maldives	Thinadhoo	47–80	$L=8.41A^{0.45}$	$r^2=0.60$	59
Spratelloides delicatulus	S.I.	Munda	18–64	$L=1.72A^{0.72}$	$r^2=0.84$	118
		Vona Vona	17–56	$L=2.39A^{0.65}$	$r^2=0.85$	249
		Tulagi	27–63	$L=4.77A^{0.50}$	$r^2=0.65$	153
	Maldives	Ari	40–57	$L=2.08A^{0.65}$	$r^2=0.77$	100
	Kiribati	Tarawa	18–62	$L=3.26A^{0.59}$	$r^2=0.90$	104
Spratelloides gracilis	S.I.	Munda	16–61	$L=2.13A^{0.68}$	$r^2=0.55$	121
		Vona Vona	14–56	$L=1.27A^{0.92}$	$r^2=0.62$	158
		Tulagi	18–58	$L=20.7A^{0.13}$	$r^2=0.03$	100
	Maldives	Alifushi	31–62	$L=0.30A+25.7$	$r^2=0.39$	129
		Thinadhoo	28–68	$L=0.43A+25.3$	$r^2=0.41$	60

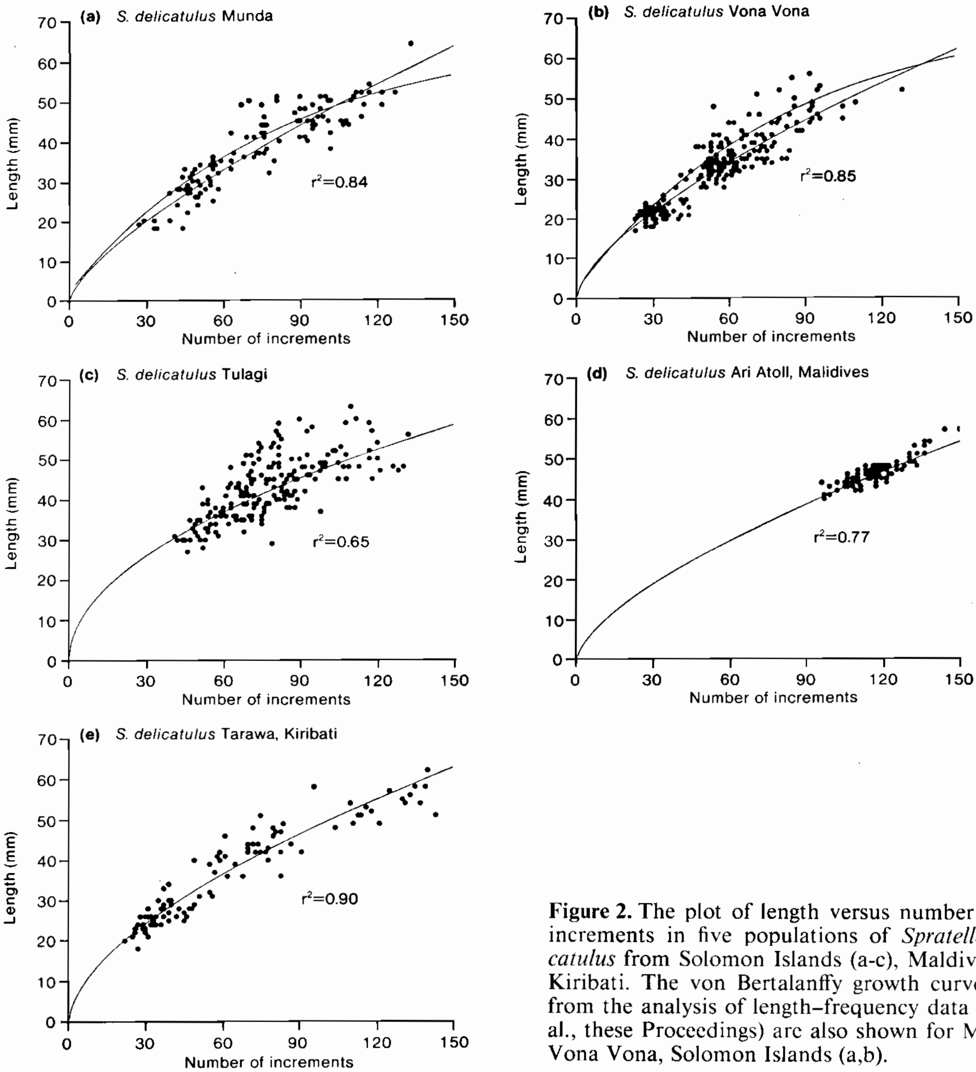


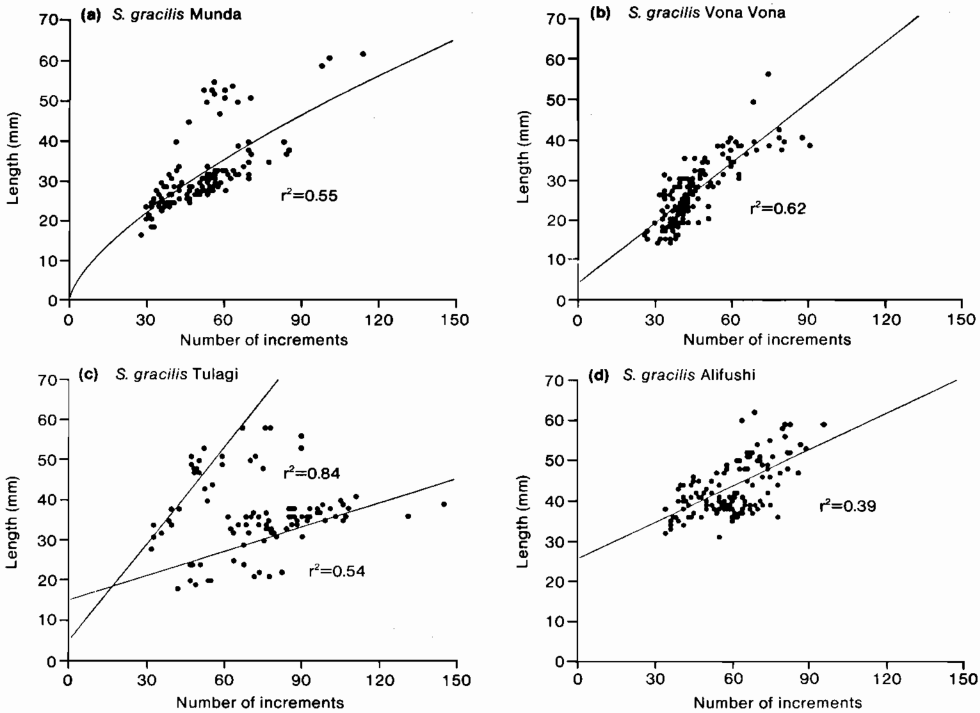
Figure 2. The plot of length versus number of otolith increments in five populations of *Spratelloides delicatulus* from Solomon Islands (a-c), Maldives (d) and Kiribati. The von Bertalanffy growth curves derived from the analysis of length–frequency data (Tiroba et al., these Proceedings) are also shown for Munda and Vona Vona, Solomon Islands (a,b).

between sites (Table 1; Fig. 2). Growth was fastest at Munda and Vona Vona in Solomon Islands and at Ari Atoll in Maldives. Fish from these sites grew faster than those at Tulagi ($P<0.05$). Munda fish also grew faster than fish from Tarawa, Kiribati ($P<0.01$). There was good agreement between the growth curves derived from otolithic and length–frequency data (Fig. 2 a,b).

S. gracilis showed exponential growth among fish sampled at Munda and Vona Vona in Solomon Islands. For the length ranges examined, fish grew linearly at Tulagi, Solomon Islands and at two sites in Maldives. Growth was faster at Vona Vona than Munda ($P<0.05$). Among the samples of fish which showed linear growth, fish from the May 1987 Tulagi sample grew faster than fish from either Maldivian sample, or the samples from Tulagi taken in March, 1988 ($P<0.05$). There was no difference between the growth rates of fish from the two Maldivian sites.

Validation Experiments

Samples of juvenile *Stolephorus* were taken on 13, 16 and 20 October 1987 from Munda, Solomon Islands. No distinct modal length group could be detected, so the smallest 20 fish collected on each date were analysed on the assumption that they formed a single cohort. The mean age increased from 32.8 ± 0.4 increments on 13th to 35.0 ± 0.8 on 16th and 37.4 ± 0.4 on 20th. The increase in the number of increments between 13th and 16th



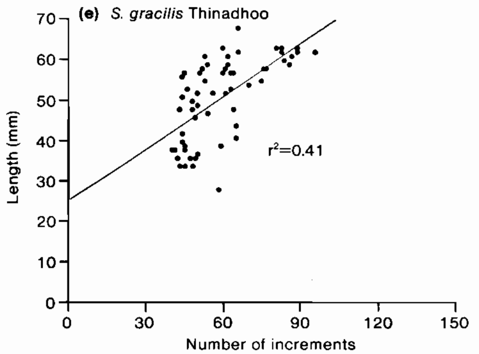


Figure 3. The plot of length versus number of otolith increments in five populations of *Spratelloides gracilis* from Solomon Islands (a-c) and Maldives (d,e).

or between 16th and 20th were not significantly different from one increment each day ($P>0.10$). However, the difference in the number of increments between 13th and 20th was significantly less than 7 (the number of days) ($P<0.05$).

Otoliths from 32 *S. delicatulus* which had been immersed in tetracycline treated seawater for 12 hours and maintained for up to 14 days were examined under UV-microscopy in an attempt to compare the number of increments in otoliths since tetracycline marking with the number of days elapsed. No tetracycline zone could be detected on any sagittae or lapillae.

In the sea-cage experiment, fish were maintained for up to 12 days and fed voraciously on the skipjack tuna eggs which were offered twice daily. However, at the end of the experiment no *Stolephorus* species remained alive in the cage, although several other species survived and were preserved for age validation studies. High mortality of *Stolephorus* juveniles was also experienced in the tank experiment, especially in the first two days. From an initial sample of over 100 fish, only four *Stolephorus* survived more than two days and these were processed for x-ray microscopy. Fifteen *Spratelloides delicatulus* and *S. gracilis* survived for 11 days. The x-ray microscopy scans (Fig. 4) showed that strontium was incorporated into the otoliths of each species. However, there was some variation between individuals in the

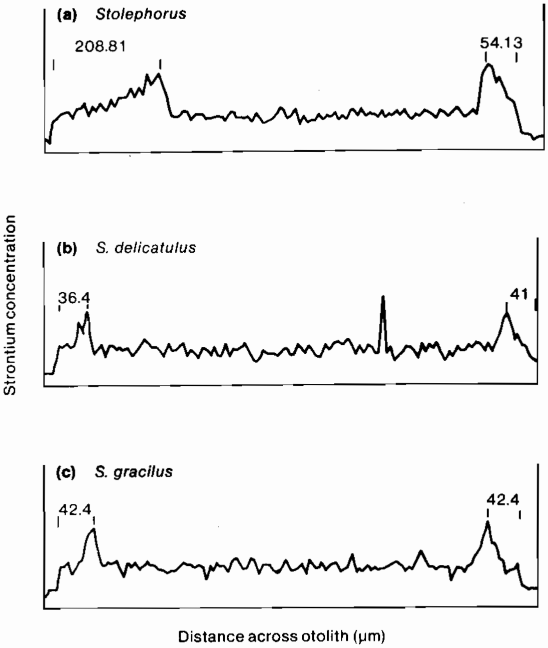


Figure 4. The change in strontium concentration across the surface of the sagittae of (a) *Stolephorus* species, (b) *Spratelloides delicatulus* and (c) *Spratelloides gracilis* using x-ray microscopy. Figures correspond to the distance (in μm) from the outer edge of the otolith to the point of maximum strontium incorporation.

amount and pattern of strontium incorporation. One *Stolephorus* juvenile did not take up any strontium and another had an increased strontium concentration over a wide band within the otolith. As a result, only two *Stolephorus* juveniles could be used for age validation. Of these, one had twelve increments and the other six increments between the site of strontium uptake and the outer edge of the otolith.

Discussion

Growth in Stolephorid anchovies and *Spratelloides* has been widely examined throughout the south Pacific. Almost all analyses have been based on the analysis of length-frequency data using ELEFAN. The results of these studies have been similar, suggesting that growth in these fish can be adequately described by the Von Bertalanffy growth function and that for *S. heterolobus,* fish live for up to 9–10 months and have growth constants (K) of 2.08–2.6 $year^{-1}$ (Tham 1966; Burhanuddin et al. 1975; Muller 1977; Dalzell 1984; Tiroba et al., these Proceedings). Conand (1988) and Dalzell and Wankowski (1980) examined otoliths of *S. heterolobus* but both had difficulty in interpreting the observed increments. However, Conand (1988) estimated the growth constant (K) from length-frequency data to be between 3.7–4.8 $year^{-1}$. These values would be consistent with the growth rates from the otolithic aging in the present study (Fig. 1).

Growth parameters for *Spratelloides delicatulus* have been estimated for fish from Fiji (Munch-Petersen 1983; Dalzell et al. 1987). Both studies estimated parameters from length-frequency data and derived values of K=4.38 $year^{-1}$. Dalzell et al. (1987) also examined otoliths from a range of fish and the estimate of K was higher (4.74) than estimated from length-frequency analysis. A similar pattern was found among Solomon Islands fish (Fig. 2; Tiroba et al., these Proceedings). Although no value of K was calculated from the aging data, there was good agreement in the growth curves derived independently from otolithic aging and the length-frequency analysis (Fig. 2). As the otolithic increments have been previously validated to be daily (Schmitt 1984), the asymptotic length (L_∞) estimated from the aging data are unrealistic suggesting that mortality may be so high that no individual survives to a length which approaches L_∞, or the von Bertalanffy growth equation is not appropriate for these fish.

There were insufficient data to derive estimates of the growth parameters for *S. gracilis* from length-frequency data in Solomon Islands or Maldives (Tiroba et al., Maniku et al. these Proceedings). However, the otolithic aging suggests that growth in *S. gracilis* was highly variable in Solomon Islands, both between sites and within a site (Fig. 3; Table 1). Other studies (Dalzell 1984, 1987) of growth of *S. gracilis* in northern Papua New Guinea derived growth parameters from both length-frequency and otolithic aging data. Both studies estimated the growth constant (K) at 4.38 $year^{-1}$ which was similar to the growth rate derived for *S. gracilis* from Munda using otolithic aging (Fig. 3a). The validation that the increments in the otoliths of *S. gracilis* are deposited daily further strengthens the argument that these fish may not conform to the von Bertalanffy growth equation. Where we had data for only adult fish (e.g. Maldives) the plots of length against age were linear (Fig. 3 d,e).

Overall, the results indicate that for each species, the number of otolithic increments was related to length. The rate of increment formation was verified as daily in *S. delicatulus* and *S. gracilis.* Due to poor survival and variable strontium uptake, the rate of increment deposition by *Stolephorus* could not be verified. However, the data suggest that the growth rate in these species may be similar to that of *Spratelloides.* These data confirm that growth in these small fish is rapid and highly variable. *Spratelloides* do not survive beyond five months and their growth pattern may not be adequately described by the von Bertalanffy equation. Validation of the rate of increment deposition in *Stolephorus* will be extremely important as baitfish stock assessments until now have been based only on length-frequency plots from ELEFAN which indicated that fish grow much more slowly than the otolithic data would suggest.

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Growth, Size and Age Composition of *Stolephorus heterolobus* in North Central Java

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Abstract

The growth, size and age composition of the anchovy, *Stolephorus heterolobus,* landed by bagan tancaps (static lift-nets) at Jepara, northern central Java were studied. A total of 12 320 specimens of *S. heterolobus* were collected from a regular sampling program of bagan landings between November 1983 and June 1985. Daily increments of the sagitta otolith were used to investigate the growth and age composition of the exploited stock. Post larval (>24 mm TL, 70 days old), juvenile and adult stages were landed by the fishery, although only juveniles above 120 days old were fully selected by the gear. Juvenile stages (33–42 mm TL, 109–192 days old), were found in almost all monthly samples, indicating that recruitment into the stock was virtually continuous. Furthermore, juveniles formed the majority of the anchovy catch in terms of both numbers (64%) and biomass (52%). Significant numbers of adults were found only in 7 of the 21 monthly samples. Total mortality, as estimated from age converted length frequency data, was high although similar to that reported in other exploited stocks. The implications of the bagan fisheries reliance on recruiting age-classes is discussed in relation to stock stability.

Stolephorus heterolobus (Ruppell, 1837) is a small anchovy that inhabits coastal regions throughout the tropical Indo-West Pacific Oceans (FAO, 1974). In Indonesia, where *S. heterolobus* dominates the anchovy community in many parts of the archipelago (Burnhanuddin et al., 1975; Sumadhiharga, 1978; Willoughby et al. 1984), species of *Stolephorus* comprise the second largest catch by weight of any genus of fish, with a total landing in excess of 98 000 tonnes (Anon. 1981). On the north coast of Java this species comprises the majority of the catch taken by the bagan tancap (fixed lift-net) fishery (Burnhanuddin et al., 1975; Willoughby et al. 1984). The bagan fishery uses light attraction to catch many small species (usually less than 100 mm TL), including other anchovies of the genus *Stolephorus.* On the north Central coast, near Jepara, densities of over 15 bagans per hectare operate in 5–20 metres of water during the west monsoon (Willoughby et al. 1984).

A regulation to ban bagan fishing throughout Indonesia was introduced by the Government in 1971 (Fishing regulation F.1/1/2/19/71), although in many regions such as Jepara, this ban has not been implemented. Concern about possible recruitment overfishing due to the use of fine meshed nets (3–5 mm) was one of the reasons given for this ban. However this concern has not been investigated because very little is known about these exploited fish stocks. In the Jepara region, unpublished data on landings at Jepara suggest that there is cause for concern as a decline in landings from 2592 tonnes in 1979 to 453 tonnes in 1981 has been reported (Willoughby et al., 1984).

In this paper we examine the growth and age composition of *Stolephorus heterolobus* landed by bagan tancaps at Jepara. No direct method of aging this species has been verified, although microscopic otolith increments have been

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reported (Muller, 1976). Therefore we assessed the periodicity of these otolith increments prior to using them in our investigation.

Methods

Sample collection

Specimens of *S. heterolobus* were obtained from static lift-net (*bagan tancaps*) catches at two fish markets in Jepara, north Central Java. Samples of lift-net catches comprising sub-samples from five to eight catches, and where possible catches from different days, were taken monthly from November, 1983 to June, 1985. 11 959 fish were collected over the 21 month sample period and from these the sagittae of 291 individuals were removed for increment counts.

Specimens for size/frequency analysis were fixed in 10% neutral buffered formalin, whilst specimens for age determination were preserved in 75% iso-propanol in sea water. Fresh length/preserved length and fresh weight/preserved weight indices were calculated and all size data were converted to fresh size.

Age and growth studies

Sagittae were extracted from a representative size range of fish collected in four samples. Otoliths from larvae caught by a plankton survey of the region were also examined. Larval otoliths were teased from surrounding tissue with a mounted entomological pin and mounted in immersion oil. Otoliths from larger speciments (>20 mm TL) were cleaned with sodium hypochlorite, washed, dried and cleared in immersion oil. Dense sagittae were ground with a graded series of alumina oxides, after partial embedding in epoxy resin, before being cleared in immersion oil.

Sagittae were examined at magnifications of either 400 or 1000x. Three counts of both large and small increments were made for each sagitta and only counts which were sufficiently similar (<5% difference between three counts of each pair) were used in analysis.

Validation of increment periodicity

1) Synchronisation of increment deposition

Daily increment deposition is generally believed to be entrained to cyclic environmental cues (Campana and Neilson, 1985). Therefore fish experiencing the same environmental conditions would be expected to show synchronisation of increment deposition (Geffen, 1987). To determine if increment deposition was synchronised within the population of *S. heterolobus,* a comparison of the state of increment deposition of the outermost increment was made for fish collected around the same time of day. Sagittae from all larvae together with 30 postlarvae caught between 0200 and 0500 h were photographed using a camera attachment on a Leitz orthoplan microscope. The negatives were projected and the width of the outermost increment was measured and compared to that of the previous/adjacent increment.

2) Comparison of predicted changes in length with field data

Differences in the age of modal length sized fish between successive monthly samples, as predicted from increment count/length data, were compared with the actual differences in modal length between samples, to test the one increment per day hypothesis.

Growth models

The growth of *S. heterolobus* has previously been described by the von Bertalanffy growth formula (VBGF), derived from length/frequency data. In order to compare growth rates derived from otolith counts in this paper with previous studies, a catabolic growth coefficient, K, was derived from age/length data using a Gulland and Holt plot (Pauly, 1980).

Stock composition analysis

Length composition was converted to age composition using the age/length relationship derived from otolith increments. Cumulative length composition was also converted to weight composition, using a calculated length-weight curve, for biomass determination.

Total mortality, in which the natural logarithms of total numbers were plotted against age in the form of a catch curve (Pauly, 1980), was calculated for the combined data and for east and west monsoon seasons. Age selectivity by the gear was estimated from the catch curve.

Results

Otolith increments

Beyond the nucleus region two sizes of otolith increments were seen under transmitted light (Fig. 1). The larger increments had a median diameter of 14 μ (range 10–16 μ) and were sub-divided by between 2 and 7 smaller bipartite increments ranging from 2 to 5 μ in thickness. Of the 297 sagittae examined only 18 were found to have increment checks, indicative of a sudden slowing down or cessation in growth (Taubert and Coble, 1977).

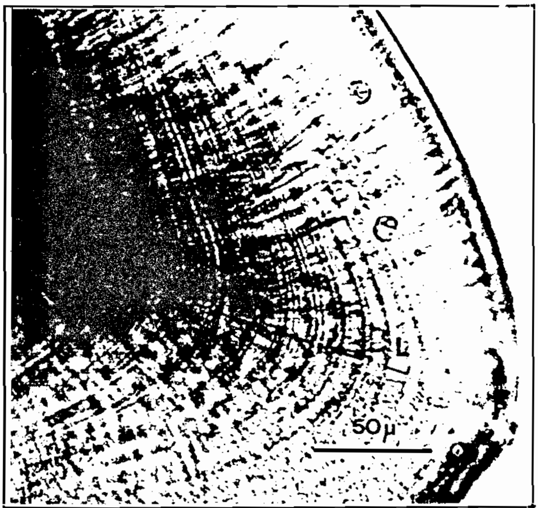

Figure 1. Sagitta otolith of *Stolephorus heterolobus* showing large (L) and small (S) increments.

Periodicity of increment deposition

1) Synchronisation of increment deposition

No significant difference in the completion of the smallest outermost increment was found in an analysis of sagittae from 30 fish caught between 0200–0500 hours (median=85%; sign test d=0.82; $P<0.05$). Increment completion ranged from 80–90% of the adjacent increment. The outermost increment in larval otoliths was approximately 10% in larvae caught between 0900 and 1000 h (N=3), 40% in larvae caught around 1200 h (N=2), and 70% in larvae caught at 17:30 h (N=4).

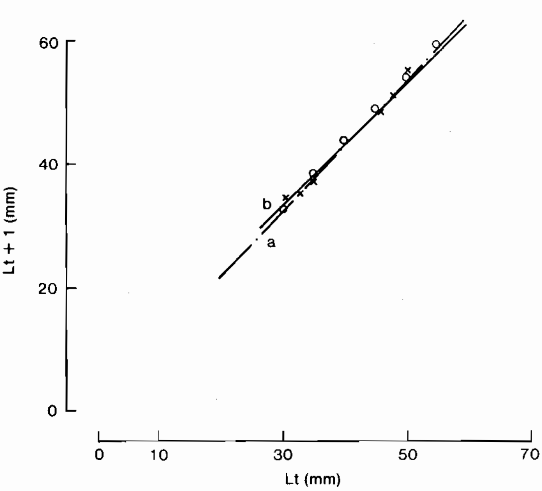

Figure 2. Ford-Walford plot derived from a) changes in modal length in length-frequency data and b) length/age data (Figure 4). The interval t + 1 was standardised to 30 days.

Mean age/length data were used to predict changes in length composition from observed starting sizes. Changes in length predicted by the smaller increments provided a good fit for changes in modal size between consecutive monthly samples (Fig. 2). The curves thus obtained have been superimposed on monthly length frequency data (Fig. 3). Thus, assuming consecutive peaks in length/frequency data correspond to the same size group, observed changes in modal length with time would support the hypothesis that the small sagitta increments are deposited daily.

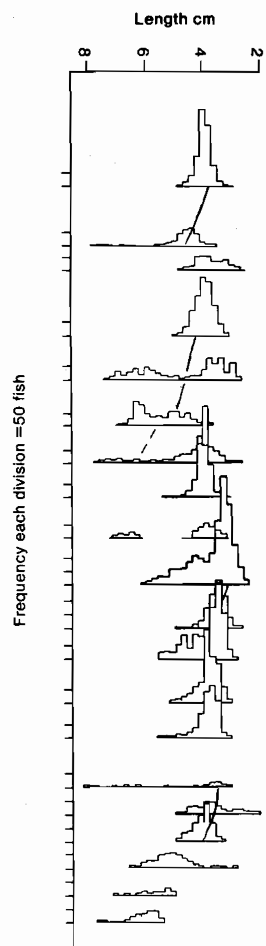

Figure 3. Length-frequency composition of monthly samples of *Stolephorus heterolobus* collected from Jepara, Java between 12.11.83 and 10.7.85.

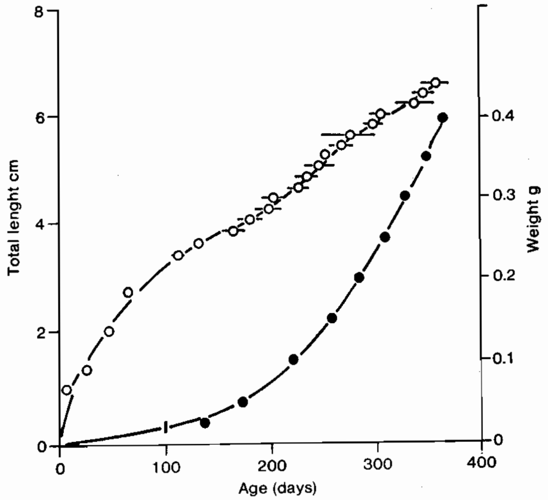

Figure 4. Relation between total length (○), dry weight (●) and age, as determined from counts of presumed daily increments, in *S. heterolobus* collected from Jobokuto market, Jepara.
Data for length/age curve presented as mean and 95% confidence limits for a given length class. Data for weight/age curve based on regression for 100 data sets.

Growth

Counts of presumed daily increments from 297 saggitta pairs were used to construct an age/length curve (Fig. 4). Whilst the growth of this species could be fitted by the formula:

$$Age = 0.375 \times Length^{1.643} \quad (r = 0.98;\ P < 0.05)$$

inspection of the growth curve indicated two phases of growth in length. Larval growth (up to 24 mm TL) was characterised by an exponential increase in length as described by:

$$Age = 1.137 \times Length^{1.128} \quad (r = 0.99;\ P < 0.01)$$

where age is in days and length is total length in mm. Following the transition to the post-larval stage, growth in length was almost linear as described by:

$$Age = 7.4L - 132.37 \quad (r = 0.993,\ P < 0.01).$$

A Gulland and Holt plot, based on data from increment counts for fish >35 mm TL, gave values of $L_\infty = 98$ mm and $K = 1.168$ (annual rate in mm), $t_0 = -5.4$ days. The von Bertalanffy curve generated from these parameters was in fairly close agreement with the growth pattern demonstrated from daily otolith increments (ANCOVA $F_{1, 36} = 3.8$; $P < 0.05$).

Counts of daily increments from 100 pairs of sagittae were used to construct an age-dry weight curve (Fig. 2). A linear transformation of logarithmically transformed data provided the best fit to the data:

$$Age = 519 \times Weight^{0.36}$$

where age is in days and weight is in grams.

The high variation in the age/weight relationship around 0.2g dry weight coincides with the earliest age of sexual maturation.

Analysis of length/dry weight indicated four growth stanzas with inflexions at around 24 mm, 38 mm and 56 mm TL, corresponding to the larval, post-larval, juvenile and adult stages (terminology of Tham, 1970; Table 1). These data were used to convert length composition to weight composition data for biomass determination.

Table 1. Length-dry weight relationships (a × length^b) for three length ranges of *Stolephorus heterolobus.*

Length range (mm)	Stage	a	b
24–34	Post-larvae	0.00020	4.34
38–56	Juvenile	0.00067	3.42
58–72	Adult	0.00097	2.74

Stock composition

The catches sampled comprised post-larval, juvenile and adult stages, with a size range from 22 to 90 mm TL. Post-larvae occurred in 11 of the 21 samples and all but four samples contained juveniles. Adults occurred in 14 samples and were most notable in the first half of the west monsoon. Small juveniles between 33–42 mm TL comprised 65.1% of the total numbers landed and 41.3% of the total biomass (Table 2). However in 17 of the 21 monthly samples they accounted for 88% by numbers and 65% of the biomass. On the basis of otolith increment counts, the age of these small juveniles ranged from 109 to 192 days old. Larger juveniles 43–53 mm TL, 193 to 260 days old, comprised 20.1% of the total numbers and 29% of the total biomass, but increments were often absent (11/21 samples) from samples. Postlarvae 24–35 mm TL, 70–120 days old comprised 1.5% of the numbers landed and 0.2% of the total biomass. Whilst adults (>240 days old) comprised

Table 2. Length and age composition of samples taken from fixed lift-net (bagan tancap) landings at Jepara, Central Java.

Length range mm	Age range days	Percentage Numbers	Percentage Biomass
22–33	70–108	1.5	0.2
34–42	109–192	65.1	41.3
43–53	200–240	20.1	29.0
54+	241+	13.3	29.5

29.5% of the total biomass, increments were absent from many (12/21) samples.

Total mortality and gear selectivity

The total mortality rate (Z) was estimated from the combined length-frequency data (Fig. 4). Total mortality for combined data was high ($Z=6.75$) although similar to that reported in Palau (Muller, 1976).

An estimate of gear selectivity, based on back extrapolation of the catch curve indicated that fish less than 90 days old were not fully selected by the gear (Fig. 4). As fish of this age have a mean body depth of 3.8 mm (Wright, 1989) and the net mesh size is 3–5 mm, this finding is not unexpected.

Discussion

Aging

Microstructural analysis indicates that *S. heterolobus* has sagitta increments homologous to the daily increments found in *Stolephorus purpureus* (Struhsaker and Uchiyama, 1976) and many other teleosts (Pannella, 1980). Whilst a direct validation of the periodicity of these increments is required, indirect evidence from both the state of increment completion and changes in size composition indicates that these increments are produced daily. Further, the scarcity of growth checks in otoliths would imply that there is no interruption in the daily deposition of increments throughout the life-cyle.

Growth

The growth of *S. heterolobus* can be divided into two phases on the basis of otolith increment/length data. Larval growth involves an exponential increase in trunk length whilst, following the transition to the post-larval stage (at a length of around 24 mm TL and age of 40–50 days) increase in length enters an almost linear phase.

The von Bertalanffy equation, derived from otolith increment/length data provided an acceptable fit to the juvenile and adult growth pattern and the value of L_∞(100 mm) was larger than the maximum length of fish collected in samples, as expected. Published estimates of the catabolic growth coefficient K, based on length frequency analysis, suggest that growth rates vary considerably between regions, ranging from 0.95 in Manila Bay (ICLARM, 1983) to 2.08 in Palau (Muller, 1976) and the Singapore Straits (Tham, 1970) (Table 3) and even between years within the same region (ICLARM, 1983). The value of K derived from age/length data in this study (1.116) was lower than most published estimates based on length-frequency data, which may reflect regional differences in growth rate. However length/frequency data can give biased estimates of growth if the development of cohorts through samples cannot be clearly distinguished. This is particularly a problem with short-lived species with a protracted spawning season (MacDonald, 1987) such as *S. heterolobus* and such factors led to problems in the analysis of length/frequency data collected from the Jepara region (Wright, 1989) and data collected by Tiews and co-workers from Manila Bay landings (1970). Consequently it is desirable to use a direct method of age determination when studying the growth of this species.

Stock composition

The importance of small juvenile age-classes to the *S. heterolobus* component of bagan catches has been clearly demonstrated in this study. Whilst many other species are taken by the fishery and may comprise nearly half of the landings (Willoughby et al., 1984) species of *Stolephorus*, and most notably *S. heterolobus*, have been reported to comprise between 82% and 86% by weight of catches (Wahyuoni, in Willoughby et al., 1984). Consequently the presence of only one or two age-classes in most monthly samples, together with the reliance on recruiting age-classes, means that the fishery is heavily dependent on sustained recruitment throughout the year. Owing to this dependence, a single recruitment failure would be expected to have a major impact on the fisheries yield. An example of the effect of a recruitment failure to a fishery dependent on *S. heterolobus*

Table 3. Values of catabolic growth coefficient, K and $L\infty$ for populations of *Stolephorus heterolobus* (MPA = modal progression analysis, Daily = daily increments, * = analysis predicted on only 3/53 modal peaks).

Location	K	$L\infty$ (mm)	Source	Method
Manila	1.60	121	ICLARM	ELEFAN
Manila	0.95	114	ICLARM	ELEFAN
Singapore	2.08	89	Tham, 1970	MPA
Palau	2.08	98	Muller, 1976	MPA
Jepara	1.17	98	—	DAILY
Jepara	2.12	98	—	ELEFAN*

was documented by Muller (1976) following a drought in Palau. The dramatic decline in landings at Jepara reported by Wahyuoni (Willoughby et at. 1984) may also be due to repeated recruitment failure, as the decline in landings (to less than a fifth of the original biomass in two years) was very rapid. However, without data on catch/effort, sampling procedure and the abundance of this species in the region, the causes of such declines remain far from clear. Furthermore, information on juvenile and adult migration is needed as the bagan tancap fishery is limited to coastal waters.

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Growth of the Tropical Anchovy, *Stolephorus nelsoni*, in Northern Australia

F.E. Hoedt*

Abstract

A study of the growth history of the tropical Australian anchovy, *Stolephorus nelsoni* was undertaken. Four growth curves were produced, the first from counts of growth increments in the sagittal otolith and the remainder from separate analyses of length frequency data collected in 1984, 1988 and 1989. Calculated values of the constants K and L_∞ were 2.16 and 105 mm from the otolith derived growth curve. These compared favourably with mean values of K=2.1 and L_∞=97.3 mm obtained from length frequency information. The study suggests that otolith increments provide a useful estimate of age in days for adult *Stolephorus nelsoni*.

STOLEPHORID anchovies in the tropical Pacific region have traditionally been aged from length frequency data (Tham 1966; Tiews et al. 1970; Dalzell and Wankowski 1980; Rawlinson 1989) and more recently using daily rings in otoliths (Struhsaker and Uchiyama 1976). The latter is a promising technique although its accuracy as an aging tool for adult fish is still uncertain (Morales-Nin 1988).

In this paper the growth history of *Stolephorus nelsoni* from Townsville, North Queensland is described using growth curves derived from otolith increment counts and length frequency analyses. The resulting growth curves derived from the two methods are then compared.

Materials and Methods

Stolephorus nelsoni were collected from Cleveland and Bowling Green Bays, North Queensland, (Fig. 1) during survey of engraulid and clupeid populations in the region. Monthly field trips using 12 mm mesh seine nets were conducted in both bays. Fish were also obtained from trawl samples (39 mm mesh, twin otter trawls) collected each month from the University research vessel 'James Kirby'.

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Engraulids were preserved in 10% seawater formalin buffered with borax to prevent otolith disintegration due to acidity. All fish were measured to the nearest mm total length.

Specimens representing the complete size range present in samples were removed for otolith aging. Both sagittal otoliths were dissected out, washed, dried, and mounted in 'Crystal Bond'

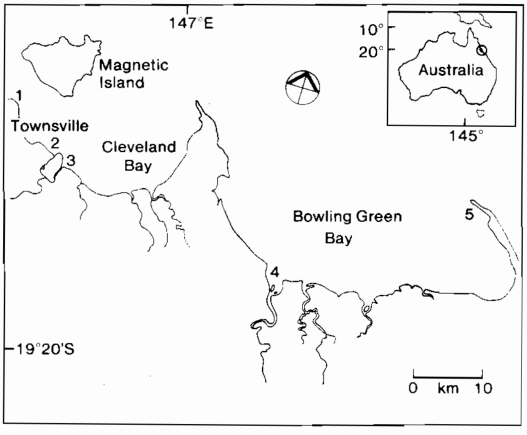

Figure 1. Sampling sites in Cleveland and Bowling Green Bays, North Queensland. 1 — Cape Pallerenda, 2 — Strand, 3 — Ross River, 4 — Houghton River, 5 — Cape Bowling Green.

thermoplastic cement on a microscope slide. Each otolith was hand ground with 1200 grade wet carborundum paper on one or both sides. The surfaces were then polished with .05 μm alumina powder on a wet leather disc. Growth increments were counted at least three times at 400 or 1000 × magnification and the mean count recorded. Only otoliths where the counts varied by less than 5% were used.

From these data the parameters K and L_∞ of the von Bertalanffy growth equation were calculated following the method outlined in Gulland (1983). The technique uses information on the average lengths of fish at the beginning and end of a constant time interval (T) (e.g. between successive samples). In this case the time interval (T) was an arbitrarily chosen 50 days from a plot of total length against counts of sagittal growth rings (Fig. 2), where the latter were assumed to be daily in periodicity. Length differences over 50 day intervals were calculated by subtracting the final length from the length at the beginning of the time interval for a range of ages (e.g. 0–50 days, 50–100 days etc.). These length increments were plotted against the initial length of the increment giving a straight line with a slope of $-(1-e^{-KT})$ and an x-axis intercept of L_∞.

The length-frequency analysis involved pooling fish from monthly catches into 5 mm size classes for each year. Fish recruited in the spring of 1988 were analysed together with the 1989 catches as the modes were continuous. This information was then put into the ELEFAN software package (ver. 1.02, ICLARM 1988) for three separate analyses. Curves were fitted by eye, altering the values of L_∞ and K to get an optimum Rn value and the best visual fit of the curves through the observed modes.

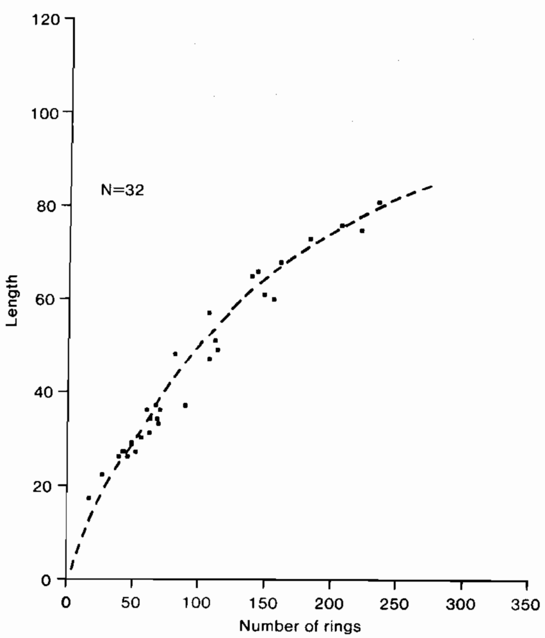

Figure 2. Total length plotted against number of rings in the sagitta of *Stolephorus nelsoni*. A growth curve fitted by eye is shown.

Results

K, L_∞ and Rn values and the resulting growth curves obtained from a length-frequency analysis performed using the ELEFAN software package are shown in Figure 3. The following numbers of fish were used in the analysis; 1984, n=313; 1988, n=1117; 1989, n=1701. The largest *S. nelsoni* caught in the study was 103 mm.

Figure 2 shows the asymptotic growth curve derived from counts of growth rings in the otolith of *S. nelsoni*. The rings in fish longer than 85 mm were very narrow and considered too difficult to count accurately with optical microscopes.

Table 1 summarises the values of K and L_∞ calculated by two methods in the present study and those derived for other stolephorid anchovies by other authors.

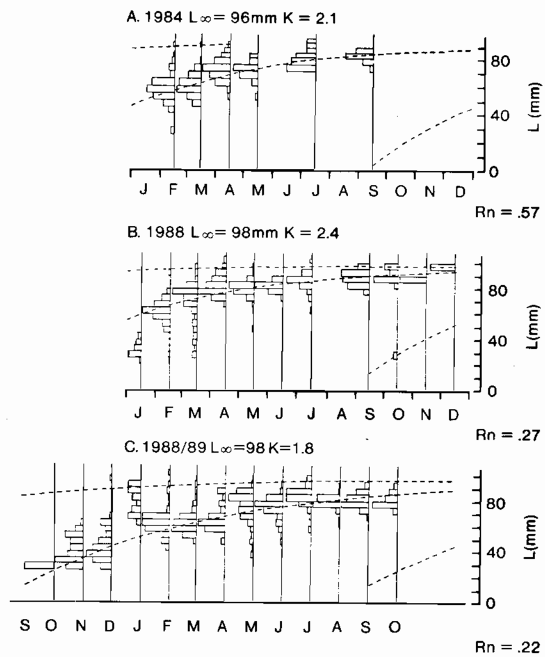

Figure 3. Monthly length–frequency plots for *Stolephorus nelsoni* collected in 1984, 1988, and 1989 with growth curves drawn by the ELEFAN software package. Values of K, L and Rn for each year are shown.

Table 1. Growth constants calculated for similar sized Indo-Pacific stolephorid anchovies from this and other studies.

Species	K (year^{-1})	L_∞ (mm)	Author
S. nelsoni	1.8–2.4	96–98	1
S. nelsoni	2.16	105	2
S. pseudoheterolobus	2.08	89	3
S. insularis	2.052	99	3
S. heterolobus	2.4–2.6	79–87	4

1. present study, length frequency analysis.
2. present study, counts of sagittal growth increments.
3. Tham (1966), length frequency analysis.
4. Rawlinson (1989), length frequency analysis.

Discussion

Growth in the tropical anchovy *Stolephorus nelsoni* can be followed graphically. New recruits from the annual spring (September/October) spawning (Hoedt 1984) comprise a mode of fish which grow to mature sizes during the following year. An analysis of three years length frequency data yielded growth curves which fitted these modes. Calculated values of the growth constants K and L_∞ were similar for each of the three years. Comparable values of these constants described the growth curve generated from counts of growth increments in the sagitta of *S. nelsoni,* suggesting that otoliths can provide reasonable estimates of age in days for this species.

Previous growth studies on similar sized tropical engraulids using length frequency analyses gave results which agree with those of the present study (Tham, 1966; Dalzell and Wankowski, 1980; Rawlinson, 1989). The calculated growth parameters indicate that these fish are reaching mature sizes within one year.

Daily growth increments in otoliths of tropical fish are potentially useful aging tools. It is however necessary to validate the periodicity of increment formation and to count increments only where they can be clearly discerned. Older fish often possess extremely narrow rings which can lead to underestimates of the true age of the fish (Morales-Nin, 1988).

Struhsaker and Uchiyama (1976) showed that *Stolephorus purpureus* of Hawaii could be aged from daily otolith growth increments present for at least the first six months of life. In the present study growth rings in the sagitta of *S. nelsoni* provide comparable age estimates to length-frequency based estimates for the first eight months of life. Beyond this age the rings become difficult to discern using optical microscopy. The use of scanning electron microscopy is suggested for aging older fish.

Acknowledgments

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IV Fisheries Management

Baitfish Stock Assessment Using the Egg Production Method: an application on the Hawaiian anchovy or nehu (*Encrasicholina purpurea*)

D.A. Somerton*

Abstract

The biomass of nehu (*Encrasicholina purpurea*) in Pearl Harbor was estimated weekly, over a two year period, using a new stock assessment procedure known as the Egg Production Method (EPM). Although the EPM was originally developed for assessing relatively long-lived, temperate anchovies (Northern Anchovy and Anchovetta), it has proven to be a low-cost, effective way of assessing the abundance of nehu, a short-lived, tropical stolephorid anchovy. The effectiveness of the EPM is largely the result of its being based on the life history stage that is the least aggregated and easiest to sample, that is, the egg stage. Because of this, the biomass estimates obtained using the EPM are less influenced by environmental fluctuations than estimates obtained using commercial catch statistics. Over the study period, nehu spawning stock biomass varied between 0.5 and 5.0 tonnes and was clearly associated with the variation in the rate of nehu bait catch for the pole-and-line tuna fishery. Stock variation also was associated with seasonal variation in reproductive output, primarily changes in weight-specific fecundity and spawning frequency and in the survival rate from the egg stage through the first feeding larvae.

STOCK assessment of baitfishes is difficult because fishery-dependent information such as catch per unit effort is often not a good indicator of relative abundance (Wetherall 1977), and fishery-independent information such as hydroacoustic data is expensive to obtain. One promising new approach, called the Egg Production Method (EPM), was developed to assess the biomass of small schooling species from the abundance of their pelagic eggs. The basic concepts of the EPM were first developed by Saville (1964) and later elaborated by Parker (1980). The estimate of biomass can be expressed algebraically as:

$$B = \frac{P}{F\ R} \qquad \text{Equation 1}$$

where B is the biomass, P is the daily production of eggs by the population, F is the fecundity per gram body weight of spawning females, and R is the proportion, by weight, of spawning females in the population. Definition of the population, and therefore the calculation of R, can be in terms of mature fish (spawning stock) or fish larger than some minimum size (commercial stock). In practice, P is estimated by sampling pelagic eggs with a plankton net and F and R are estimated by sampling adult fish.

The EPM was initially applied to the California anchovy (*Engraulis mordax*; Lasker 1985) and anchovetta (*E. ringens*; Alheit 1985), both relatively large, long-lived, temperate species, but it is also ideally suited for stock assessment of the smaller, shorter-lived anchovies and sprats used as baitfishes by the tuna pole-and-line fisheries. One such species is the Hawaiian anchovy or nehu (*Encrasicholina purpurea*). Nehu are endemic to the Hawaiian Islands and occur exclusively within enclosed bays, especially those that receive significant freshwater input. Typical of many tropical

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stolephorid anchovies (Dalzell 1987), nehu are short-lived (Struhsaker and Uchiyama 1976) and spawn almost continuously throughout the year (Tester 1955, Clarke 1987). Unlike most other baitfishes, however, nehu occur in shallow, turbid areas during the day and migrate at night to deeper, clearer areas where they spawn and feed. The commercial fishery exploits this unusual behaviour and captures nehu with seines in their shallow daytime habitat (Uchida 1977).

In this paper an application of the EPM is applied to a population of nehu occurring within Pearl Harbor, Oahu, emphasising aspects which differentiate this from previous applications on temperate species. As nehu have a high biological turnover rate and are subjected to an intensive fishery, stock assessment must be frequent to resolve important aspects of population change. For this reason, nehu stock assessment surveys were conducted weekly rather than yearly as they have been for temperate species. In addition, the application of the EPM on nehu differed from previous studies (Picquelle and Stauffer 1985) in the methods used to estimate F and R. These differences primarily reflect the biological differences between nehu and temperate anchovies but also include measures intended to reduce the time requirements of sampling and sample processing.

Materials and Methods

Pearl Harbor was sampled weekly from 3 April 1986 to 7 April 1988. Each sampling day was separated into two periods: egg and plankton sampling and adult sampling. Eggs and plankton were sampled between 0700 and 1200 hours with a systematic sampling design (Cochran 1963) in which a single sample was taken near the geographic centre of each of 39 strata. The net used was 5 m long and 1 m in diameter at the mouth and constructed of 335 μm Nitex[1]. To allow its use from small boats, the net was not towed but instead was thrown overboard and sampled as it descended to the bottom (average depth of the sampling sites was about 12 m). Compared with a typical towed plankton net, our sampling net had two design features added to increase its effectiveness. First, to increase the sinking speed, lead weights (5 kg) were attached to the steel ring that held the mouth open. Second, to ensure closure of the net, a retrieval line was attached, not to the ring itself, but to a choke collar surrounding the net. Mesh bags of 335 μm Nitex were used as cod ends. When retrieved, these bags were sealed and placed in a 10% buffered formaldehyde solution.

In the laboratory, the plankton samples were examined without subsampling, and all nehu eggs and all large crustacean zooplankters, previously identified as preferred nehu food (Hiatt 1951), were counted. Egg and plankton densities at each station were estimated by dividing the counts by an estimate of the filtered volume computed as water depth multiplied by the mouth area of the net.

Adult nehu were sampled in a 1.5-hour period preceding sunset when the eggs to be spawned that evening were clearly hydrated and easily distinguished from unhydrated, mature eggs (Clarke 1987). Adults were captured, along with juveniles, using a beach seine of the same mesh size (9 mm) and design characteristics as a commercial nehu seine except that it was cut to approximately one-third scale (70 m long by 3 m deep) so that it could be set from a small boat. Nehu schools were located in their preferred daytime habitat, that is, shallow, turbid areas, with the same searching techniques used by commercial vessels. Schools were quickly surrounded with the seine, and a random sample of the catch was taken and immediately preserved in a 10% buffered formaldehyde solution.

In the laboratory, a subsample of nehu was drawn from each field sample: 1) An initial subsample of approximately 50 fish was randomly chosen. 2) In order of size, starting with the apparent largest individual, fish were removed from the subsample and examined microscopically for sex and stage of maturity. 3) If less than 25 mature females were obtained from the initial subsample, additional subsamples were drawn and examined completely in the same manner until at least 25 mature females were obtained. 4) To increase the speed of classifying fish, if six juveniles were drawn in succession from a subsample, all of the remaining fish in that subsample were also classified as juveniles without examination. Because individuals were chosen according to size, the remaining fish were smaller than any that had been visually classified and therefore were likely to be immature.

The criteria used to classify fish were based upon the following gross morphological features partly adapted from Clarke (1987):

- largest ova measuring ≥0.7 mm in length indicated a mature female with hydrated eggs;
- largest ova measuring 0.5–0.7 mm in length indicated a mature female with unhydrated eggs;
- testis depth (dorsal-ventral) measuring ≥ eye diameter indicated a mature male;

[1] Reference to trade names does not imply endorsement by National Marine Fisheries Service, NOAA.

— largest ova measuring < 0.5 mm or testis depth measuring < eye diameter indicated a juvenile.

After the subsample was chosen and classified, the following biological attributes were measured. Standard length (in millimetres) was measured for all mature fish and for the first 25 randomly chosen juveniles; any remaining juveniles were counted but not measured. Total body weight (in milligrams) was measured, after blot drying, for all fish measured for length except females with hydrated eggs; ovary-free body weight was measured for all females. Batch fecundity was estimated for females with hydrated eggs by teasing apart both of the ovaries and counting under a microscope all hydrated ova. Each count was replicated, and fecundity was estimated as the mean of the two counts. Over the 105 consecutive weeks of sampling, this process was repeated for each of 162 seine samples.

Data analysis and biomass estimation

Evaluation of Equation 1 requires estimates of *P*, *F*, and *R*. These estimates were obtained as follows. Daily egg production was estimated as

$$P = \Sigma D_i V_i; \qquad \text{Equation 2}$$

where D_i is the egg density at the ith station, and V_i is the volume of the ith stratum. The summation is over all 39 strata. Weight specific fecundity was estimated as

$$F = \frac{\Sigma E}{\Sigma W_{fh}} \qquad \text{Equation 3}$$

where ΣE is the sum of all hydrated ova, and ΣW_{fh} is the sum of the corrected total body weight of mature females with hydrated eggs. Spawning proportion was estimated as

$$R = \frac{\Sigma W_{fh}}{\Sigma W_m + \Sigma W_{fh} + \Sigma W_{fu}} \qquad \text{Equation 4}$$

where ΣW_m and ΣW_{fu} are the sums of the total body weights of males and of females with unhydrated eggs. The W_{fh} were corrected for the temporary weight gain due to egg hydration by regressing W_{fu} on ovary-free weight for females with unhydrated ovaries, then predicting W_{fh} from the ovary-free body weights of females with hydrated ovaries. When the commercial population rather than the spawning population was estimated, Equation 4 was modified slightly to include in the denominator the term ΣW_j or the sum of the total body weights of juveniles.

Variance and bias of the estimated biomass were approximated by using the delta method (Seber 1973). The variance estimator was

$$V(B) = B^2[CV(P)^2 + CV(F)^2 + CV(R)^2]; \qquad \text{Equation 5}$$

and the bias estimator was

$$\text{bias}(B) = B[CV(F)^2 + CV(R)^2]; \qquad \text{Equation 6}$$

where *CV* represents the coefficient of variation.

The variances needed to evaluate Equations 5 and 6 were estimated as follows. The variance of the daily egg production, *P*, was calculated as

$$V(P) = \Sigma V_i^2 V(D_i); \qquad \text{Equation 7}$$

where $V(D_i)$ was approximated as the variance in D_i among three adjacent stations, because the plankton net samples were not replicated at each station. The variances of the biological parameters were estimated as

$$V(\overline{X}) = \frac{\Sigma(X_i - \overline{X})^2}{N(N-1)} \qquad \text{Equation 8}$$

where X_i is the ith sample mean for one of the biological parameters and $\overline{X}$ is the mean of N sample means. Since the number of samples collected each week was always small and sometimes even insufficient to estimate variance, the weekly estimates of the means and variances of the biological parameters were calculated from a pool of all samples within a 5-week moving time window centred on the particular week.

Results and Discussion

Biomass estimates

Weekly spawning and commercial biomass estimates (Figure 1) had similar patterns of variation over time, but the commercial biomass estimates were always larger with wider confidence intervals. Over the 2-year period, the population fluctuated seasonally with maximum abundance in March-April and perhaps again in late July-August and a minimum in November. This pattern of variation was similar to that observed in the abundance of nehu eggs in Kaneohe Bay, Oahu (Tester, 1955).

Egg production

Estimates of daily egg production can be influenced by two sources of bias. First, an overestimation can occur if the eggs of other fishes are misidentified as the target species. For nehu, such misidentification is unlikely because no other fishes in Pearl Harbor have eggs similar to those of nehu (Tester 1951; Clarke 1987). However, in areas where several closely related species spawn

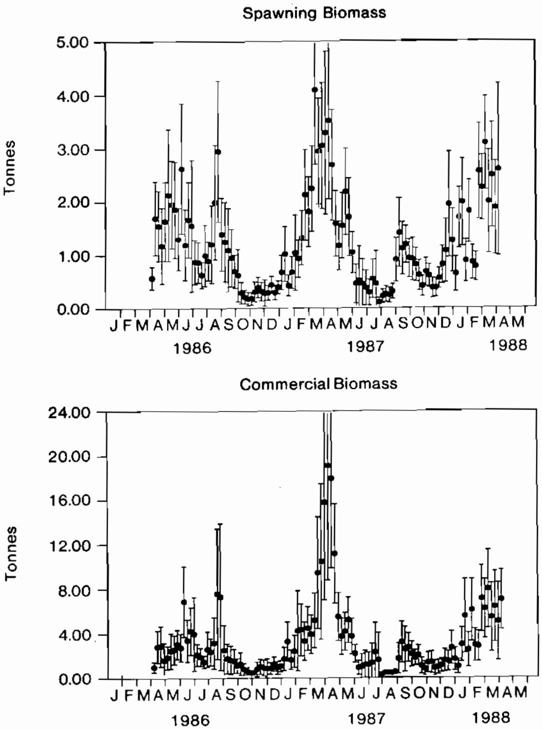

Figure 1. Weekly estimates and 95% confidence intervals of the spawning and commercial biomasses of nehu within Pearl Harbor in metric tonnes.

concurrently, egg identification may be problematical. Second, an underestimation can occur if egg mortality is high and the time between spawning and sampling is large. In northern anchovy, for example, the egg mortality rate was estimated at 53% per day (Smith and Lasker 1978), but we believe that nehu egg mortality is substantially less.

Egg mortality can be attributed to either predation or abnormal embryological development. Predation by the adults accounted for 32% of the egg mortality in northern anchovy (Hunter and Kimbrell 1980) but is probably much lower in nehu because eggs are rarely found in adult gut samples (Hiatt 1951). Mortality due to abnormal development could be significant in nehu but would be difficult to quantify because, based on our preliminary studies of egg density, dead nehu eggs sink rapidly in water with densities typical of Pearl Harbor and thus, are likely to escape capture. Because some egg mortality is likely, we believe that our estimates of egg production, based on the abundance of eggs roughly 16 hours after spawning, may be too low.

Reproductive parameters

Previous applications of the EPM (Alheit 1985; Hunter and Macewicz 1985) have used postovulatory follicles to identify spawning females. Instead, we chose to use the presence of hydrated eggs, primarily because histological preparation is not required and identification is, therefore, faster and easier. The use of hydrated ova, however, imposes a restriction on the time that the population can be sampled, to ensure correct identification of spawning females. This restriction reduces the level of precision in the biomass estimates that might have otherwise been achieved and subjects the estimates of spawning proportion to a potential bias.

The appropriate period for sampling adults is bounded between the time of day when hydrated ova are sufficiently enlarged to be recognisable and sunset when migration to deeper water begins (Clarke 1987). Recognisable hydrated ova may occasionally be observed during the early afternoon, but Clarke (1987) has found that not until two hours before sunset did all prespawning females have some ova $\geqslant$ 0.7 mm. Since the definition of the correct time window for sampling is so important, our study repeated part of Clarke's (1987) study by sampling adult nehu at approximately half-hour intervals throughout the late afternoon and found that a smaller time window of 1.5 hours was required to ensure correct identification. This time period was so short that we were only able to obtain an average of 1.6 adult samples each week and occasionally experienced periods in which no samples could be obtained.

Not only is the time period for adults sampling short, but it occurs immediately before spawning when segregation of sexually active and inactive fish may occur. Previous studies on northern anchovy (Picquelle and Stauffer 1985) and anchovetta (Alheit 1985) have found that active females segregate from inactive females and aggregate with males near the time of spawning. For nehu, segregation of active from inactive females, aggregation of active females with males, and segregation of adults from juveniles were tested and all were highly significant (chi-square test of homogeneity; $P<0.001$). This means that some segregation had occurred by the time the adult sampling period began. Such segregation increases biological heterogeneity among schools, and thereby increases the variance in the estimates of the proportion spawning.

In addition to its influence on the precision of the biomass estimates, the use of hydrated ova to identify spawning females is subject to one important source of sampling bias: differential catchability between sexually active and inactive females. For both northern anchovy (Picquelle and Stauffer 1985) and anchovetta (Alheit 1985), active females have a higher vulnerability to the sampling gear, perhaps due to a difference either in net avoidance or in depth distribution. For nehu, however, active and inactive females are apparently equally vulnerable, at least during the adult sampling period, because both occur in the shallow, nearshore areas sampled during the day (Clarke 1987). Furthermore, using postovulatory follicles and estimated rates of ova development from fish sampled at all times of day, Clarke (1987) estimated that individual nehu spawn every other day or, expressed as the inverse, that nehu have a daily spawning proportion of approximately 0.50. Since our estimate of mean proportion spawning, 0.53 (95% confidence interval, ± .04), is not significantly different from Clarke's (1987), it is unlikely that our sampling was biased.

Considerations for other baitfish applications

Other applications of the EPM on baitfishes are likely to also require frequent sampling, but lack sufficient resources for processing a large number of adult samples. Our approach to this problem was to save time by using hydrated ova rather than postovulatory follicles to identify spawning females. However, other shortcuts could be taken, especially when there is little temporal variation in adult parameters. One approach is to save time in sampling and sample processing by calculating biomass estimates based on long-term mean parameter values instead of weekly estimates. To determine how accurate such biomass estimates would have been for nehu, we compared the estimates calculated using the smoothed parameter values to those computed using the overall mean parameter values. The results indicated that roughly 58% of the variability in spawning biomass and 35% of the variability in commercial biomass were explained by the variability in the biomass estimates computed from long-term means. Much of the loss in predictability, however, was at high frequencies, while most of the low frequency and seasonal fluctuations are preserved (Fig. 2). For still further savings in time, this approach could be extended by simply eliminating adult sampling altogether and treating egg abundance as a proxy for fish abundance similar to the way catch per unit effort is used.

Factors influencing nehu population fluctuations

Since the nehu population in Pearl Harbor is closed, receiving little or no immigration (Tester and Hiatt 1952), the observed variation in abundance (Fig. 1) must be due to variations in the recruitment of juveniles and the mortality rate of adults. Recruitment to the nehu population depends to some degree upon the biomass of adult females, the production of feeding larvae per gram of female, and the survival of feeding larvae to adulthood. Although survival of feeding larvae in our study was not considered, the variation in larval production was examined. Larval production per gram of female can be considered as the product of three components: 1) the production of eggs per gram of female body weight (Fig. 3d), 2) the proportion of the population spawning each day (Fig. 3c), and 3) the survival of eggs through the stage of first feeding larvae (Fig. 3e). All three of these components are seasonal, but their product, that is, the production of feeding larvae per gram of adult female (Fig. 3f) has a conspicuously strong seasonal pattern that is similar to those of the mean water temperature within Pearl Harbor (Fig. 3a) and to the density of the crustacean zooplankters that are the primary component of nehu food (Fig. 3b).

The total mortality rate of adults is the sum of both natural and fishing mortalities. Based on our preliminary studies of the Pearl Harbor population, natural mortality appears to be nearly constant over time, but fishing mortality varies greatly. Since the catch rises and falls almost synchronously with the estimated spawning biomass (Fig. 1), the fishery is bait limited and responds quickly to changes in bait availability. This response occurs in two ways. First, when bait abundance increases, the bait catch of individual vessels tends to increase, at least until capacity is reached. Second, more vessels fish in Pearl Harbor when the catch rates there are high relative to other baitfishing areas. The link between changes

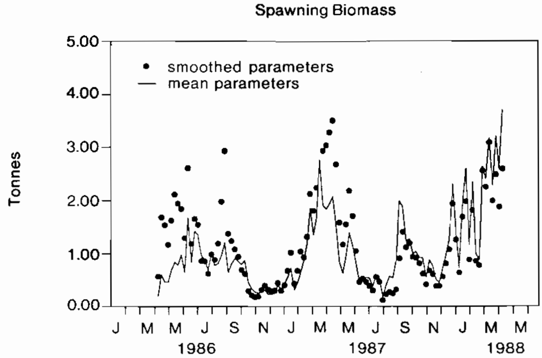

Figure 2. Spawning biomass calculated by using the smoothed weekly mean estimates of the adult parameters (F and R) and by using the total overall mean of the adult parameters.

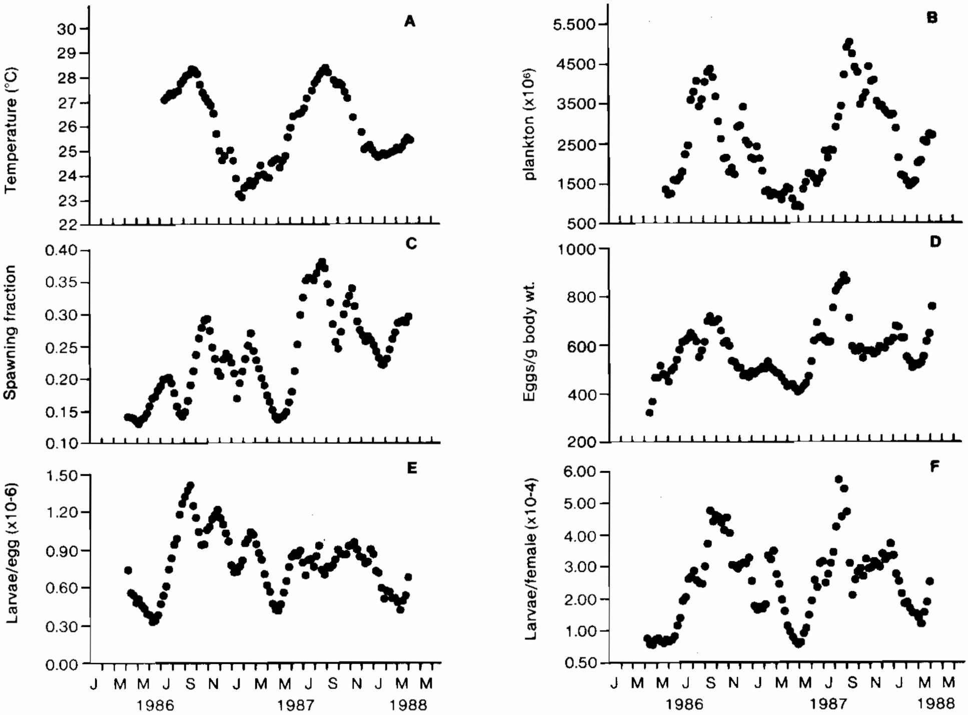

Figure 3. Weekly estimates of A) mean water temperature in Pearl Harbor, B) total abundance of all crustacean zooplankters identified as nehu food, C) proportion of the population, by weight, comprised of spawning females, D) batch fecundity expressed as eggs per gram body weight of spawning female, E) a crude estimate of early larval survival calculated as the total number of feeding larvae caught in one week divided by the number of eggs produced in the previous week, and F) number of feeding larvae produced by 1 gm of spawning female, that is, the product of C, D, and E.

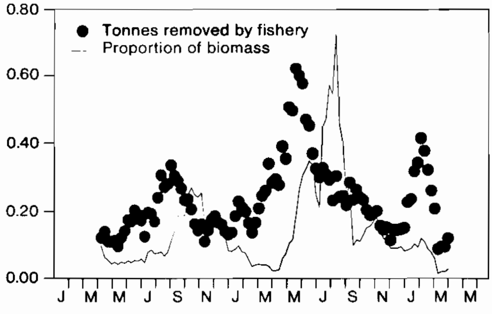

Figure 4. Catch of nehu within Pearl Harbor, expressed in tonnes and as a proportion of the estimated commercial biomass. This proportion is also known as the exploitation rate.

in effort and changes in nehu abundance is subject to inertia, and for a time, effort can remain high, or even increase, when the population begins to fall. As a result, the proportion of the population taken, or the exploitation rate, increases markedly (Fig. 4) and the abundance of nehu rapidly falls.

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Reef Fish and Fisheries in Solomon Islands and Maldives and Their Interactions with Tuna Baitfisheries

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Abstract

The interrelationships of commercial tuna baitfisheries and artisanal-subsistence reef fisheries in Solomon Islands and Maldives were studied. In Solomon Islands, baitfish comprised about 25% of the diet of 28 predatory species. In Maldives only 10 species ate baitfish. Experimental gill netting in lagoons indicated that baitfish predators formed 6–16% of catches in Solomon Islands and 22% of catches in Maldives.

To simulate the subsistence fishery in Solomon Islands, fishing competitions (using droplining, spearfishing and trolling) were held. Droplining, the predominant technique, contributed most to the overall catch, although trolling was important in one area. It was concluded that most fish caught by the subsistence fishery do not eat baitfish although many of the species caught by trolling are baitfish predators. Catches from drive-in netting and poisoning sessions were also monitored in Solomon Islands; very few baitfish predators were caught. Unless there is an increase in trolling, there is little evidence that the commercial baitfishery in Solomon Islands has a direct trophic effect on the subsistence reef fishery. In Maldives at least four major baitfish predators are important in the developing reef fish fishery. Baitfish predators may become a significant proportion of artisanal catches in Maldives in the future.

THE pole-and-line tuna industries of Solomon Islands and Maldives depend on regular supplies of live baitfish, mainly of the families Clupeidae, Engraulidae, Apogonidae and Caesionidae. These are caught in coral reef lagoons. In Solomon Islands the effect of commercial baitfishing on the larger predatory fishes that form the basis of the traditional inshore subsistence fishery is of major importance. Although catches of reef fish in the Maldives have previously formed only a small proportion of artisanal fisheries, they are now increasing to meet both tourist and local demands; hence information on interactions with baitfishing was required. The most commonly expressed concern in both countries was that a reduction in the numbers of baitfish would affect the numbers of predatory inshore fishes, because baitfish are the food of these fishes. In a collaborative project, the CSIRO Division of Fisheries, the Fisheries Division of Solomon Islands and the Marine Research Section of Maldives studied the effects of tuna baitfishing on other subsistence and artisanal fisheries. The relative importance of baitfish in the diets of various piscivores was established (Blaber et al. 1990) and subsistence fisheries in Solomon Islands were surveyed (Leqata et al., these Proceedings). In the present paper we report on whether baitfish predators are a significant proportion of the catches of the artisanal subsistence fisheries.

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Methods

Solomon Islands

Two major tuna baitfishing grounds — Roviana Lagoon (Munda) in Western Province and Tulagi Lagoon in Central Province — were studied, as well as a lagoon that is not baitfished — Vona Vona, in Western Province. The physical characteristics of the lagoons are described in detail by Stoddart (1969). Essentially all are shallow (up to 40 m) and semi-enclosed by fringing coral reefs. They contain many small islands, coral reefs and intertidal reef flats and have coral sand bottoms interspersed with coral rubble and patches of seagrass.

The fish fauna of relevance to the subsistence fishery was investigated from five sources:

1) Gill nets of 50, 75, 100, 125 and 150 mm stretch mesh were deployed for two to three weeks in April 1987, July 1987, January 1988 and August 1988. As catches were very low at Tulagi this site was not sampled after April 1987. Catch rates are expressed as g of fish per 100 m net per hour.
2) The catches from fishing competitions (see below).
3) The catches of subsistence drive-in netting operations were monitored.
4) The catches of subsistence fish poisoning sessions (kwarao) were monitored.
5) Larger species caught incidentally by tuna baitfishers were retained.

All fish were measured (standard length except for sharks) and weighed. The stomachs of all piscivores (possible baitfish predators) were preserved in 10% formalin.

The species composition of the subsistence fishery was estimated by conducting fishing competitions at Munda and Vona Vona. This method was chosen in preference to trying to monitor the catches of the many villages scattered beside the lagoons. The competitions were designed to minimise the bias inherent in different fishing methods. Advance publicity and separate prizes for the three common traditional methods of fishing (droplining, spearfishing and trolling) and for men, women and children, ensured a wide spread of fishing effort and encouraged the use of most commonly practised techniques. Competitions were held at Munda in July 1987, January 1988 and August 1988, and at Vona Vona in January and August 1988. Each person's catch was sorted, the species identified and weighed and the method of fishing recorded.

Maldives

Lagoon fish were sampled in Alifushi lagoon (Raa Atoll) in November 1987, and in Manyafushi lagoon (South Male Atoll) and Madugadi lagoon (Ari Atoll) in April 1988, using a fleet of gill nets of the same specifications as those used in Solomon Islands. Catch rates are expressed as g of fish per 100 m net per hour. All fish were measured and weighed and the stomachs of piscivores preserved in 10% formalin.

Results

Solomon Islands

Gill netting

A total of 1785 fish of 142 species weighing 2350 kg were caught in the four sampling periods. Catch rates were highest in Vona Vona (900 g) and lowest at Tulagi (256 g) (Table 1). Sharks contributed most to the catch rates (overall 462.9 g, 64.6%). The teleosts with the highest catch rates were *Chanos chanos, Scomberoides lysan, Caranx melampygus* and *Valamugil seheli,* although there were considerable differences between sites (Table 1). *Scomberoides tol* was important at Vona Vona and Munda but not at Tulagi. Similarly *Lutjanus gibbus, L. bohar, Carangoides ferdau* and *Carangoides oblongus* were common at Vona Vona and Munda but absent from Tulagi.

Fishing competitions

The 26 species that each contributed more than 1% to the combined catches (by weight) are shown in Table 2. In all, 3548 fish weighing 989 kg were landed. Of these, 62% were caught by droplining, 23% by trolling and 15% by spearfishing. *Lethrinus ramak* was the most numerous species and also contributed most to overall weight. The species making up more than 1% each of the weight of the catches at Munda and Vona Vona are shown in Tables 3 and 4. The Munda catches were dominated by the piscivores *Scomberomorus commerson, Katsuwonus pelamis* and *Caranx melampygus,* whereas the more sedentary omnivores *Lethrinus ramak, L. lentjan* and *Epinephelus microdon* were the top three species at Vona Vona. The percentage weight of fish caught by each technique and the numbers of fishermen using each technique for each competition are shown in Table 5. Droplining was responsible for 80% of the catch at Vona Vona in both competitions. In contrast, trolling was the dominant method at two of the three competitions at Munda. It is significant, however, that droplining was the most important method during the second Munda competition when more fishermen participated.

Drive-in netting

Catches were dominated by mullet (*Valamugil seheli*) and sedentary reef-attached species. Piscivores made up less than 5% of catches (Table 6).

Table 1. Overall gill net catch rates from Solomon Islands for all species with a catch rate over 1 g per 100 m net per hour, and catch rates at the three sampling sites.

Species	Catch rate (g per 100 m net/h)			
	Overall	Tulagi	Munda	Vona Vona
Carcharhinus amblyrhynchos	148.5	31.9	220.0	100.7
Sphyrna mokarran	81.1	—	—	196.9
Carcharhinus cautus	50.3	—	56.7	60.0
Carcharhinus sorrah	42.3	—	33.4	66.1
Carcharhinus melanopterus	39.2	33.5	35.6	33.5
Carcharhinus limbatus	36.9	—	24.1	63.3
Nebrius ferrugineus	33.0	—	—	80.2
Chanos chanos	25.2	2.6	40.8	15.6
Triaenodon obesus	21.9	98.9	6.3	15.4
Scomberoides lysan	21.4	1.2	23.9	25.5
Caranx melampygus	19.2	1.5	17.2	27.3
Rastrelliger kanagurta	18.4	5.0	30.8	9.4
Valamugil seheli	15.9	5.1	31.1	3.0
Scomberoides tol	14.6	—	15.6	18.4
Alepes sp.	8.2	—	0.8	19.0
Lutjanus gibbus	7.8	0.8	4.0	14.2
Scomberoides commersonianus	7.1	—	0.3	16.9
Carangoides ferdau	7.1	—	8.7	7.6
Albula vulpes	6.9	—	13.0	2.5
Caranx sexfasciatus	5.8	—	3.7	8.3
Lutjanus bohar	5.5	—	6.5	6.2
Sphyrna lewini	5.5	—	10.6	1.7
Lactarius lactarius	5.2	0.9	10.7	0.8
Sphyraena putnamiae	5.0	—	2.7	9.6
Caranx ignobilis	4.8	—	1.7	9.8
Carangoides oblongus	4.4	—	4.9	5.3
Plectorhinchus schotaf	4.1	22.2	2.7	—
Caranx papuensis	4.0	10.5	3.7	2.4
Negaprion acutidens	3.7	—	6.0	2.3
Kyphosus cinerescens	3.6	—	2.4	6.0
Gnathanodon speciosus	3.5	2.9	4.6	2.5
Euthynnus affinis	3.2	—	7.0	—
Chirocentrus dorab	2.8	1.2	1.8	4.5
Atule mate	2.8	—	3.0	3.5
Tylosurus crocodilus	2.6	3.6	2.2	2.8
Kyphosus vaigiensis	2.2	—	—	5.4
Carangoides bajad	2.1	—	2.4	2.4
Anodontostoma chacunda	2.0	4.0	0.7	2.8
Lutjanus argentimaculatus	1.9	3.6	1.3	2.0
Epinephelus tauvina	1.6	4.1	1.1	1.8
Rachycentron canadus	1.2	—	—	3.0
Tylosurus acus	1.1	6.4	0.2	0.4
Liza vaigiensis	1.1	—	2.3	—
Uraspis uraspis	1.0	—	2.6	—
Total catch rate	716.6	255.9	669.5	900.0
Total weight of fish (kg)	2352.4	109.7	1007.4	1235.3
Total number of individuals	1785	94	860	831
Total number of species	142	36	95	90

Poisoning sessions

Species identified from 'Kwarao' sessions are listed in Table 7. Catches were almost entirely made up of sedentary reef-attached species.

The incidence of baitfish in the diets of piscivorous species

A summary of the diet analysis is shown in Table 8. The percentage contributions by dry weight of baitfish to the diets of the 28 major baitfish predators are indicated. Further details of complete predator diets have been published separately (Blaber et al., 1990).

Comparison of baitfish taken by predators and by the baitfishery

The most important taxa to the baitfishery are, in

Table 2. Species that formed more than 1% weight (g) of the combined catches of five fishing competitions, showing percentages taken by dropline (%d) spear (%s) or trolling (%t) (n = number of fish, — = not caught).

Species	g	%g	%d	%s	%t	n
Lethrinus ramak	97700	9.9	9.8	<0.1	—	917
Scomberomorus commerson	72625	7.3	0.5	—	6.8	20
Katsuwonus pelamis	65000	6.6	—	—	6.6	14
Epinephelus microdon	40405	4.1	2.3	1.8	—	27
Caranx melampygus	33330	3.4	0.7	—	2.7	33
Lethrinus lentjan	32915	3.3	3.3	—	—	174
Cheilinus undulatus	30440	3.1	2.3	0.8	—	29
Lutjanus gibbus	30385	3.1	2.7	0.4	—	295
Balistoides viridescens	28180	2.8	2.8	—	—	38
Pseudobalistes flavimarginatus	27650	2.8	2.8	—	—	40
Lethrinus elongatus	22115	2.2	2.2	—	—	44
Cephalopholis boenack	21271	2.2	2.2	—	—	269
Caranx ignobilis	18705	1.9	1.5	—	0.4	13
Sphyraena barracuda	18125	1.8	—	—	1.8	4
Bulbometapon muricatum	16350	1.7	—	1.7	—	3
Plectropomus leopardus	16030	1.6	0.8	0.1	0.7	15
Scolopsis temporalis	15530	1.6	1.6	—	—	96
Choerodon anchorago	13405	1.4	1.3	0.1	—	75
Symphorichthys spilurus	12525	1.3	1.3	—	—	5
Gnathanodon speciosus	12325	1.2	0.6	0.6	—	9
Lutjanus carponotatus	11910	1.2	1.1	0.1	—	65
Plectorhinchus schotaf	11010	1.1	—	1.1	—	7
Lutjanus fulvus	10900	1.1	0.7	0.4	—	85
Lethrinus mahsena	10705	1.1	1.1	—	—	88
Plectorhinchus chaetodontoides	10375	1.0	—	1.0	—	9
Scarus ghobban	10170	1.0	—	1.0	—	15
Overall totals (all fish)	988820		61.5	14.4	23.1	3548

Table 3. Species that formed more than 1% of the combined catch of three fishing competitions held at Munda, Solomon Islands.

Species	Weight (g)	% weight
Scomberomorus commerson	71600	13.6
Katsuwonus pelamis	65000	12.3
Caranx melampygus	27455	5.2
Balistoides viridescens	19735	3.7
Sphyraena barracuda	18125	3.4
Cheilinus undulatus	17825	3.4
Epinephelus microdon	15075	2.9
Pseudobalistes flavimarginatus	13460	2.6
Plectropomus leopardus	12795	2.4
Symphorichthys spilurus	12525	2.4
Scarus ghobban	9570	1.8
Lutjanus gibbus	9360	1.8
Carangoides fulvoguttatus	9255	1.8
Lethrinus ramak	9115	1.7
Macolor niger	7875	1.5
Euthynnus affinis	7710	1.5
Plectorhinchus chaetodontoides	7075	1.3
Lethrinus lentjan	6740	1.3
Lutjanus guilcheri	6640	1.3
Elagatis bipinnulata	6330	1.2
Plectorhinchus schotaf	6145	1.2
Lethrinus rubrioperculatus	5785	1.1

Total weight (all fish) 526410 g
Total number of individuals = 1191
Total number of species = 135

Table 4. Species that formed more than 1% of the combined catch of two fishing competitons held at Vona Vona, Solomon Islands.

Species	Weight (g)	% weight
Lethrinus ramak	88585	19.2
Lethrinus lentjan	26175	5.7
Epinephelus microdon	25330	5.5
Lutjanus gibbus	21025	4.5
Lethrinus elongatus	17400	3.8
Cephalopholis boenack	16515	3.8
Bulbometapon muricatum	16350	3.5
Caranx ignobilis	14330	3.1
Pseudobalistes flavimarginatus	14190	3.1
Scolopsis temporalis	13955	3.0
Cheilinus undulatus	12615	2.7
Lutjanus carponotatus	10565	2.3
Choerodon anchorago	10550	2.3
Gnathanodon speciosus	9025	2.0
Balistoides viridescens	8445	1.8
Caranx tille	7790	1.7
Lethrinus mahsena	6605	1.4
Lutjanus fulvus	6590	1.4
Caranx papuensis	6095	1.3
Caranx melampygus	5875	1.3
Diagramma punctatum	5325	1.2
Alectis ciliaris	5000	1.1
Plectorhinchus schotaf	4865	1.1
Epinephelus ongus	4700	1.0

Total weight all fish = 462410 g
Total number of individuals = 2357
Total number of species = 123

Table 5. Percentage weight of fish caught by different methods (D = dropline, S = spearfishing, T = trolling) and the number of fishermen using each method (F) in fishing competitions in Solomon Islands.

Competition site	%D	F	%S	F	%T	F	Total F
Munda July 1987	26.4	12	11.7	2	61.9	11	25
Munda January 1988	64.3	33	20.1	5	20.9	5	43
Munda August 1988	31.7	8	3.7	1	64.6	5	14
Vona Vona January 1988	80.1	43	18.1	5	1.6	1	49
Vona Vona August 1988	80.4	31	19.6	4	0	0	35
Overall combined	61.5	127	15.4	17	23.1	22	166

Table 6. Species composition of combined catches of nine subsistence drive-in netting operations using approximately 200 m of gill nets over a total of four hours.

Species	weight (d)	weight %	number
Valamugil seheli	17775	17.9	14
Symphorichthys spilurus	14000	14.1	4
Carangoides ferdau	11820	11.9	21
Bulbometapon muricatum	11500	11.6	1
Pseudobalistes flavimarginatus	11340	11.4	5
Albula vulpes	7055	7.1	3
Arothron mappa	7030	7.1	2
Gerres acinaces	5730	5.8	18
Liza vaigiensis	3675	3.7	6
Carcharhinus melanopterus	2000	2.0	1
Arothron hispidus	1650	1.7	1
Rastrelliger kanagurta	1335	1.3	3
Caranx papuensis	1230	1.2	2
Siderea picta	1125	1.1	1
Siganus canaliculatus	605	0.6	4
Gnathanodon speciosus	475	0.5	1
Scolopsis temporalis	310	0.3	1
Caranx melampygus	250	0.3	1
Lactoria cornuta	200	0.2	1
Conger cinereus	73	<0.1	1
Choerodon anchorago	53	<0.1	1
Lutjanus ehrenbergi	20	<0.1	1
Totals	99251		93

Table 7. Species identified from 'Kwarao' poisoning sessions in Roviana lagoon near Munda, Western Province, Solomon Islands.

Acanthurus gahhm
Chaetodon ephippium
Ctenochaetus striatus
Hemigymnus melanopterus
Lethrinus elongatus
Lethrinus ramak
Lethrinus rubrioperculatus
Lutjanus semicinctus
Ostracium tuberculatum
Paraupeneus barberinus
Paraupeneus cyclostomus
Pentapodus caninus
Rhinecanthus verrucosus
Scarus bleekeri
Scarus dimidiatus
Scarus ghobban
Scarus tricolor
Scolopsis cancellatus
Siganus puellus
Zebrasoma veliferum

order of importance, the pelagic *Stolephorus* spp., *Spratelloides* spp., *Herklotsichthys* spp. and *Sardinella* spp. Those of the families Apogonidae and Atherinidae are of secondary importance (Evans and Nichols, 1984). The pelagic group of baitfish was the most important prey for most baitfish predators (Table 8). However, *Caranx melampygus, Cephalopholis miniata, C. boenack, C. sexmaculata, Chirocentrus dorab, Epinephelus ongus* took mainly Apogonidae; and *Lutjanus ehrenbergi, L. fulvus* and *Sphyraena barracuda* took Atherinidae. All baitfish made up nearly 25% of the combined diets and the important pelagic baitfish groups contributed 19%.

The gill net catch rates of the major baitfish predators at each sampling site are shown in Table 9. Baitfish predators made up 6% of the catch at Tulagi, 16% at Munda and 12% at Vona Vona.

The 28 major baitfish predators comprised 22% of overall competition catch weight (Table 10). More than half the weight was contributed by

Table 8. Percentage contribution by dry weight of baitfish to the diet of the 28 major baitfish predators in Solomon Islands (1 = Apogonidae; 2 = Atherinidae; 3 = Caesionidae; 4 = Clupeidae [unidentified]; 5 = Engraulidae [unidentified]; 6 = Herklotsichthys spp.; 7 = Sardinella spp.; 8 = Spratelloides delicatulus; 9 = S. gracilis; 10 = S. lewisi; 11 = Spratelloides spp. [unidentified]; 12 = Stolephorus devisi; 13 = S. heterolobus; 14 = Stolephorus spp. [unidentified]).

	Baitfish													
Predator species	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Atule mate	—	16.1	—	—	—	3.1	—	4.9	—	—	—	—	—	42.9
Auxis thazard	—	—	—	2.2	—	—	—	17.7	—	—	—	—	—	—
Carangoides bajad	7.7	—	—	—	—	—	—	19.7	—	—	39.5	—	—	1.9
Caranx melampygus	6.1	2.3	—	0.9	—	—	—	0.3	—	—	2.8	—	—	2.8
Cephalopholis boenack	17.6	2.6	—	—	—	2.6	—	—	—	—	—	—	—	—
Cephalopholis microprion	—	—	—	—	—	—	—	—	—	—	—	—	—	26.7
Cephalopholis miniata	57.6	—	—	—	—	—	—	—	—	—	—	—	—	10.0
Cephalopholis sexmaculata	85.1	—	—	—	—	—	—	—	—	—	—	—	—	—
Chirocentrus dorab	21.8	—	—	—	—	—	—	2.7	—	—	—	—	—	—
Epinephelus ongus	20.0	—	—	—	—	—	—	—	—	—	—	—	—	—
Euthynnus affinis	0.7	0.1	—	—	—	—	—	3.8	—	—	—	—	71.2	12.4
Gazza minuta	3.5	—	—	—	—	—	—	—	—	1.1	0.6	13.8	19.1	22.8
Lutjanus biguttatus	—	—	—	—	—	—	—	—	—	—	—	10.4	—	33.3
Lutjanus ehrenbergi	10.2	53.0	—	—	—	—	—	21.3	—	—	2.2	—	—	—
Lutjanus fulvus	—	10.1	—	—	—	—	—	—	—	—	—	—	—	—
Lutjanus semicinctus	0.4	—	—	—	—	10.1	—	—	—	—	—	—	—	—
Lutjanus vitta	—	—	—	—	—	—	—	69.6	—	—	—	—	—	—
Megalaspis cordyla	—	1.3	—	—	—	—	—	34.1	—	—	6.2	8.2	—	29.3
Plectropomus leopardus	—	—	—	—	—	41.2	—	—	—	—	—	—	—	—
Rastrelliger kanagurta	1.8	—	—	—	—	—	—	0.2	—	1.2	—	—	—	68.5
Scomberoides lysan	—	12.0	2.1	1.1	—	3.8	—	24.0	1.3	—	4.8	—	6.5	22.6
Scomberoides tol	—	3.7	—	—	—	—	—	11.0	—	—	9.2	—	12.7	20.9
Scomberomorus commerson	—	—	—	—	—	—	19.7	—	—	—	—	—	—	1.9
Sphyraena barracuda	—	9.9	—	3.0	—	—	—	—	—	—	—	—	—	—
Sphyraena obtusata	—	—	—	—	—	—	—	3.8	—	5.6	0.2	7.0	—	79.1
Sphyraena putnamiae	0.1	5.9	—	—	—	17.5	—	3.7	—	—	—	—	—	—
Sphyraena qenie	—	—	—	—	—	56.7	—	—	—	—	—	26.9	—	16.4
Tylosurus crocodilus	—	—	—	—	—	51.6	—	—	7.6	—	—	—	—	—

Table 9. Gill net catch rates (cr) (g per 100 m net per hour) of major baitfish predators at the three sampling sites in the Solomon Islands.

	Sampling site					
	Tulagi		Munda		Vona Vona	
Predator species	cr	%cr	cr	%cr	cr	%cr
Atule mate	—	—	3.0	0.5	3.5	0.4
Carangoides bajad	—	—	2.4	0.4	2.4	0.3
Caranx melampygus	1.5	0.6	.17.2	2.6	27.3	3.0
Cephalopholis boenack	0.2	<0.1	—	—	—	—
Chirocentrus dorab	1.3	0.5	1.8	0.3	4.5	0.5
Epinephelus ongus	—	—	0.3	<0.1	—	—
Euthynnus affinis	—	—	7.0	1.0	—	—
Gazza minuta	—	—	—	—	<0.1	<0.1
Lutjanus ehrenbergi	—	—	—	—	0.8	<0.1
Lutjanus fulvus	—	—	1.0	0.1	0.6	<0.1
Lutjanus semicinctus	—	—	0.3	<0.1	—	—
Megalaspis cordyla	—	—	—	—	0.7	<0.1
Rastrelliger kanagurta	5.0	1.9	30.8	4.6	9.4	1.0
Scomberoides lysan	1.3	0.5	23.9	3.6	25.5	2.8
Scomberoides tol	—	—	15.6	2.3	18.4	2.0
Sphyraena barracuda	2.3	0.9	—	—	0.3	<0.1
Sphyraena putnamiae	—	—	2.7	0.4	9.3	1.0
Tylosurus crocodilus	3.6	1.4	2.2	0.3	2.8	0.3
Overall	15.2	5.9	108.2	16.1	105.5	11.6
Total catch rate	255.8		669.5		900.9	

Table 10. Percentage contributions of major baitfish predators to the catches (by weight) of fishing competitions.

		Munda			Vona Vona	
Predator species	Overall	1	2	3	1	2
Auxis thazard	0.3	—	—	2.0	—	—
Carangoides bajad	0.3	—	0.6	0.8	—	—
Caranx melampygus	3.4	4.0	8.2	2.0	1.6	—
Cephalopholis boenack	2.2	0.1	1.8	0.2	3.0	6.2
Cephalopholis microprion	0.3	0.1	0.9	0.1	—	0.4
Cephalopholis miniata	0.2	—	0.9	—	0.1	—
Cephalopholis sexmaculata	0.1	—	0.2	—	0.2	—
Chirocentrus dorab	0.1	—	—	—	—	0.8
Epinephelus ongus	0.6	0.5	2.8	—	1.1	0.5
Euthynnus affinis	0.8	3.1	1.8	—	—	—
Lutjanus biguttatus	0.1	—	—	—	0.1	0.2
Lutjanus ehrenbergi	<0.1	—	0.1	—	—	0.2
Lutjanus fulvus	1.1	0.9	1.4	—	1.2	2.4
Lutjanus semicinctus	0.6	—	1.6	0.2	0.4	—
Lutjanus vitta	0.3	0.4	1.0	—	—	—
Megalaspis cordyla	0.5	0.7	1.0	0.8	—	—
Plectropomus leopardus	1.6	3.4	2.1	2.4	0.8	0.3
Scomberoides lysan	<0.1	—	—	—	0.1	—
Scomberomorus commerson	7.3	35.5	3.7	17.6	—	1.2
Sphyraena barracuda	1.8	1.8	4.9	2.8	—	—
Sphyraena putnamiae	0.3	0.6	—	—	0.6	—
Tylosurus crocodilus	0.3	0.6	—	—	0.7	—
Total % of overall weight	22.2	51.7	33.0	28.9	9.9	12.2
Overall weight (kg)	989	112	251	163	377	857
Overall number of individuals	3548	157	906	128	1593	764

troll-caught species such as *Scomberomorus commerson, Caranx melampygus, Euthynnus affinis* and *Sphyraena barracuda.*

Maldives

A total of 1818 fish of 118 species weighing 1054 kg were caught by gill netting. The overall catch rate was 1094 g; the species with a catch rate over 1 g are listed in Table 11. Unlike Solomon Islands, gill net catches, these were not dominated by sharks, which in Maldives made up only 10.5% of overall weight. The dominant group were the 13 species of Scaridae (parrotfishes) which comprised 21% of the catch by weight. The single most important species by weight was *Valamugil seheli,* while the most numerous species was *Upeneus sulphureus.*

Table 11. Overall gill net catch rates (cr) from Maldives for all species where the catch rate exceeded 1 g per 100 m net per hour) and the total number (n) of each species caught.

Species	cr (g per 100 m net per hour)	n
Valamugil seheli	63.8	61
Sphyraena forsteri	63.2	138
Scarus prasiognathus	60.1	47
Caranx melampygus	56.5	102
Upeneus sulphureus	56.0	307
Cetoscarus bicolor	51.9	18
Trachinotus russelli	49.0	113
Triaenodon obesus	46.9	7
Carcharhinus melanopterus	45.0	9
Sphyraena novaehollandiae	36.6	67
Hipposcarus harid	34.0	49
Carangoides orthogrammus	28.6	24
Carcharhinus amblyrhynchos	27.0	7
Naso brachycentron	26.6	12
Scarus rubroviolaceus	26.3	19
Caranx sexfasciatus	26.0	34
Carcharhinus wheeleri	23.3	2
Carangoides ferdau	21.0	17
Kyphosus cinerescens	20.6	29
Scarus frenatus	14.0	31
Gerres acinaces	13.7	49
Scarus enneacanthus	12.7	13
Pseudobalistes flavimarginatus	12.6	4
Paraupeneus barberinus	12.5	23
Gerres oyena	12.3	39
Strongylura leiura	12.0	18
Scarus gibbus	11.0	5
Gymnosarda unicolor	10.2	2
Scarus scaber	9.5	48
Tylosurus acus	9.1	10
Aphareus furcatus	8.9	17
Sargocentron spiniferum	8.5	14
Myripristis adustus	8.5	85
Monotaxis grandoculis	8.3	14
Naso unicornis	7.7	5
Albula vulpes	7.2	4
Lutjanus bohar	7.2	4
Kyphosus vaigiensis	7.1	9
Lutjanus monostigma	6.8	7
Crenimugil crenilabis	6.7	8
Balistoides viridescens	6.4	2
Siganus argenteus	5.5	16
Siganus stellatus	5.4	16
Macolor niger	5.0	4
Scarus ghobban	5.0	5
Siganus puelloides	4.6	12
Scomberoides lysan	4.6	6
Aetobatus narinari	4.4	1
Cephalopholis argus	4.3	11
Ostracion cubicus	4.3	3
Lutjanus gibbus	4.0	9
Lethrinus xanthochilus	3.7	4
Polynemus sexfilius	3.7	8
Tylosurus crocodilus	3.6	3
Amblygaster clupeoides	3.6	21
Paraupeneus cyclostomus	3.5	6
Acanthurus nigricauda	3.3	15
Plectorhinchus orientalis	3.2	3
Cheilinus trilobatus	3.2	8
Lethrinus harak	2.9	4
Epinephelus tauvina	2.9	2
Acanthurus tennenti	2.5	10
Lutjanus kasmira	2.3	16
Neoniphon opercularis	1.9	11
Caesio lunaris	1.5	5
Scarus niger	1.5	3
Euthynnus affinis	1.5	3
Orectolobus sp.	1.3	1
Lethrinus ramak	1.3	2
Myripristis hexagona	1.2	16
Epinephelus faveatus	1.2	1
Ostracium tuberculatum	1.2	1
Coris gaimardi	1.1	8
Heniochus sp.	1.1	6
Neoniphon argenteus	1.0	12
	1093.9	1818

Diet analyses indicated that 10 species ate baitfish. These predators are listed in Table 12; collectively they made up 22% of the catch by weight (238 g) and numbers (409 fish).

Comparison of baitfish taken by predators and by the baitfishery

Caesionidae, *Spratelloides gracilis* and Apogonidae together comprise over 90% of the total baitfish catch, with *S. gracilis* (25%) the single most important species (Anderson and Hafiz, 1988). *S. gracilis* and Apogonidae are not large components of the diets of predators, but Caesionidae may be important, although our sample sizes are low.

Discussion

The competition data provide the only source of information on the species composition of the subsistence fishery of the baitfish ground areas of

Table 12. Percentage contribution by dry weight of baitfish to the diet of the 10 major baitfish predators in Maldives (1 = Apogonidae; 2 = Atherinidae; 3 = Caesionidae; 4 = Clupeidae [unidentified but not *Spratelloides* spp.]; 5 = *Spratelloides delicatulus*; 6 = *S. gracilis*; 7 = *Stolephorus heterolobus*; n = number of stomachs analysed).

Predator species	n	1	2	3	4	5	6	7
Aphareus furcatus	13	—	—	52.0	—	1.0	1.5	—
Carangoides orthogrammus	22	2.7	—	—	—	—	—	—
Caranx melampygus	82	0.3	8.1	—	—	0.2	—	—
Caranx sexfasciatus	13	13.3	—	—	—	—	—	—
Euthynnus affinis	3	—	—	—	—	21.2	8.3	4.5
Gymnosarda unicolor	2	—	—	100.0	—	—	—	—
Lutjanus kasmira	5	—	—	—	—	61.0	—	—
Scomberoides lysan	4	—	—	—	—	97.4	—	—
Sphyraena forsteri	123	—	—	—	86.0	—	—	—
Sphyraena novaehollandiae	65	—	—	—	99.0	—	—	—

Solomons Islands. The proportions of different fishing methods used in the competitions are similar to those indicated by the results of the subsistence fishery survey (Leqata et al., these Proceedings). The survey also showed that droplining (including handlining) was the most commonly used fishing technique but that trolling was also important at Munda. The only comparable data from the same region of the Pacific are those of Wright and Richards (1985) on the fishery of the Tigak Islands of northern New Guinea. They drew on records from a fish-buying depot and monitored the catches of four families of fishermen. A total of 253 species of 43 families were recorded, which is broadly comparable with the 183 species of 31 families caught in the smaller Solomons competitions. If netting, the method of the small-scale commercial fishery in the Tigak Islands, is excluded from the data, the subsistence fishery catches about 75% by linefishing and 20% by spearfishing. The competitions in Vona Vona lagoon had a similar result, although at Munda trolling was also important, probably because of greater use of outboard-powered canoes.

The overall similarity of the competition catches and the Tigak Islands catches, together with supporting data from Solomon Islands fishery survey (Leqata et al., these Proceedings), suggests that the competitions may approximate the landings of the subsistence fishery. Therefore it is significant that most of the fish caught in the Solomons competitions, and almost all caught by droplining (the favoured method) are not baitfish predators. Most of the important carangid predators of baitfish (e.g. *Scomberoides* spp.) are seldom or never caught by the subsistence fishery. *Caranx melampygus* is an exception, but although it is a baitfish predator, baitfish make up only 14% of its varied diet. The lutjanids and serranids are important in the fishery and some are baitfish predators, but they mainly eat baitfish of secondary importance such as apogonids. Several troll-caught species such as *Euthynnus affinis* feed predominantly on baitfish and trolling was important at Munda in terms of weight of fish landed. However, droplining was still the most common method at Munda. Therefore unless there is a marked increase in trolling among fishermen, there is little likelihood of a significant direct trophic interaction between the subsistence fishery and the commercial tuna baitfishery.

Reef fish form only a small proportion of the artisanal and subsistence fisheries in Maldives (Anon., 1984). However, catches are increasing in tourist areas. At least four baitfish predators — *Aphareus furcatus, Caranx melampygus, C. sexfasciatus* and *Sphyraena forsteri* — are significant in the developing reef fishery (Waheed, 1988; Van der Knaap, 1988). Baitfish groups such as caesionids and apogonids that are important in the diet of many sedentary reef-attached species are a more important component of the baitfishery in the Maldives than they are in the Solomons. This information together with the gill net catch data, suggests that baitfish predators might possibly form a significant proportion of future artisanal catches.

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Subsistence Fishing in Solomon Islands and the Possible Conflict with Commercial Baitfishing

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Abstract

A survey was carried out on a total of 495 households, representing a population of 3 016, at three sites in Solomon Islands using a purpose-designed questionnaire in order to obtain information relating to the subsistence fishing activities of rural communities. Results indicate that the lagoon areas near rural communities are most commonly used as fishing grounds. Droplining and handlining are the dominant fishing techniques. Fishing was not identified as a major source of income at any of the sites; fishing takes place on average 1–3 times a week, primarily for home consumption.

A close correlation was found between the results of the survey and catch and effort data obtained through organising fishing competitions; the latter appears to be an excellent means of rapidly assessing subsistence fisheries. The age composition of the population in each area, the amount of time spent fishing by different age groups, and the major types of bait used are also discussed.

COMMERCIAL fisheries in Solomon Islands are based on tuna resources estimated to have a sustainable yield of (at least) 75 000 t per year (Gibson, 1985). Current annual production is between 35 000 and 40 000 t, almost all of which is caught in and around the Main Group Archipelago (MGA).

The country's economy remains dominated by primary production of commodities such as tuna, palm oil, copra and cocoa, of which the commercial tuna fisheries play a dominant role: fish and fish products generated export revenues of around SI$84.7 million in 1988, accounting for just under 50% of the foreign exchange earnings for that year (SIG, 1988).

The majority of tuna caught in the country is taken using the pole-and-line method (See Nichols and Rawlinson, these Proceedings). The pole-and-line fleet, which relies on a nightly supply of suitable baitfish species, catches bait at night on specific lagoon/reef areas known as baitgrounds using powerful underwater lights and stick-held lift nets. Pole-and-line fishing started in 1971, when the Solomon Islands Government (SIG) agreed to a survey of the tuna and bait resources in the country by Taiyo Fishing Company of Japan. This successful survey led to the formation of a joint venture company, Solomon Taiyo Ltd, whose pole-and-line fleet has grown over the years to 22 vessels of 60–100 gross registered tonnes today. A second company, National Fisheries Developments Ltd. was established in 1977, and today operates a fleet of 11 pole-and-line boats. These commercial fishing companies are among the major non-government employers in the country (Cook, 1988).

In recognition of the importance of the baitfishery to the operations of the pole-and-line fleet, SIG initiated a baitfish sampling program in 1982 to begin collection of biological data which would ultimately provide an insight into the fisheries dynamics and biology of the important bait species (Nichols, 1988). This program was expanded in 1986 with the implementation of a three year collaborative research program between the Fisheries Department and the Commonwealth Scientific and Industrial Research Organisation

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(CSIRO) to investigate in more detail the biology and population dynamics of the major baitfish species. Funding for this Baitfish Research Project (BRP) was provided by the Australian Centre for International Agricultural Research (ACIAR).

One of the major objectives of the program was to determine possible adverse effects of commercial tuna baitfishing in Solomon Islands on the larger predatory fishes which form the basis of the traditional subsistence fishery. A concern commonly expressed by rural fishermen is a belief that the removal of baitfish by the night-time baitfishing activities of the commercial pole-and-line fleet results in a reduction of prey for piscivorous reef fish, hence a reduction in subsistence catches, as the reef fish are believed to move away to areas of low baitfishing activity in search of prey. In order to achieve this objective, reef fish communities at three target sites (two important baitfishing grounds and one non-baitfished 'control site') were sampled using a variety of gillnets and other gear (Blaber et al. these Proceedings). Stomach content analysis of the reef fish caught has indicated the relative composition of baitfish in the diet of these fishes (Blaber et al., 1990).

In order primarily to assess the importance of the trolling technique which was identified by Blaber et al. (1990) as the fishing method used by subsistence fishermen that catches mostly baitfish predators, a questionnaire survey was carried out on the rural populations at the three target sites: Tulagi, Munda and Vona Vona. In addition, the survey allowed the collection of more comprehensive data on the rural subsistence fishery, which in turn indicated the fishing techniques most commonly employed by rural fishermen, the areas most commonly fished and a number of other factors regarding the nature of the fishery.

This paper details the methodology employed and results obtained from the survey.

Method and Materials

Objectives

The primary objective of the questionnaire survey was to determine by interviewing as many households as possible in the villages of Munda and Vona Vona Lagoon and the villages around Tulagi the following:

- — the main fishing grounds used by rural fishermen e.g. outside reef edge, inside lagoon, etc;
- — the main fishing methods used;
- — the main fishing gears and assets owned;
- — the relative importance of fishing to household income;
- — who goes fishing in each household and what percentage they represent of the total population; and
- — the amount of time spent fishing.

This data was then used to assess:

- — the importance of fishing for food and income;
- — the areas fished and whether these overlap with baitfishing operations; and,
- — the major fishing methods used in the subsistence fishery.

The survey also provided an opportunity to obtain subsidiary information regarding the rural population, e.g. age distribution, frequency of eating and sources of obtaining fish, and types of bait important to the rural fisherman.

Sampling Sites

Two major tuna baitfishing grounds, Munda in the Roviana lagoon, Western Province and the baiting area adjacent to Tulagi in Central Islands Province, plus a non-baitfished site, Vona Vona Lagoon in the Western Province, were the target sites for the baitfish project (refer map — Fig. 1). Munda and Tulagi baitgrounds are close to the two tuna shore bases at Noro on New Georgia Island and Tulagi base in the Florida Islands, respectively, and are therefore heavily utilised by pole-and-line boats for baitfishing after off-loading the tuna catch at the bases (Evans and Nichols, 1984). Vona Vona Lagoon which is physically similar to Munda baitground, is located nearby, and has no active baitfishery but a very active subsistence fishery. It was therefore chosen as the control site for the BRP, making the logistics of sampling reef fish and baitfish at these two sites easier.

Essentially, Munda (in the Roviana Lagoon) and Vona Vona Lagoon are very similar; they are shallow, up to 40 metres in depth and semi-enclosed by fringing coral reefs. These lagoons contain numerous small islands and coral reefs with inter-tidal reef flats. The Tulagi baitground is somewhat different: the island of Tulagi itself is situated among the high islands of the Florida Islands group to the north of Guadalcanal (Fig. 1). No well defined lagoon system exists; the individual islands are surrounded with fringing reefs and separated by considerable depths of water, exceeding 100m in places. The baitfishery is active in an area between the two major high islands, which are separated by a deep, mangrove lined channel, running approximately north-south. Active subsistence fisheries exist in all three sites.

Initially, a rapid reconnaissance survey of a few randomly chosen households in each village from

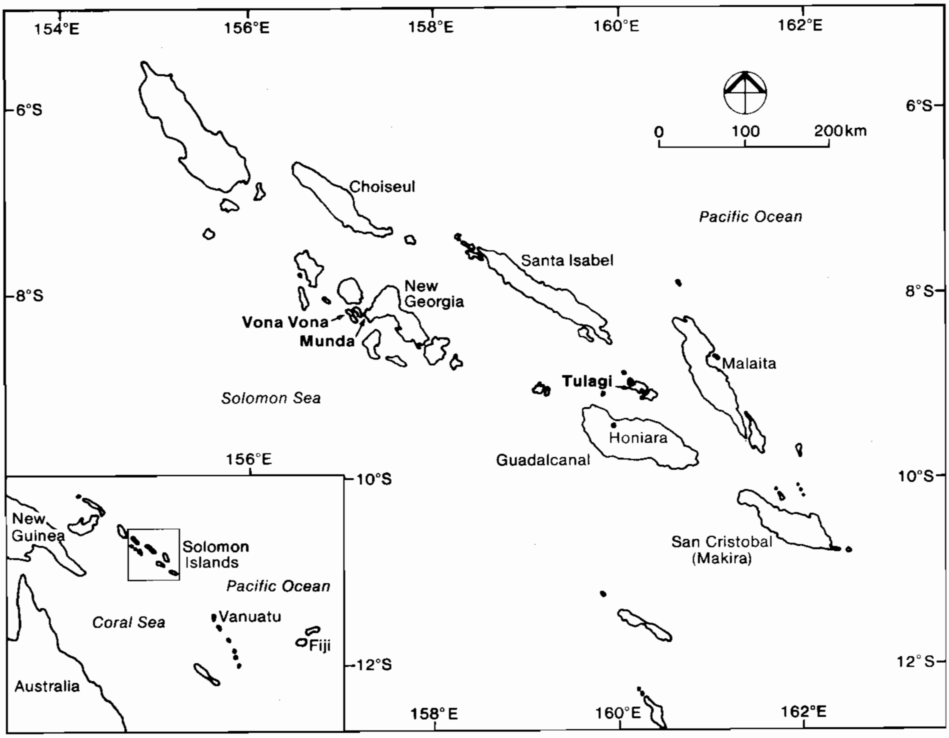

Figure 1. Map of the Solomon Islands, showing the questionnaire survey areas: Munda (Roviana Lagoon) and Vona Vona Lagoon in the Western Province, and Tulagi in the Florida Islands, Central Isles Province.

the three sites was undertaken using a purpose designed survey sheet (Appendix 1). This initial survey yielded useful insights into the nature of the subsistence fishery, and facilitated the construction of a purpose-designed questionnaire sheet for the comprehensive subsistence fishing survey (Appendix 2). As many households at each of the three survey sites as possible were interviewed, with questions directed to the head of the household in most cases. Both questionnaire formats incorporated the ideas of other authors (eg. Cook, 1988; Felfoldy-Ferguson, 1988; Munro and Fakahau, 1988).

Publicity

Prior to the survey operation, each village in the survey area was forewarned through radio messages, word of mouth, public announcements through the churches and visits to the villages concerned shortly before the survey team arrived. After notification, a house to house series of interviews was carried out. The survey team consisted of four members, and a period of 1–2 weeks was spent covering each site. The only major problem encountered during the survey was that on a few occasions, due to the absence of the occupants at the time of the visit, some households were not sampled. Some households were reluctant to answer questions from expatriate team members, which was overcome by being accompanied by local members of the community, who, in such cases, acted as interpreter.

Results

A total of 214 households (1313 persons) were surveyed, in the Munda area, 159 households (1027 persons) in Vona Vona and 122 households (676 persons) at Tulagi during the course of the field work (Table 1). This represented an average coverage rate of 69.4% of households in all three areas combined when compared with published census statistics, and 65.1% coverage of the population (Government Statistics Office, 1989).

On completion of all surveys from the three sites, the data collected were compiled and analysed using DBASE II software on a HP 150II micro-computer. Graphical presentation of data was achieved using Drawing Gallery software on a HP Vectra micro-computer.

Table 1. Estimated coverage of the rural population at each survey area.

Site	Est. Population	Surveyed Population	% Cover	Est. Households	Surveyed Households	% Cover	Persons per House (Census)	Persons per House (Survey)
Munda	2 111	1 313	62	326	214	66	6.48	6.14
Vona Vona	1 505	1 027	68	215	159	74	7.00	6.46
Tulagi	1 020	676	66	172	122	71	5.93	5.54

Note: Estimated values from 1986 Population Census (Government Statistics Office, 1989).

Fishing grounds important to the subsistence fishery

Fishing areas in the questionnaire were divided into eight distinct types: 'DISTANT' grounds, meaning fishing areas well away from the lagoon/reef edge, 'OUTER EDGE' meaning the area of the lagoon/reef edge drop-off, 'OUTER REEF', meaning fishing actually on the relatively shallow zone along the lagoon reef, 'DEEP LAGOON' meaning the deep water within the lagoon but away from shoals and islands, 'SHALLOW LAGOON' meaning shallow water areas within the lagoon near islands, shoals, cays etc., 'SHORE' meaning fishing along and from the shore-line, 'MANGROVES' meaning fishing within mangrove systems, and 'OTHERS': any other nominated fishing area not covered adequately by the foregoing.

Fishermen were asked during the survey to name the fishing areas they usually use in decreasing order of importance. These rankings were then assigned a 'score' indicating importance (8 for the most important to 0 for areas never fished). A weighted index of importance for each ground was then calculated by summing the score for each fishing area across all households, and then dividing the score by the number of households surveyed.

Figure 2 is a histogram of weighted indexed values calculated for each fishing area for all three survey sites (a score of 8 on the y-axis would indicate that every household in an area considered a particular fishing ground as number one in importance). It is clear that the shallow and deep areas within the lagoon are the primary and secondary fishing areas used by the subsistence fisherman in all three sites, with fishing along the shore coming a close third in all cases: this is primarily due to women and children casting fishing lines from the shore. The outer edge of the lagoon reef and fishing on outer reefs (reefs seaward of the lagoon edge) were of roughly equal importance, after fishing from shore.

Fishing along mangroves is more important in Tulagi than Munda or Vona Vona, due to the fact that there is no true 'lagoon' environment at the Tulagi baitground, and also the area abounds with mangrove systems along the shores in close proximity to the villages. Munda also has extensive mangrove systems, but these are only actively fished by the small communities residing very close to them. Fishing on distant reefs (well away from the lagoon and its seaward reef) was of equal, if minor, importance in all three sites.

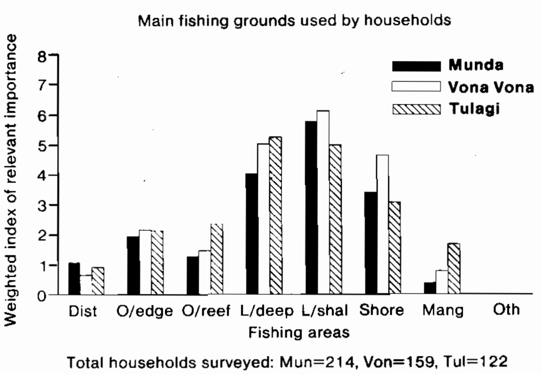

Figure 2. Main fishing grounds used by subsistence fishermen at Munda, Vona Vona and Tulagi.

Fishing methods used

A similar weighted index of relative importance was calculated for the fishing methods named by fishermen. The resulting histogram is shown in Figure 3. Fishing methods employed in the sub-

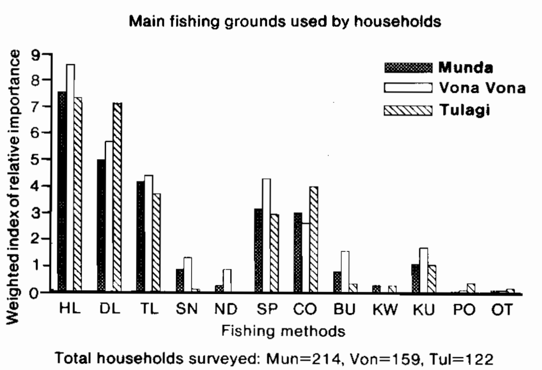

Figure 3. Main fishing methods used by subsistence fishermen at Munda, Vona Vona and Tulagi. Handlining = HL, droplining = DL, towlining (or trolling) = TL, set-net = SN, net-drive = ND, spearfishing = **SP**, collecting = CO, Buna = BU, Kwarao = KW, Kura = KU, Fishing Pole = PO, and others = OT.

sistence fishery include handlining droplining, towlining (or trolling), using set-nets, a technique called net-driving, spearfishing with powered spearguns or simple hand-spears, collection of sessile organisms at low tide or diving on shallow reefs using goggles or a face-mask, using 'custom techniques' (see below), using a fishing pole and one or two other very minor techniques.

In all three sites, it was apparent that handlining (fishing with an un-weighted monofilament line and a baited hook, whereby the hook is thrown away from the boat, left to sink and then slowly drawn back), is the most important fishing method used, with droplining (vertically fished handlines with weights attached to fish on the bottom) coming a close second. Both handlining and droplining were identified as the dominant fishing technique at all three sites, with towlining (or trolling, where a baited hook or artificial lure is towed behind the boat), spearfishing and collecting being roughly equal in third place.

Certain traditional 'custom' methods of fishing, although well known, were of relatively minor importance. These include methods such as: 'Buna' — which utilises natural plant toxins to intoxicate fish in shallow waters during periods of the year when tidal range is smallest; 'Kwarao' whereby jungle vines are used to surround coral-associated fish schools in shallow water by a large number of villagers, and 'Kura' (a technique which is used only in deep water outside the lagoon) where a stone is used to take the hook to the bottom, whereupon the line is pulled, releasing the stone (coconut fronds wrapped around the stone stay attached to the hook and act as a lure). Also of minor importance was the use of pole-and-line techniques (with baited hooks or lures), set nets (anchored gill-nets) and drive netting (where a gill-net is placed near the reef, and groups of villagers form a semicircle around the fish and drive them into the net by splashing the water). Very few other fishing methods were named as being important to the fishermen.

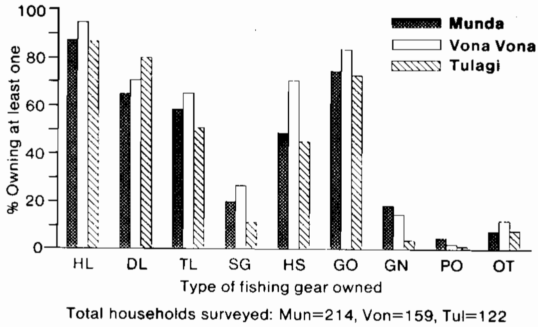

Figure 4(a). Percentage of households owning at least one item of each type of fishing gear at Munda, Vona Vona and Tulagi. Handline = HL, dropline DL, towline TL, powered speargun = SG, simple hand-spear = HS, goggles or face-mask = GO, gill-net = GN, fishing pole = PO and others = OT.

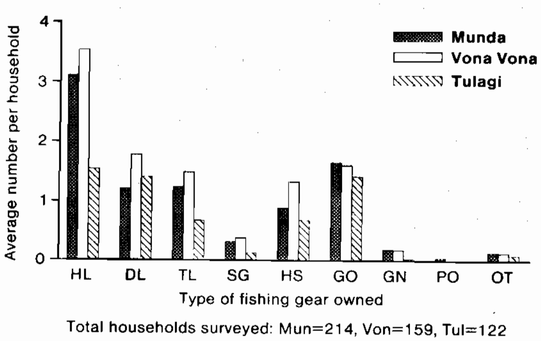

Figure 4(b). Average number of main items of fishing gear owned by households at Munda, Vona Vona and Tulagi.

Fishing gears owned

Figure 4(a) details the percentage of households owning at least one of each gear type: fishing gear types used in the subsistence fishery include handline, dropline, towline powered speargun, simple hand-spear, goggles or face-mask, gill-net, fishing pole and others.

It is apparent that handlines, droplines and goggles are the major fishing items owned at the survey sites. Towlines and simple hand-spears were also owned by more than 50% of households. Sophisticated gear types involving substantial capital costs, such as gill-nets and powered (elasticated) spearguns, were owned by far fewer households, especially in the Tulagi area. Less than 5% of households own fishing poles at all sites. The relatively high percentage ownership of handspears in Vona Vona is attributed to the greater importance of this method of fishing in the Lagoon. Squid are commonly taken using hand-spears and used for bait.

Figure 4(b) details the average number of each fishing gear type owned by households at each site. Households in Munda and Vona Vona possessed more than three handlines on average, and about 1.5 handlines per household in Tulagi. The numbers of droplines, towlines, handspears and goggles owned were roughly equal at around 1–2 per household.

Fishing assets owned

The questionnaire asked for information regarding the type of boats used by the rural populace. Fishing boats were divided into boats with sails, paddle-powered dug-out canoes, dug-outs with outboard motors, fibreglass canoes (always powered by outboards), and other boats. Figure 5(a) details the percentage of households at each site owning each boat type; the ownership of insulated fibreglass fish boxes or 'eskies' (in which fish is preserved in ice) is also indicated.

The commonest fishing platform used by households in all three sites is the dug-out paddle canoe: the percentage of households owning at least one at each of the three areas was Munda 64%, Tulagi 77% and Vona Vona 82%. These typically range from 3 to 5 metres in length, and are usually powered by a single paddle, although outboard motors (generally 8–25 hp) or sails are sometimes seen on such home-made canoes. Fibreglass canoes, requiring outboard motors for propulsion, are very scarce in Vona Vona, and less than 10% of households in Munda and Tulagi possessed such items. Sail powered canoes, although important in other areas of the Pacific, are rarely seen in Solomon Islands: less than 8% of households at each survey site possessed sail-powered canoes. Virtually no other fishing platform is used in the subsistence fishery besides the canoe.

Fish eskies are owned by around 9% of the households in Tulagi and Munda, but only 2.5% of households in Vona Vona. This is a reflection of the fishing activity at the three sites: fishermen in Munda and Tulagi are more active at selling fish to guest-houses, businesses and large urban populations than their counterparts in the Vona Vona Lagoon, where fishing is predominantly a subsistence activity.

Figure 5(b) indicates the importance of the paddle-powered dug-out canoe in the rural fishery, and other fishing assets owned, expressed

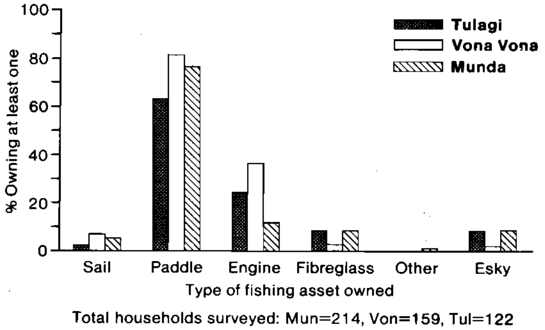

Figure 5(a). Percentage of households owning at least one item of each type of fishing asset at Munda, Vona Vona and Tulagi.

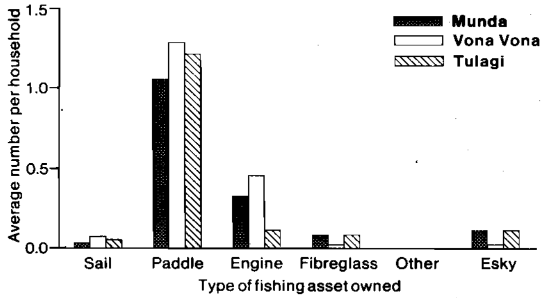

Figure 5(b). Average number of main fishing assets owned by households at Munda, Vona Vona and Tulagi.

as an average of the number owned per household. The pre-eminence of the dug-out paddle-canoe is clearly indicated, with an average of between 1 and 1.5 owned per household at the three sites. Munda and Vona Vona households possessed on average more outboard engines than Tulagi, reflecting the fact that Vona Vona people especially are basically isolated from main commercial shipping lines, and rely almost totally on outboards for daily carriage of goods. The same situation exists in Munda, where small-scale commercial activities are heavily dependent on canoe transport. Tulagi, on the other hand, is well serviced by private and commercial shipping to Honiara.

Relative importance of fishing for income

Source of income as stated by the rural population was indexed and weighted in the same way as previously described. Figure 6 indicates the relative importance of the different sources of income at each survey site. Very few other sources of monetary income were identified during the survey in addition to marine resource exploitation, copra

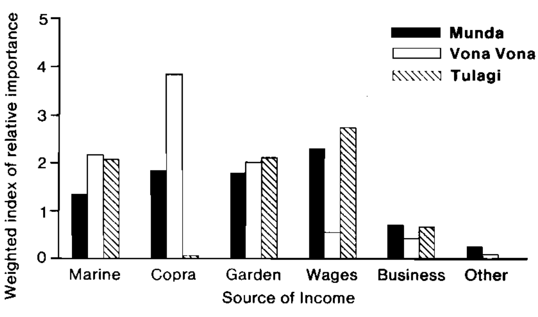

Figure 6. Main sources of income for households at Munda, Vona Vona and Tulagi.

production, sale of garden produce, formal employment for wages, and small-scale business activities.

Copra production as a source of income is the dominant activity in Vona Vona, where the population is spread over a large number of small, low-lying islands, on which coconut plantation smallholdings thrive. Income derived from wages is more important in Munda and Tulagi, where Government administrative centres and other formal employment opportunities exist. Income derived through the sale of garden produce is of roughly equal importance in the three survey areas: income derived from the sale of excess agricultural production is common throughout the Solomons, especially in areas of higher population density on the main islands. Small-scale business activities, mostly store operators and fuel suppliers, are of roughly equal importance.

Participants in the rural fishery and amount of time spent fishing

Age groupings for participants in the rural fishery are divided into adults (>14 years) and children (<14 years) of each sex. Stacked histograms indicating the frequency of fishing for each population

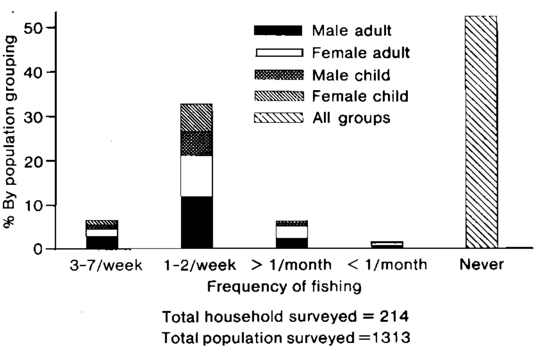

Figure 7(a). Frequency of fishing by population grouping at Munda.

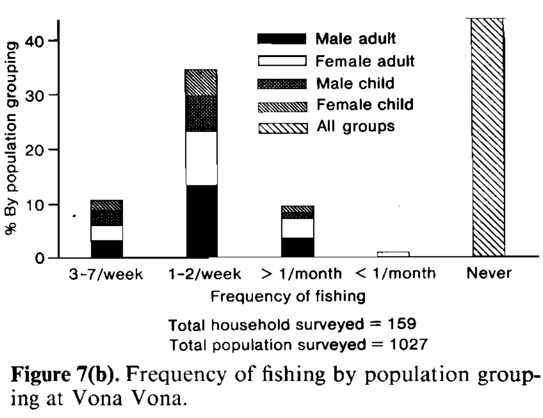

Figure 7(b). Frequency of fishing by population grouping at Vona Vona.

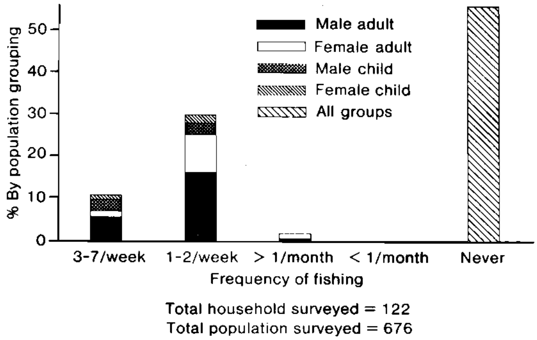

Figure 7(c). Frequency of fishing by population grouping at Tulagi.

grouping for Munda, Vona Vona and Tulagi are given in Figures 7(a) to 7(c) respectively.

A striking feature in the results obtained is that a considerable proportion of the population in each area reported that they never undertake fishing activities: 53% of the surveyed population in Munda, 44% in Vona Vona and 56% in Tulagi reported no fishing (these data were not broken down by age groups). In all three sites, each age group gave an average fishing frequency of 1–2 times/week. Males and females of both age groups fished in approximately the same proportions in Munda; both adult and child males are apparently slightly more active in the subsistence fishery in Vona Vona Lagoon, and in Tulagi, adult males are about twice as active as adult females in the fishery.

Age composition of the rural population

Figure 8 gives age structure information of the population at Munda, Vona Vona and Tulagi. It is strikingly apparent that the greater part of the population at all sites is very young (<19 years). Solomon Islands has one of the highest rates of

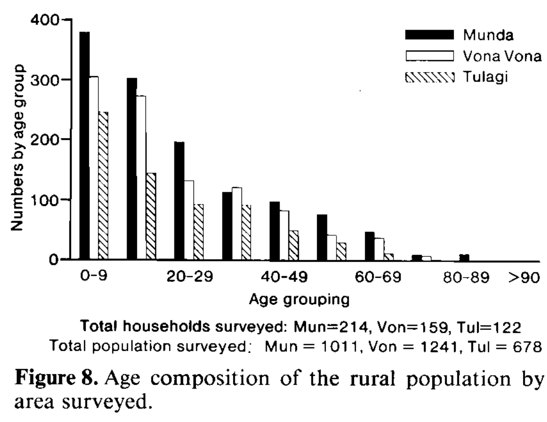

Figure 8. Age composition of the rural population by area surveyed.

population increase in the world at 3.5% per annum (Government Statistics Office, 1989). The 1986 Census estimated that 58% of the population of 285176 people were less than 19 years of age, a figure that is borne out by the questionnaire survey results. Such a rapidly growing population will continue to place increasing pressure on marine resources as a source of food and also for income-earning opportunities in the future, a fact that is primary concern to the Solomon Islands Government.

Fish consumption

Fish consumed by the rural populations surveyed comes from the following sources: fresh own caught, fresh bought (or bartered for) fish, free fish (i.e. fish given away by relatives/friends, or collected from the tuna fishing bases) or tinned fish (virtually no other sources were identified). Figure 9(a) indicates the weighted indices of relative importance calculated for each source of fish at each survey site. Own caught fish was the dominant source of fish for the rural people at all sites, especially in the more isolated Vona Vona Lagoon, where other options for obtaining fresh and tinned fish are fewer. Bought, free and tinned fish were of roughly equal importance at each site.

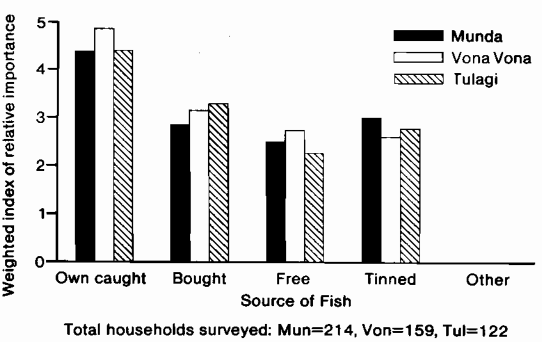

Figure 9(a). Source of fish consumed by households at each survey site.

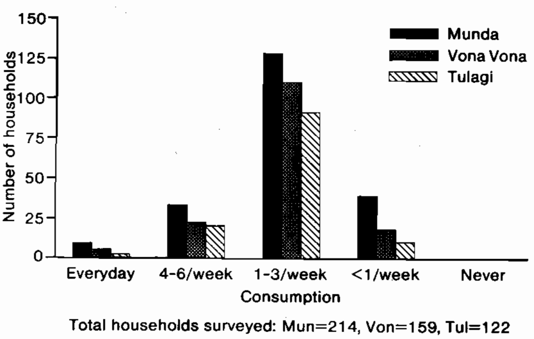

Figure 9(b). Frequency of fish consumption by households at each survey site.

Frequency of fish consumption is shown in Figure 9(b). It is apparent that at each site, fish is consumed on averge 1–3 times/week. No households reported that fish are never eaten. Both fish and shellfish are important sources of food throughout the Solomons, with an estimated per caput consumption of 60 kgs/year (SIG, 1984).

Fishing bait

An interesting insight into the important types of fishing bait used was given during the questionnaire survey, the results of which are shown in Figure 10. Major bait types include crab (mostly land hermit crabs), squids, small fishes (e.g. clupeids), big fish cut up for bait, and others (mostly octopus, but also sea shells.). Data were only collected for Munda and Vona Vona for which indices of relative importance were calculated. Results indicate that fishermen are fairly opportunistic in their choice of bait at each of the two sites, but squid as a bait is far more important in Vona Vona Lagoon than at Munda: the fishermen here consider squid highly as a bait, and often actively spear fish for them before a fishing trip. The practice of cutting up big fish for bait is less common as might be expected; such fish are better utilised for home consumption or sale.

Discussion

Fishing methods and gear used by rural fishing communities in Solomon Islands have been documented in the past in Marovo Lagoon, Western Province (Hviding, 1988), in Ontong Java, Malaita Province, (Bayliss-Smith, in press; Beasley, 1937; Lazarus and Beasley, 1937), on the island of Tikopia, Malaita Province (Firth, 1984), the island of Malaita, Malaita Province (Edge-Par-

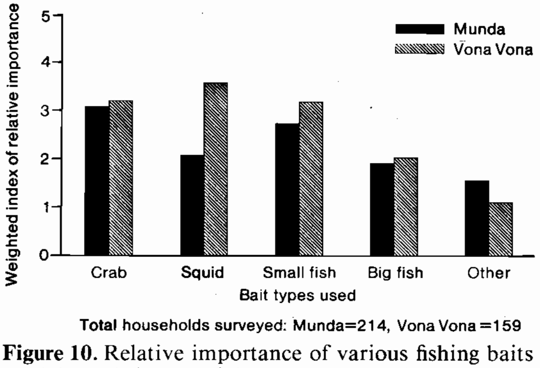

Figure 10. Relative importance of various fishing baits used by subsistence fishermen at Munda and Vona Vona.

tington, 1912), Isabel Island, Isabel Province (Edge-Partington, 1915), and the island of Santa Ana, Makira Province (Wata, 1985). A general account of fishing methods and gears in Solomon Islands is given by Griffiths (1944) and Anell (1955). The present study is, however, the first time a questionnaire survey of this kind has been carried out in Solomon Islands to obtain information regarding the activities of subsistence fishermen.

Based on population figures obtained from the 1986 Population Census, the questionnaire survey covered 66% of households in Munda, 74% in Vona Vona and 71% in Tulagi (Table 1). The survey therefore covered a representative proportion of the rural population in each site. The number of people per household as determined during the 1986 Population Census is also given in Table 1. The questionnaire survey estimated very similar numbers per household, indicating that the data collected can be considered accurate.

Importance of fishing for food and income

Almost 90 percent of the country's population reside in rural villages (Government Statistics Office, 1989). Subsistence fishing is therefore of primary importance as a source of food, and in some cases income, for rural communities.

While most of the catch is consumed by the family, there is considerable sharing of catch, especially in Vona Vona, among immediate 'wantoks' (relatives) and neighbours, and some sale of surplus production in the village or nearby population centres. Figure 6 indicates that income derived from fishing is not the major source of income at any site. The importance of copra as an income earner for households in Vona Vona is understandable considering the relative isolation of the area. In Munda and Tulagi many people have formal employment, as might be expected. The recent opening of Noro township to the north of Munda (where Solomon Taiyo Ltd. operate a tuna shore base and large cannery) has provided many in the area with full-time paid employment. The Noro cannery and township, which opened shortly after the survey finished, will become a major source of formal employment in the area.

Areas fished

In each of the three sites, it is evident that the subsistence fishery exploits mostly the inner lagoonal areas, in both shallow and deep areas. These are also the areas where commercial tuna baitfishing operations take place in order to provide a continuous nightly supply of baitfish for pole-and-line fishing operations (Evans and Nichols, 1984; Nichols and Rawlinson, these Proceedings). As a result, there is overlapping of fishing between baitfishing operations and the regular fishing grounds of the local people (in the areas around Munda and Tulagi — Vona Vona has no commercial baitfishery).

Although fishing grounds overlap, there is no direct competition between subsistence fishermen and the commercial pole-and-line boats as each is exploiting different resources. Indeed, it is often the practice of subsistence fishermen at Munda and Tulagi to fish around the underwater lights of the pole-and-line vessel at night while the vessel is baitfishing (after the bouke-ami net is hauled, predatory fish are sometimes caught along with the baitfish eg. carangids (Rawlinson, these Proceedings), and these are given free to the fishermen: this is, however, an increasingly rare event in recent times).

Fishing methods used

Hand-lining from either a dug-out paddle canoe or along the shorelines is by far the most dominant fishing method used intensively by households in Munda, Vona Vona and Tulagi. Monofilament nylon lines with single or multiple hooks are baited with squid, octopus, fish or crabs which are thrown into deeper and shallow areas of reefs or along the drop-offs of the lagoon and outer reefs. Due to their availability, inexpensiveness, ease of use and suitability for use in small dug-out canoes, such gear is very popular. Drop-lining remains the second most important fishing method used. The only major difference between these two techniques is that the former involves the throwing of a baited line some distance away from the canoe, and is very common among children who fish along shorelines or shallower areas. The latter is usually carried out in deeper areas, with weights added onto the baited line, which is then fished on the bottom.

The local fishing method called 'kura' is very similar to droplining, except that this technique is only used in oceanic waters and targets on pelagic species, e.g. *Sphyraena* spp., *Scomberomorus commerson*, etc.

Blaber et al. (these Proceedings) conclude that only if there is a marked increase in the use of the trolling technique in the subsistence fishery will there be any likelihood of a significant direct trophic interaction between the subsistence fishery and the commercial tuna fishery. The present study has attempted to more thoroughly examine the importance of techniques employed in the subsistence fishery at the three survey sites, and at the same time obtain additional information of interest regarding the rural fishing population.

From the results obtained, it is apparent that dropliningand handlining, predominantly from dugout paddle-canoes, are the major fishing activities employed by rural fishermen. Using the results of Blaber et al. it is apparent that the species of reef fish that are regularly taken with droplining (and handlining) do not constitute major baitfish predators.

The questionnaire survey results support in general terms the relative importance of droplining to subsistence catches. The relative importance of trolling to the rural fisherman appears to have been over-estimated by the competition results, primarily because the prizes offered were biased towards using those methods which would take baitfish predators.

An interesting and important follow-up to the present study would be to actually identify the species composition and weight by species taken by a representative number of fishermen in each of the three sites, and record the gear used in each case. This would further support the inference that the existing subsistence fishery is not adversely affected by trophic interactions with the commercial baitfishery.

Acknowledgments

We wish to thank George Hitu and Meloty Alex for their enthusiastic help and support during the surveys. Thanks are also due to the people of Munda, Vona Vona, and Tulagi who, in one way or another, made this undertaking possible, and also to Alan Greenwood of the Computer Section, Fisheries Dept., for assistance in computer matters.

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Analysis of Catch and Effort Data for the Solomon Islands Baitfishery

by N.J.F. Rawlinson* and P.V. Nichols**

Abstract

A baitfishing logbook recording system was introduced by Solomon Islands Government in order to obtain detailed catch and effort data from the commercial pole-and-line fleet. An analysis of these data is presented: the bait-catch rose steadily to a record level of 2 498 t in 1988. Average catch per unit effort (approximately 50 buckets per haul) for the whole baitfishery has shown no real decline over the years, although intra- and inter-year fluctuations take place. The catch and effort data for two of the most important bait-fished areas are compared. Total catches are broken down by species in an attempt to assess the impact of baitfishing effort on the dominant species in the bait catch.

POLE-AND-LINE fishing is the mainstay of the tuna industry in Solomon Islands. In 1988 marine products, primarily tuna and tuna products, accounted for just under 50% of total foreign exchange earnings. The industry clearly plays a major role in the economy of Solomon Islands (Nichols and Rawlinson, these Proceedings).

A pre-requisite for successful pole-and-line fishing for skipjack tuna (*Katsuwonus pelamis*) is a regular and adequate supply of suitable baitfish. Baitfish are small pelagic species which are thrown live into the sea from pole-and-line fishing vessels in an attempt to attract (or 'chum') the tuna to the boat and excite them into a feeding frenzy so that the fish can be poled onboard. Solomon Islands possesses large quantities of suitable baitfish species. The two most important species which compose approximately 80% of the commercial baitfish catches in Solomon Islands, are the Engraulid anchovies *Stolephorus heterolobus* and *Stolephorus devisi* (Evans and Nichols, 1984; Rawlinson, these Proceedings).

Baitfishing in Solomon Islands is carried out at night in shallow lagoonal areas using the 'boukeami' technique. Details of the fishing method and the fishing areas within Solomon Islands are outlined byEvans and Nichols, 1984 and Nichols and Rawlinson, these Proceedings.

The quantity of baitfish taken by a pole-and-line vessel is dependent upon the carrying capacity of the live bait-tanks or baitwells. The average maximum permissible stocking density of a baitwell, to avoid mortalities from overcrowding, for the vessels that operate in Solomon Islands is between 40–60 buckets—a bucket holds 2.2 kg of baitfish (Nichols and Rawlinson, these Proceedings). The number of baitwells a vessel has is dependent on its size. Captains of vessels try to maximise the number of buckets of bait that are loaded into the baitwells and will make as many hauls of the bait net as time allows to achieve this. Depending on the size of the pole-and-line boat each vessel strives to catch between 120 and 300 buckets of baitfish every night before going fishing the following day. During the 1989 season there were 33 pole-and-line vessels (see Nichols and Rawlinson, these Proceedings) operating in Solomon Islands for the ten month season, attempting to catch this amount of bait each night.

Monitoring of the amount of bait caught by pole-and-line boats was initiated in 1971 when the industry first started in Solomon Islands. However these records were not accurate and made no account of the effort required to catch the bait other than the nights fished. This data was con-

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sidered insufficient and in 1981 a new baitfish logbook recording system was introduced into the industry by the Fisheries Division. Every vessel, by law, had to complete a logsheet for every night's baitfishing activities, recording the baitground where fishing took place and the number of buckets of bait caught in each haul of the bait net (Evans and Nichols 1984; and Nichols and Rawlinson, these Proceedings).

This paper discusses the compilation of these catch and effort data from the commercial pole-and-line vessels since 1981 and its analysis. Data are considered for the whole of Solomon Islands and also on an individual location basis for two heavily baitfished areas.

Catch data recorded in buckets makes no account of the species composition of the catch. An attempt is made in this paper to link species composition and catch and effort data for the two major species in the Solomon Islands baitfishery, *Stolephorus heterolobus* and *S. devisi.*

Sample Sites

There are 87 registered baitgrounds within Solomon Islands of which 9 are in Central Isles Province, 1 in Guadalcanal Province, 46 in Western Province, 10 in Malaita Province, 1 in Makira Province and 20 in Ysabel Province. Pole-and-line vessels have operated at most of these sites and the catch data from every site was combined to analyse the overall state of the Solomon Islands baitfishery.

The two heavily fished sites discussed in this paper are Munda in the Western Province and Tulagi in Central Isles Province. Both these baitfishing areas are in close proximity to one of the main fishing bases in Solomon Islands. Munda is close to the Noro base and Tulagi to the base which is situated at Tulagi. Due to their proximity to the bases these baitgrounds have experienced disproportionately high fishing effort as vessels invariably use these baitgrounds after unloading their catch.

A physical description of the two sites is given by Leqata et al., these Proceedings. Essentially however, Munda is a shallow (<25 m) lagoonal area and the Tulagi baitfishing ground is a deep passage between two islands and experiences more oceanic influence.

Methods and Materials

Completed catch logsheets are returned to Fisheries Division on a monthly basis from the commercial companies operating in Solomon Islands. Logsheets are then checked and transcribed on to a single piece of paper for each month's baitfishing operations. This is to keep a check on the accuracy of records as logbook recorders onboard vessels will change during the season and new people often fill in the sheets incorrectly.

One recurring problem was that recorders confused the word 'haul' with the word 'pool', the local name given to a baitwell. This meant that recorders would fill in the number of buckets of bait placed in each baitwell as opposed to the number of buckets of bait caught in a particular haul of the net, thereby giving an erroneous record of effort. This situation was remedied by changing the word 'haul' to the word 'net' so recorders were asked to fill in buckets per net totals. This reduced the confusion greatly. The completion of logsheets and the recording procedures are described more fully by Evans and Nichols, 1984, and Nichols and Rawlinson, these Proceedings.

Monthly records were then entered onto computer data files. The original systems were written in Basic language and run on Hewlett Packard HP85 and HP87 microcomputers. With an upgrade in computer hardware at Fisheries Division, the baitfish catch and effort entry and analysis system was re-written on a DBaseII software package to run on a Hewlett Packard HP150 microcomputer (Rawlinson, 1987).

Both systems allowed the analysis of the data on a monthly and yearly basis. Catch (buckets), effort (hauls) and nights fished for each individual baitground within Solomon Islands were extracted from the data files.

Results and Discussion

Overall situation in Solomon Islands

The Solomon Islands baitfishery has grown steadily since 1971 to reach record catch levels in 1988 of 1 135 289 buckets or 2 498 t of baitfish (Table 1). The majority of the baitfishing effort expended in Solomon Islands takes place in the Western Province with the Central Isles and Ysabel Provinces being of secondary importance (Table 1). Catch per unit effort or the number of buckets of bait taken in one haul of the net between 1981 and 1988 for the whole Solomon Islands baitfishery varied from 44 buckets per haul at its lowest to 58 buckets per haul at its highest (Table 2).

The relationship between catch and effort during this period was linear (Nichols and Rawlinson, these Proceedings.), Figure 1. Dalzell and Lewis (1988) noted that there was little evidence of curvature in scatters of catch versus effort in the Papua New Guinea and Fiji baitfisheries as well as Solomon Islands, and that a similar 'linear' catch-fishing effort relationship was found for

Table 1. Baitfish catch and effort by province, 1974–1988.

	Central Prov.		Western Prov.		Malaita Prov.		Makira Prov.		Isabel Prov.		G/canal Prov.		Non-Baitgrounds :		Total:	
	Buckets	Hauls	Buckets	Hauls	Buckets	Hauls	Buckets	Hauls	Buckets	Hauls	Buckets	Hauls	Buckets	Hauls :	Buckets	Hauls
1974	70 841	NI	0	NI	436	NI	0	NI	72 793	NI	0	NI	0	NI :	144 070	NI
1975	48 332	NI	71 333	NI	436	NI	0	NI	124 097	NI	0	NI	0	NI :	244 198	NI
1976	40 280	NI	199 602	NI	0	NI	0	NI	73 689	NI	0	NI	0	NI :	313 571	NI
1977	30 073	NI	248 933	NI	567	NI	0	NI	141 320	NI	0	NI	0	NI :	420 892	NI
1978	16 164	NI	343 899	NI	2 274	NI	0	NI	84 528	NI	0	NI	0	NI :	446 865	NI
1979	114 257	NI	292 221	NI	0	NI	0	NI	161 518	NI	0	NI	0	NI :	567 996	NI
1980	77 775	NI	376 208	NI	14 410	NI	0	NI	140 562	NI	0	NI	0	NI :	608 956	NI
1981	47 363	1 000	385 638	6 355	2 405	62	0	0	175 639	3 152	0	0	0	0 :	611 045	10 569
1982	141 640	2 632	410 902	9 109	6 883	203	0	0	112 773	2 552	0	0	0	0 :	672 198	14 496
1983	264 939	5 085	548 537	11 104	9 319	123	0	0	72 784	1 208	52	3	149	4 :	895 780	17 527
1984	93 358	2 642	563 479	11 696	5 161	180	241	6	145 966	3 498	68	6	5 297	139 :	813 570	18 167
1985	166 001	3 673	690 730	13 616	16 263	318	0	1	129 199	2 176	4 848	86	8 496	154 :	1 015 537	20 024
1986	86 597	2 302	716 825	13 120	4 001	157	0	0	256 490	6 031	1 189	43	10 161	225 :	1 075 263	21 878
1987	82 449	3 173	769 626	15 964	8 334	199	2	1	63 982	1 394	9 214	434	22 726	506 :	956 333	21 671
1988	129 745	3 588	899 300	15 445	1 937	45	0	0	98 550	2 085	4 914	159	843	29 :	1 135 289	21 351
Total	1 409 815	24 095	6 517 233	96 409	72 425	1 287	243	8	1 853 890	22 096	20 285	731	47 672	1 057	9 921 563	145 685
% Total	14.21	16.54	65.69	66.18	0.73	0.88	0.002	0.005	18.69	15.17	0.20	0.50	0.48	0.73	100.00	100.00

Note: One bucket of bait = approx. 2.2 kgs wet weight of baitfish.
NI = No Information.

Table 2. Baitfish catch per unit effort (CPUE) by province 1981–1988.

	Central	Western	Malaita	Makira	Isabel	G/canal	Other	Total
1981	47.36	60.68	38.79	—	55.72	—	—	57.81
1982	53.81	45.11	33.91	—	44.19	—	—	46.37
1983	52.10	49.40	75.76	—	60.25	17.33	37.25	51.11
1984	35.34	48.18	28.67	40.17	41.73	11.33	38.11	44.78
1985	45.19	50.73	51.14	—	59.37	56.37	55.17	50.72
1986	37.62	54.64	25.48	—	42.53	27.65	45.16	49.15
1987	25.98	48.21	41.88	2.00	45.90	21.23	44.91	44.13
1988	36.16	58.23	43.04	—	47.27	30.91	29.07	53.17

Note: CPUE = Catch Per Unit Effort = Number of Buckets of Bait Caught Per Haul.

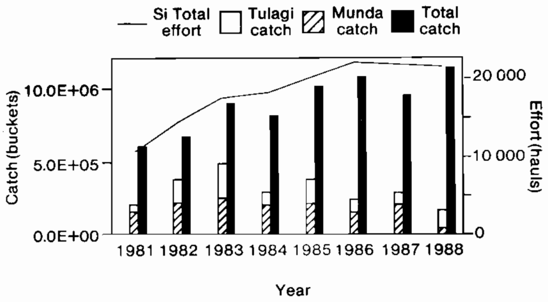

Figure 1. Solomon Islands Baitfishery 1981–1988.

small pelagic fisheries which catch mainly stolephorid anchovies in parts of the Philippines (SCSP 1976, 1977, 1978). Dalzell and Lewis (1988) state that the lack of pronounced curvature in the catch-effort relationship may be due to the dynamics of the pole-and-line fishery, as baitfish are essential to the capture of tuna and that fishermen will quickly leave a baitground when catches decline and will try other locations for bait supply.

This is the case in Solomon Islands with 87 alternative baitgrounds to choose from. The selection of baiting locations by the fishermen is a trade-off between being in close proximity to the tuna fishing grounds and the expected catch rates from a baitground at that particular time. For this reason the baitfishery in Solomon Islands is self-regulatory. When catch rates in a particular baitground decrease the fishermen move to new baiting locations. This movement gives the baitfish at the first site time to undergo a recovery period due to the reduced fishing effort. Therefore at present levels of fishing effort the catches of baitfish will be sustainable in large enough quantities to allow the pole-and-line fleet to operate efficiently.

There are however, certain individual baitgrounds within each Province which are more heavily fished than others. The baitgrounds of Tulagi in Central Isles Province and Munda in the Western Province are two examples, Figure 1. Other Provinces do have sites which are favoured by fishermen but these are not as important as Munda and Tulagi. Since 1987 there has been a gradual decline in the use of these two baitfishing grounds due to declining catch rates in the case of Tulagi and the opening of alternative baitgrounds close to the Noro base which has taken fishing pressure away from Munda. A large percentage of the baitfishing effort during 1988 took place at baitgrounds in the Marovo Lagoon in the Western Province (SIG, unpublished data).

The two sites of Munda and Tulagi therefore need to be monitored more closely. If a collapse of the baitfish stocks occurred at either of these sites it would have adverse economic effects on the operations of the pole-and-line vessels. The situation in Munda has been improved by opening a new baitground at Rarumana in the Vona Vona Lagoon, which is also close to the Noro base. However, there are no alternative sites in close proximity to Tulagi.

The catch and effort data for the two sites are analysed in more detail in the next section.

Munda

Figure 2 is a plot of catch of baitfish against effort at Munda for the 1981–1989 fishing seasons (data for 1989 are up until the end of September). The major reason for the decline in effort during the 1988 and 1989 seasons is because a new baitfishing ground in close proximity to the Noro fishing

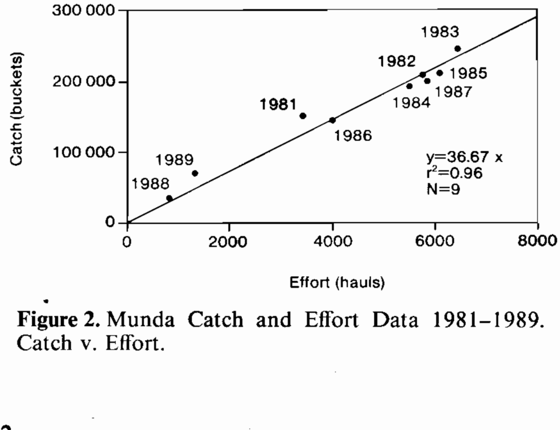

Figure 2. Munda Catch and Effort Data 1981–1989. Catch v. Effort.

base was opened. The relationship between the catch and effort is linear. The gradient of the line of catch regressed against effort is a measure of the average catch per unit effort over the time period from 1981 to 1989. The value is 36.67 buckets of baitfish per haul, or 80.7 kilograms per haul.

The plot of catch per unit effort, as buckets of bait per haul, against effort in hauls is presented in Figure 3. The catch per unit effort totals for all seasons are very similar though there is a trend of decreasing catch per unit effort with higher fishing effort.

Schaefer (1954) developed a model which in its simplest form is a linear relationship between catch per effort and effort and is of the form:

$$C/f = a - bf \qquad \text{Equation 1}$$

where C=Catch, f=Effort and 'a' and 'b' are constants.

From Figure 3, the data for Munda have been regressed to give the equation:

$$C/f = 49.8 - 0.00235\ f \qquad \text{Equation 2}$$

From Equation 1, Maximum Sustainable Yield (MSY) and Optimum Fishing Effort, f opt can be directly calculated:

$$MSY = a^2/4b \qquad \text{Equation 3}$$

and

$$f\ opt = a/2b \qquad \text{Equation 4}$$

Using 'a' and 'b' from Equation 2 this gives:

MSY=263 834 buckets of bait per year

and

f opt=10 596 hauls per year

Equation 1 can also be transformed into a parabolic function by multiplying both sides of the equation by the fishing effort to give:

$$C = af - bf^2 \qquad \text{Equation 5}$$

Using 'a' and 'b' from Equation 2 this line has been plotted in Figure 4, along with the actual data points of annual catch and effort for the years 1981–1989. The line is the theoretical yield curve for the baitfishery at Munda. The 1983 data point which stands above the line may be due to the fishing that took place in January and February of that year; this did not happen during other years. The catch rates at this time of year are generally high due to the seasonality in production of the fishery. The optimum fishing effort has not yet been reached and effort has remained on the left ascending arm of the curve (Figure 4).

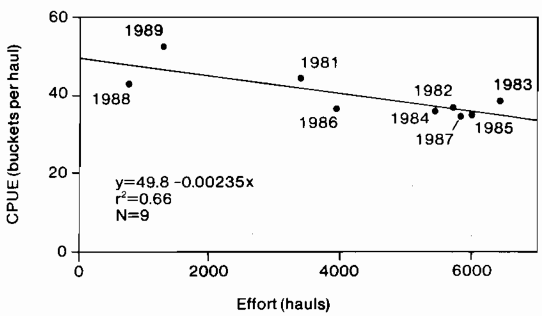

Figure 3. Munda Catch and Effort Data 1981–1989. Catch per Unit Effort v. Effort.

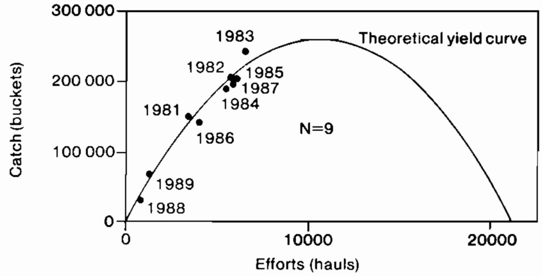

Figure 4. Munda Catch and Effort Data 1981–1989. Catch v. Effort, with Theoretical Yield Curve.

Figure 5 shows plots of catch and catch per unit effort against time. The gaps between years where no catch has been made are because there is a closed season for pole-and-line fishing. The closed season is not a management measure but is due to the fishing crews' holidays. The closure of the fishing season usually takes place between December and February of each year but in recent seasons this period of time has become shorter.

The plots in Figure 5 show some interesting trends:

- lower catch per unit effort (CPUE) occurs at the same time as lower catches;
- lower CPUEs usually occur during the middle of the year;
- CPUEs are generally higher after the closed season to fishing;
- CPUEs are generally higher in a year that has followed a year of low catches.

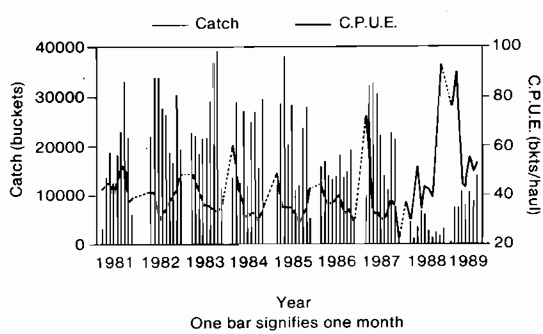

Figure 5. Munda Catch and Effort Data 1981–1989. Catch and Catch per Unit Effort v. Time.

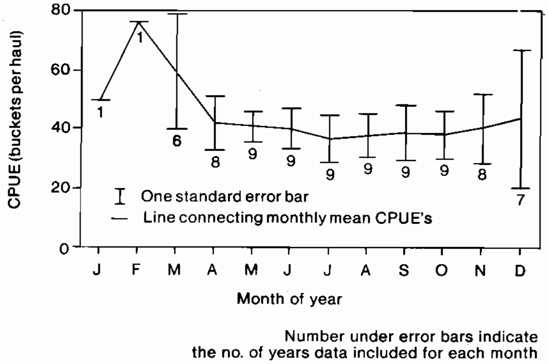

Figure 6. Munda Catch and Effort Data 1981–1989. Mean Catch per Unit Effort per Month v. Month.

The first finding is consistent with the fact that if catch rates in a particular baitground decrease then the fishing vessels move to new grounds, thereby giving rise to less fishing effort and less catch.

Lowest CPUEs occurring in the middle of the year seems to show that the production of the baitfish is seasonal. Dalzell and Lewis (1988) state that small pelagic fishes are likely to be strongly influenced by environmental conditions and in tropical zones the major influences are the monsoon winds which blow, according to season, from north to south. Figure 6 is a plot of the mean catch per unit effort recorded by month over the last nine years against the month of the year. The plot shows highs in March and December (excluding January and February as only one year's data has been recorded for these months). The standard error bars in these months are also the widest which implies higher annual variability in the catch per unit effort, perhaps caused by differences in levels of recruitment of new fish to the baitfishery. Lowest rates of catch are recorded in July.

The main spawning season and main recruitment periods for the major baitfish species occur in March/April and October to December of each year (Tiroba et al., Milton et al., these Proceedings). The spawning aggregations and/or pulses of new recruits increase the abundance of baitfish at this time of year giving rise to higher catch rates.

The trends to higher CPUEs seem to show a possible link between previous fishing effort and catch per unit effort. For this reason an attempt has been made to apply the following methods to the data:

Gulland's Method

Ricker (1975) pointed out that abundance of an exploited year class at any time depends partly on the rates of fishing and hence levels of fishing effort that have prevailed during the years it has been in the fishery. Therefore a relationship should exist between abundance and past effort, and this will be better if recruitment and natural mortality have been reasonably steady (Gulland, 1961).

The relationship between abundance and past fishing effort can be either linear or curvilinear (Ricker, 1975). Gulland (1961) stated that this line will be very close to the true relationship between catch per unit effort (abundance) and effort in a steady state. This approach has been applied to the baitfish data from Munda.

Annual Catch per Unit Effort v. Mean Monthly Fishing Effort of the Previous Year

The annual mean catch per unit effort has been plotted against the mean monthly fishing effort for the previous year (this is the total fishing effort for the year divided by 12 months). This plot is shown in Figure 7.

The relationship is linear and so the following argument applies:

$$Ye/fe = a - b\ fe \qquad \text{Equation 6}$$

where Ye=Equilibrium yield, fe=Equilibrium effort and 'a' and 'b' are constants. From this MSY and f opt can be estimated from Equations 3 and 4.

From Figure 7, the relationship is described by:

$$Ye/fe = 49.5 - 0.0269\ fe \qquad \text{Equation 7}$$

and using Equations 3 and 4,

MSY = 22 784 buckets per month

and

f opt = 920 hauls per month

Monthly Catch per Unit Effort v. Mean Fishing Effort of Previous 12 Months

Monthly catch per unit effort figures were plotted against the mean fishing effort of the previous 12

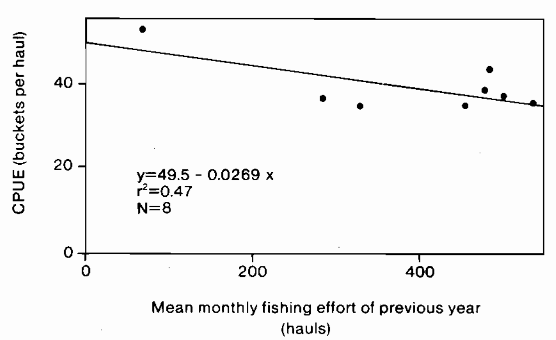

Figure 7. Munda Catch and Effort Data 1981–1989. Catch per unit Effort v. Mean Monthly Fishing Effort of Previous Year.

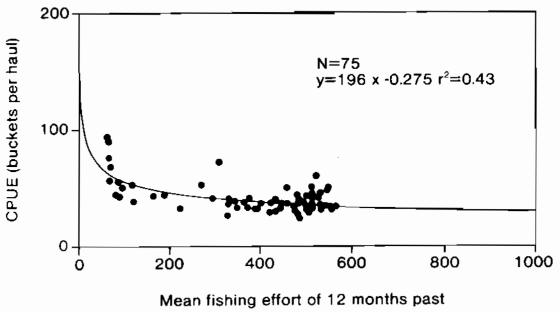

Figure 8. Munda Catch and Effort Data 1981–1989. Catch per Unit Effort v. Mean Fishing Effort of 12 Months Past.

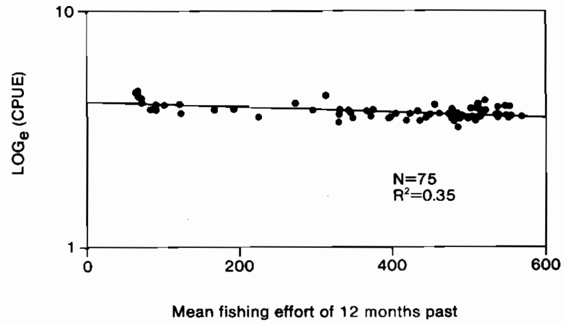

Figure 9. Munda Catch and Effort Data 1981–1989. Natural Logarithm of Catch per Unit Effort v. Mean Fishing Effort of 12 Months Past.

months (this figure was calculated by summing the fishing effort of the 11 months directly prior to the month being considered plus the fishing effort for that month, and calculating the mean by dividing through by 12 months). The plot is shown in Figure 8 and an exponential curve fitted to the data points. The goodness of fit of the curve is not high due to the seasonality effect of the seasonal production of baitfish as described above. Year to year variations in recruitment cause some months to have abnormally high catch per unit effort.

The relationship is curvilinear and this is described by the Gulland-Fox Exponential Model (Ricker, 1975). The model states that considering the biological processes involved, the relation between catch in numbers per unit effort (C/f) and mean(f) of earlier years would be expected to be negative and concave upward. The existence of appreciable natural morality will tend to make the line less curved. However, if yield is in terms of weight (Y) instead of numbers, the larger the mean effort, mean(f), the smaller will be the average size of fish in the catch, which tends to make the line of Y/mean(f) against mean(f) more curved. The combination of this with the effect of natural mortality can result in a line that agrees closely with the simple relationship:

$$\ln (Y/f) = a + b(\text{mean}(f)) \qquad \text{Equation 8}$$

The steady-state statistics that provide maximum yield for this Gulland-Fox exponential model are summarised below:

Optimum fishing effort:

$$fs = 1/b \qquad \text{Equation 9}$$

Maximum Sustainable Yield:

$$MSY = (e^{(a-1)})/b \qquad \text{Equation 10}$$

and Catch per Unit Effort at MSY:

$$Us = e^{(a-1)} \qquad \text{Equation 11}$$

With estimates of catchability (q) Maximum Stock Size can also be calculated. A good estimate of q, however, is not available.

Figure 9 is a plot of the natural logarithm of CPUE (Y/f) regressed against the mean effort for the previous twelve months (fm), and the expression takes the form:

$$\ln (Y/f) = 4.076 - 1.02 \times 10^{(-3)}\ fm \qquad \text{Equation 12}$$

Using the equations 9 to 11, an estimation of Maximum Sustainable Yield has been calculated along with the other parameters listed, using parameters 'a' and 'b' in equation 12. The results of these calculations are:

Optimum Fishing Effort:

fs = 980 hauls per month

Maximum Sustainable Yield:

MSY = 21 247 buckets per month

and Catch per Unit Effort at MSY:

Us = 21.7 buckets per haul

A reservation has to be made concerning these results because any estimated magnitude of yield will tend to be less than if a fit were made on a non-logarithmic basis (Ricker, 1975). Therefore the above numbers may be under-estimates of the true figures.

The estimated MSY for Munda is 21 247 buckets of baitfish per month, or 46.7 tonnes per month. Referring to Figure 4 this level of fishing effort has been surpassed during many months since 1981 but never has this effort been maintained for every month of a year. Overall these high levels of fishing effort have not caused any significant changes to the catch rates at Munda although the levels of CPUE have gradually declined from 1981 to 1987, until the year of very low fishing effort in 1988. After 1988 the CPUE at Munda increased significantly. However, if the catch data are broken down on an annual basis the levels of effort greater than MSY have had some effects on the overall species composition of the baitfishery.

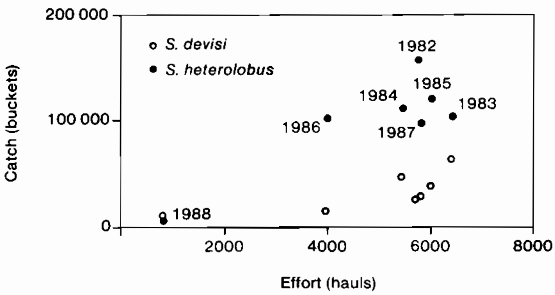

Figure 10. Munda Catch and Effort Data 1981–1988. Catch by Species v. Effort.

Using available species composition information (Rawlinson, these Proceedings) catch data was produced on an annual basis for the two main species in the baitfishery, *Stolephorus heterolobus* and *S. devisi,* by multiplying the percentage composition of each species by the total annual catch. Dalzell (1984) found no significant difference between the mean annual percentage species composition by numbers and the mean annual percentage by weight composition.

The catch data by species was plotted against the total effort for the year and this is presented in Figure 10. The relationship between catch and effort for *S. heterolobus* shows some linearity but with a more random scatter than for all species combined (Figure 2). The relationship for *S. devisi* however, shows more linearity but with slight upward curvature at higher levels of fishing effort. The pattern implies that with higher fishing effort there is a change in species composition, with an increase in the proportion of *S. devisi* and a decrease of *S. heterolobus.* With sustained fishing catches over the MSY the stocks of *S. devisi* would presumably decrease, with either another species taking its place or a complete collapse of the whole fishery. This scenario is unlikely to happen because with decreasing catch rates vessels move to alternative baitfishing grounds. The opening of new baitgrounds has reduced the fishing pressure to the extent that it is well below optimum. It should also be noted that data from field work undertaken in October 1989 show that the species composition of the commercial catches changed from earlier in the year (when *S. devisi* was the most dominant species in the bait catch) and *S. heterolobus* was once again the most important species in the catch (unpublished data). This was following the reduction in effort during previous months.

Dalzell (1984) reported similar species fluctuations in the Papua New Guinea baitfishery. To fully understand the mechanisms whereby one species in the baitfishery becomes more numerous because of the decline of another, a detailed analysis of the biology of the individual species concerned is required.

Tulagi

A plot of catch versus fishing effort at Tulagi for 1981 to 1989 fishing seasons (data for 1989 are until the end of September) is shown in Figure 11. The relationship is again linear. The average catch per unit effort over this period was 42.9 buckets of bait per haul but this varied from year to year.

Catch per unit effort against effort by year is plotted in Figure 12. The scatter of points is very random and it is not possible to fit a straight line and apply the Schaefer model as with the Munda data.

Figure 13 is a plot of catch and catch per unit effort against time. The general trends that were identified for Figure 5 for the Munda data also apply to the situation in Tulagi.

The seasonality of production of the baitfish is again well pronounced in Figure 13 as it was for the Munda situation. A plot of the mean catch per unit effort recorded by month over the last nine years against month is made in Figure 14. The same kind of seasonal effect was seen in the Munda data. When the two lines of mean catch

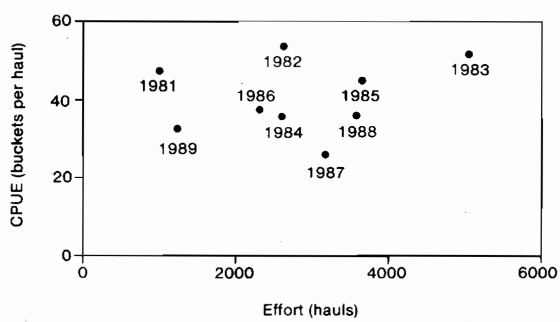

Figure 11. Tulagi Catch and Effort Data 1981–1989. Catch v. Effort.

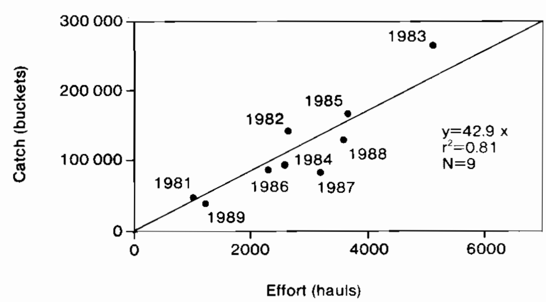

Figure 12. Tulagi Catch and Effort Data 1981–1989. Catch per Unit Effort v. Effort.

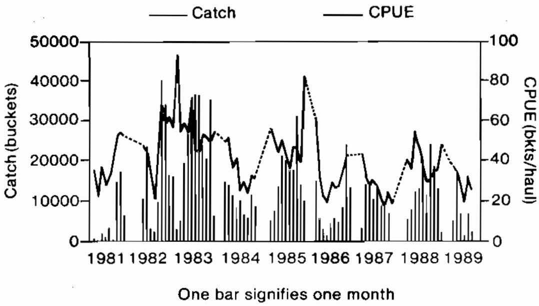

Figure 13. Tulagi Catch and Effort Data 1981–1989. Catch and Catch per Unit Effort v. Time.

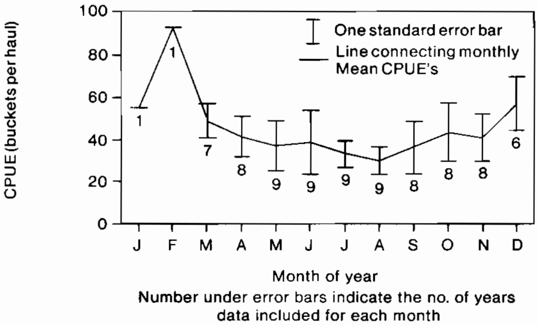

Figure 14. Tulagi Catch and Effort Data 1981–1989. Mean Catch per Unit Effort per Month v. Month.

per unit effort for Munda and Tulagi are superimposed upon each other (Fig. 15), the seasonal trend for both sites can be seen but the times of peak production are at different times of the year. The highest peak for Munda occurs in March whereas in Tulagi it is in December. It must be remembered that March is usually the time when fishing restarts after the closed season. This period of low fishing effort is likely to be adding to the effect of the high in catch per unit effort. The low in production occurs in July and August.

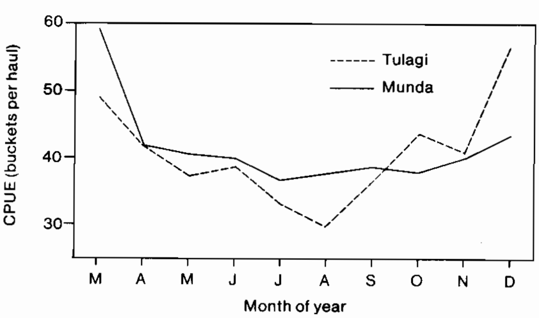

Figure 15. Catch and Effort Data 1981–1989. Mean Catch per Unit Effort per Month v. Month of Year.

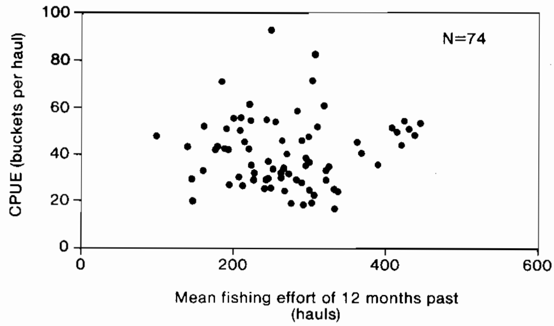

Figure 16. Tulagi Catch and Effort Data 1981–1989. Catch per Unit Effort v. Mean Fishing Effort of 12 Months Past.

An attempt was made to apply the Gulland-Fox Exponential model to the Tulagi data. The plot of CPUE against mean fishing effort of the 12 months past (Figure 16) gave a completely random scatter of points and no attempt was made to fit a line to the data. As the model states, the relationship between CPUE and mean fishing effort will be better if natural mortality and recruitment are fairly constant. It is considered that natural mortality for the main baitfish species remains relatively constant from year to year (Tiroba et al., these Proceedings) which would imply that variation in recruitment causes the lack of any kind of relationship in the data.

Dalzell (1984) found a linear relationship between parental stock size and the magnitude of recruitment for the baitfish species in Papua New Guinea. He suggested that the fluctuations in baitfish stocks year to year can partly be explained by the vulnerability of clupeoids to both adverse environmental conditions and fishing pressure.

In order to understand the situation in Tulagi, a much better understanding of recruitment into the fishery is required. Fishing effort in Munda explains a fair proportion of the fluctuations in abundance of the baitfish stocks. Very little of the changes in stock abundance can be explained by fishing effort in Tulagi and a better understanding of the environmental processes involved is required to address the recruitment problem.

The significant difference between Munda and Tulagi is the physical appearance of the two sites, Munda being a shallow lagoonal area and Tulagi being a deepwater passage between two islands with a strong oceanic influence. Munda is at the western end of the large Roviana Lagoon and is the only area within the Lagoon where baitfishing takes place (other parts of the lagoon are too shallow to allow the safe passage of commercial fishing vessels). To the western end of Munda is the Vona Vona Lagoon which joins Roviana.

Therefore the Munda baitground is adjacent to areas of similar baitfish habitat and is likely to have an influx of baitfish from them, as levels of the stocks are being reduced by fishing effort. Tulagi however, is adjacent to the open sea and does not have the link with other large expanses of baitfish habitat. The stocks of bait at Tulagi probably do not have the same influx of bait species as may occur in Munda. Catches in Tulagi occasionally include the arrival of schools of *Stolephorus punctifer,* a more oceanic species (Dalzell, 1986) which enhances the available supplies of bait.

As no estimate for MSY for Tulagi has been possible using the approaches discussed in this paper, the levels of MSY for Munda are used as a guide. Catches exceeded the annual MSY calculated for Munda in 1983. There was immediately a drop in catch per unit effort the following year which forced fishing vessels to move elsewhere to find bait. Effort in Ysabel Province increased nearly three times from 1983 to 1984. The Tulagi baitground makes up the whole of the Central Provinces catch and effort (Table 1). In 1985 fishing effort again increased with a higher catch per unit effort from the previous year. Since then catch per unit effort (and therefore abundance of baitfish) has never reached the same levels and hence there has been a reduction in fishing effort as boats moved to alternative sites to capture baitfish.

Figure 17 shows the plot of catch by species against effort for the two main species (*S. heterolobus* and *S. devisi*). As with the Munda data, *S. devisi* shows a linear relationship between catch and effort whereas *S. heterolobus* seems to have suffered under high fishing pressure. After the high in fishing effort in 1983 there was a reversal in importance by species in 1984 when *S. devisi* was dominant. After the low fishing effort of 1984, *S. heterolobus* once again returned to dominance until 1988, though proportions between the two species were more equal. In 1988, *S. devisi* became the dominant species in the catch even though fishing effort was exceptionally high the

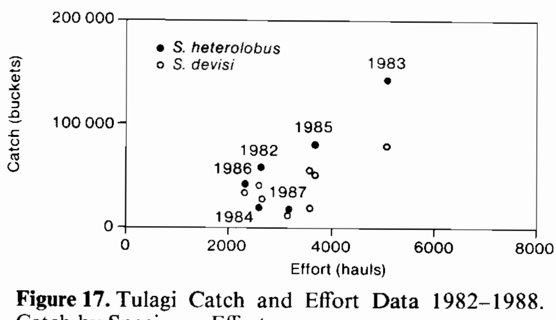

Figure 17. Tulagi Catch and Effort Data 1982–1988. Catch by Species v. Effort.

previous year. An explanation for this is difficult without further analysis of the data and knowledge of reproductive activity and recruitment over this period.

Conclusions

The baitfishery in Solomon Islands is self-regulatory because of the nature of the pole-and-line fishery, which requires adequate supplies of bait to go fishing for tuna, but has a large number of alternative baiting sites. As long as there is no substantial increase in fishing effort due to an increase in size of the fishing fleet, adequate quantities of baitfish will remain available for the pole-and-line fleet to operate efficiently.

The analysis of catch and effort data on an individual site basis is complicated by a number of factors. Seasonality of production and variation in size of recruitment from year to year are the most important. Due to the relationship between parental stock size and recruitment, fishing effort will have an important effect on future recruitment to the fishery.

The difference in the physical nature of baiting locations may also have a pronounced effect on the production of the fishery. The situation in Munda is more stable and predictable than that of Tulagi. This is due to more constant levels of recruitment from either the addition of juvenile fish or from immigration of fish from adjacent areas or a combination of both. Tulagi however, must rely on the addition of juvenile fish and the strength of this recruitment will rely heavily on environmental conditions as well as parental stock levels. It may be that fishing effort in 1983 was so high that parental stock levels were reduced to such an extent that recruitment the following year was very low and that continued fishing effort during the following years have never allowed the stocks, primarily *S. heterolobus* and *S. devisi*, to return to their previous levels. Favourable environmental conditions may cause strong recruitments from time to time which may give rise to higher catch rates over a short period, but the Tulagi situation should be monitored closely and any increase in fishing effort reviewed very carefully.

If management measures did need to be imposed, the most suitable method would be a reduction in fishing effort. The estimates of optimum fishing effort and MSY for Munda from the three different methods are consistent and are a good guide if restrictions on fishing effort are required. However as the importance of the pole-and-line fishery may decline, with the movement of the tuna industry to purse-seining, such restrictions may not be required at Munda. However, as fishing effort moves to different areas then monitoring the levels of catch and effort should also be undertaken eg. for the Marovo lagoon, now the most important baitfishing area within Solomon Islands (SIG, unpublished data.)

Although it may not be essential to know the baitfish stock sizes for the pole-and-line fishery, because of its self-regulatory nature, they may become important if in the future there is requirement to exploit the baitfish stocks for direct human consumption as occurs in Asia.

Acknowledgments

Thanks are given to the two pole-and-line fishing companies in Solomon Islands, Solomon Taiyo Limited and National Fisheries Developments Limited, for their co-operation and assistance in supplying the baitfish logsheets to Solomon Islands Fisheries Division on a regular basis. Special mention must go to the employees of the companies whose task it is to record the nightly baitfishing catch and effort data and for the accuracy in which this is done.

The Statistical section of Solomon Islands Fisheries Division are thanked for their hard work in transcribing the monthly raw data and for the hours of key punching required to enter the information onto a computerised database.

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Catch Composition of the Tuna Baitfishery of Solomon Islands and Possible Impact on Non-Target Species

by N.J.F. Rawlinson*

Abstract

Information is given on the species composition of commercial baitfishing catches by the pole-and-line fishing fleet in Solomon Islands from two sites. The catches from a third site using experimental fishing gear are also detailed. Bait catches are dominated by the Engraulid anchovies, *Stolephorus heterolobus* and *Stolephorus devisi*, but large intra- and inter-annual variability in species composition of the catch takes place. The occurrence of non-target species in the bait catches is detailed with special reference to the juveniles of reef fish species, the adults of which are important to rural subsistence fishermen in Solomon Islands. An attempt is made to quantify the numbers of juvenile reef fish caught in commercial catches to try and assess the potential impact on the recruitment of reef fish by commercial baitfishing operations. A seasonal pattern in the numbers and variety of non-target species in the catch is discussed.

THE pole-and-line fishing fleet in Solomon Islands caught 33 051 t of tuna (or 76% of the total domestic catch) in 1988 (SIG, 1988) and is the mainstay of the tuna industry within the country (Nichols and Rawlinson, these Proceedings).

The pole-and-line method of catching skipjack tuna (*Katsuwonus pelamis*) from surface schools cannot be employed without a large supply of acceptable baitfish. Baitfish are small pelagic species which are used to 'chum' schools of skipjack to the fishing vessels before fish can be poled onboard. The types and characteristics of what constitutes a good baitfish species are well described in Hester (1974), Baldwin (1977), Smith (1977) and Yuen (1977).

The catching of baitfish in Solomon Islands is a separate fishery to the tuna fishery in time, location and method. Fishing takes place at night from designated baitifishing grounds (mainly lagoonal areas) using the bouke-ami technique (stick-held liftnet in conjunction with underwater lights). Details of fishing methods and fishing areas within Solomon Islands can be found in Evans and Nichols (1984) and Nichols and Rawlinson (these Proceedings). During the 1988 fishing season, 2 498 t of baitfish were caught by local pole-and-line vessels in Solomon Islands (SIG, 1988; Rawlinson and Nichols, these Proceedings).

In recognition of the importance of the baitfishery to the operations of the pole-and-line fleet, the Solomon Islands Government (SIG) started a baitfish sampling program in 1982. Observers worked on commercial vessels and collected samples of bait during the nightly fishing operations. These samples were collected primarily to provide an insight into the dynamics of the fishery and the biology of the important bait species (Nichols, 1988). Samples were also analysed to give an indication of the species composition of the catch. Two Stolephorid anchovies, *Stolephorus heterolobus* and *Stolephorus devisi*, constituted 80% by number of the catch (Evans and Nichols, 1984). This result agreed with the findings of the South Pacific Commission (SPC) made during two research surveys to investigate the skipjack and baitfish resources in Solomon Islands: once in 1977 and again in 1980 (Argue and Kearney, 1982).

The baitfish sampling program was expanded in 1987 with the implementation of a three year

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collaborative research program between the Fisheries Division of SIG and the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia to investigate in more detail the biology of the major baitfish species and to address the issue of interactions between commercial baitfishing and the rural subsistence fisheries. Funding for this Baitfish Research Project (BRP) was provided by the Australian Centre for International Agricultural Research (ACIAR).

Lewis (1983) identified three main areas where commercial baitfishing may have detrimental effects on subsistence fisheries. Firstly, the reduction in the amount of forage available for desirable predatory species, which has always been the main concern of rural fishermen in Solomon Islands (Evans and Nichols, 1984; Nichols and Rawlinson, these Proceedings). This issue is addressed more fully by Blaber et al. (these Proceedings). Secondly, the depletion of the common stock which is discussed in more detail by Rawlinson and Nichols (these Proceedings). The third area identified was the effect baitfishing may have on the recruitment of juvenile fish. This paper identifies the main taxa of the juvenile reef fish taken in baitfish catches and attempts to quantify the numbers caught.

Sampling during the BRP was designed to collect samples of the important baitfish species being studied. However, the collection of random samples was continued in order to monitor the catch composition of the baitfishery at the research sites. These samples extended the time series of data on the species composition of the baitfish catch and these results are presented in this paper. The random samples also gave an indication of the levels of by-catch (non-baitfish species taken during baitlight operations). As the levels of capture of by-catch species were not identified as a priority area for study at the beginning of the project, sampling was not designed to fully address this issue. However, the data collected are outlined and recommendations to improve sampling to address this area more fully are given.

Objectives

With the available data:

- identify the species of fish that are caught during baitfishing operations and their relative importance within the catch composition;
- determine the abundance of by-catch species i.e. non-baitfish species within the catch;
- determine whether there are differences between sites in the species and numbers of by-catch;
- determine whether there are seasonal or monthly patterns in abundance of by-catch species;
- assess whether the by-catch species are of importance in the subsistence fishery at the baitfishing area;
- estimate the numbers of subsistence fishery species being taken as by-catch by commercial baitfishing operations.

Materials and Methods

Sample sites

The three sites where baitfish sampling took place were Munda in the Roviana Lagoon, the southern part of Vona Vona Lagoon, both in the Western Province of Solomon Islands and Tulagi in the Central Islands Province (Fig. 1). The selection of these sites and their physical appearance are described in Leqata et al. (these Proceedings). Essentially the sites at Munda and Vona Vona are very similar shallow lagoonal areas, whereas the Tulagi site is considerably deeper and is subject to more oceanic influence. Munda and Tulagi experience heavy baitfishing pressure (Rawlinson and Nichols, these Proceedings) whereas Vona Vona is not utilised for baitfish. For this reason Vona Vona was used as a control site.

Sampling methods

When sampling was initiated in 1982 Fisheries Observers undertook fishing trips on board commercial pole-and-line vessels. One of their duties was to collect a sample of baitfish from the nightly fishing operations. Samples were collected in a fine-meshed net as the buckets of bait were being transferred into the baitwells. The baitfish collected were put inside plastic bottles and preserved in 10% formaldehyde. The samples were marked with the date and place of capture.

The use of Fisheries Observers on board commercial vessels had the disadvantage that samples could only be collected from where the vessels were operating. Pole-and-line vessels in Solomon Islands use a large number of different baitgrounds during the fishing season. This led to the sampling of baitfish catches from many different areas but did not give a good time-series from any one site. This method of sampling from commercial vessels continued until the end of December 1986.

In order to get time-series data collections of baitfish, samples were obtained on a monthly basis from the three sampling sites described above. Random sub-samples of the baitfish catch were collected from the commercial pole-and-line vessels operating at Munda and Tulagi at least

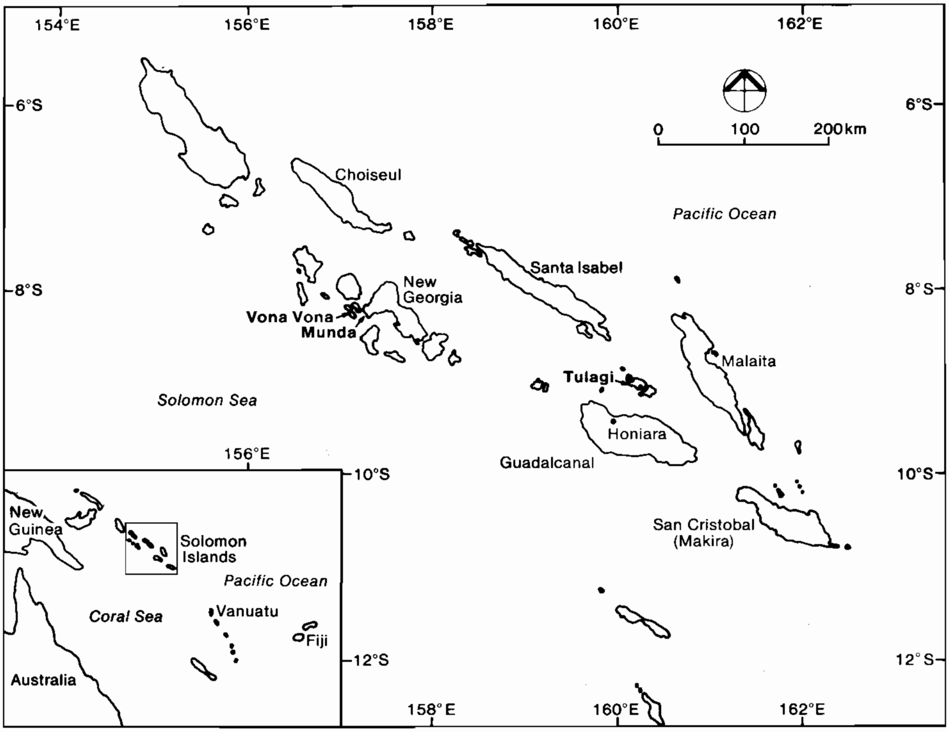

Figure 1. Map of Solomon Islands, showing position of Munda, Tulagi and Vona Vona.

once a month over the study period from March 1987 to April 1989. Collectors of the samples travelled in a power-driven canoe to meet the commercial vessels in the baitgrounds at night. After samples had been taken the sample collectors were able to leave the vessel. While the collector was on board samples were collected in the same way as described above.

A similar sub-sample of baitfish was collected at least once a month from Vona Vona using a small-scale method for their capture. An underwater light (500 W) powered by a portable 2.2 kW generator was used in conjunction with two boats (one 10.5 m and the other 7.5 m). The two boats were kept apart by tying bamboo poles (10 m long) bow-to-bow, and stern-to-stern. A net, constructed of the same mesh size as those of commercial vessels (4 mm square), ten metres square and approximately three metres deep was lowered between the two boats to a depth of about 15 m. When the net had been set, the underwater light was raised slowly and its brightness dimmed before being fixed in position between the middle of the boats and above the baitnet. Once the baitfish had aggregated closely around the light the net was hauled by three men on each boat. This method was also used to collect samples of baitfish at Munda and Tulagi when no commercial vessels were operating (i.e. during the closed season to pole-and-line fishing which usually occurs between December and February of each year).

All fish in the samples were identified mainly using the guide of Lewis et al. (1983) and Munro, (1967) to at least family level with the exception of fry and larvae too small for positive identification. These were listed as 'Others'. The number and fork length of each species in every sample were recorded. These data were compiled to give the species composition of baitfish catches by numbers. Monthly and annual samples were pooled and the total number of fish by species was divided by the total sample size for the month or year to give percentage composition of the catch by species.

Results and Discussion

Species caught during baitfishing operations and their relative importance

The most important species and families caught from the Munda and Tulagi sites from 1982 to 1989 are shown in Tables 1 and 2 respectively. Fish captured from both commercial vessels and

Table 1. Munda percentage bait-catch composition.

	1982[a]	1983[a]	1984[b]	1985[b]	1986[b]	1987[c]	1988[c]	1989[c]
ENGRAULIDAE	88.3	68.3	84.9	77.3	84.1	76.6	50.4	68.1
Stolephorus heterolobus	74.4	42.3	57.4	57.5	70.2	47.8	18.4	15.2
Stolephorus devisi	12.5	25.5	24.2	18.2	11.0	14.4	26.7	51.9
Stolephorus insularis	—	0.2	0.7	0.2	—	1.1	1.1	0.3
Stolephorus indicus	—	—	2.2	—	0.1	—	—	—
Stolephorus punctifer	1.4	0.3	—	—	—	—	0.1	—
Stolephorus juveniles	—	—	—	—	2.8	13.1	4.0	0.4
Thryssa baelama	—	—	—	1.4	—	0.2	0.2	0.2
DUSSUMIERIIDAE	0.2	20.3	9.9	15.2	8.3	10.1	23.1	18.5
Spratelloides gracilis	—	—	7.4	1.8	0.1	0.4	0.3	10.5
Spratelloides lewisi	—	16.2	2.3	1.2	5.1	6.2	11.8	7.7
Spratelloides delicatulus	0.2	4.1	0.2	12.2	3.1	2.4	11.1	0.3
CLUPEIDAE	3.7	3.6	1.0	1.3	1.7	4.0	12.3	9.5
Amblygaster sirm	0.4	—	—	—	—	—	0.3	0.6
Herklotsichthys sp.	—	—	—	0.2	—	2.8	2.5	2.6
Herklotsichthys quadrimaculatus	2.2	3.0	0.8	0.7	1.2	1.1	7.3	4.6
Pellona ditchela	1.1	—	—	0.2	0.4	0.1	0.2	1.7
SCOMBRIDAE	—	0.1	0.1	0.3	0.2	0.1	0.2	1.4
APOGONIDAE	1.1	0.4	0.2	1.1	2.6	4.9	7.7	0.2
ATHERINIDAE	0.8	0.1	3.0	3.1	1.1	1.6	2.5	1.0
CAESIONIDAE	0.5	—	0.6	0.1	0.1	0.4	0.2	0.5
LEIOGNATHIDAE	0.5	0.7	0.1	0.3	1.0	0.8	1.0	0.1
CARANGIDAE	—	—	—	0.4	0.2	0.3	0.1	0.1
OTHERS	4.9	6.5	0.2	0.9	0.7	1.2	2.5	0.6
No. of samples taken	57	32	40	63	12	27	15	7
No. of fish sampled	4317	2304	2579	5033	1247	20898	8350	6757
Months sampled	Aug-Oct	Feb May-Sep	Mar,Apr, Aug,Oct	Mar-Nov	Mar Apr,Sep	Mar-Dec	Jan-Dec	Jan-Apr

Notes:
[a] Source: Evans and Nichols (1984)
[b] Source: SIG (Unpublished Data)
[c] Source: Baitfish Research Project

Table 2. Tulagi percentage bait-catch composition.

	1982[a]	1983[a]	1984[b]	1985[b]	1986[b]	1987[c]	1988[c]	1989[c]
ENGRAULIDAE	69.4	86.2	79.9	83.4	92.2	64.3	63.4	77.5
Stolephorus heterolobus	41.1	54.0	22.6	48.5	49.0	21.4	15.3	15.8
Stolephorus devisi	20.0	30.2	44.3	31.4	39.8	19.1	42.2	59.6
Stolephorus insularis	0.7	0.1	2.1	0.2	0.3	0.9	1.0	1.6
Stolephorus indicus	—	—	—	—	—	—	—	—
Stolephorus punctifer	7.4	0.5	10.4	2.8	3.0	2.0	1.9	—
Stolephorus juveniles	—	1.3	—	—	—	12.6	2.5	—
Thryssa baelama	0.2	—	0.4	0.6	0.2	8.4	0.4	0.5
DUSSUMIERIIDAE	2.9	7.4	11.1	11.6	1.4	13.9	22.9	6.6
Spratelloides gracilis	—	3.2	7.3	4.0	—	1.4	0.1	0.3
Spratelloides lewisi	—	1.6	1.4	2.3	0.9	7.3	18.8	5.3
Spratelloides delicatulus	—	2.3	1.4	2.0	0.1	3.1	0.8	0.9
CLUPEIDAE	4.3	2.1	2.7	1.6	1.1	9.3	6.2	9.7
Amblygaster sirm	1.6	0.3	—	0.1	0.1	1.5	0.3	0.3
Herklotsichthys sp.	—	—	—	—	—	0.2	2.0	6.5
Herklotsichthys quadrimaculatus	—	0.6	2.7	0.2	—	5.6	2.8	2.4
Pellona ditchela	2.7	0.7	—	0.4	0.3	1.7	0.2	0.4
SCOMBRIDAE	1.6	0.1	—	0.8	0.3	0.7	0.6	0.7
APOGONIDAE	—	0.1	0.1	0.1	1.9	0.6	0.5	0.1
ATHERINIDAE	3.0	0.1	0.9	0.6	0.9	6.0	3.3	3.4
CAESIONIDAE	2.6	—	0.1	0.3	0.1	2.2	—	0.7
LEIOGNATHIDAE	—	0.3	3.7	0.7	0.2	0.4	2.1	0.1
CARANGIDAE	1.2	—	—	—	—	0.2	0.3	—
OTHERS	15.0	3.7	1.5	0.9	1.9	2.4	0.7	1.2
No. of samples taken	30	157	21	60	11	25	19	4
No. of fish sampled	2516	12089	1388	4578	1818	12983	8255	1987
Months sampled	Jul Oct-Nov	Jan-May, Jul,Aug, Dec	Mar-May Aug,Oct, Nov	Mar-Nov	Mar,May, Jun,Sept	Apr-Dec	Jan-Dec	Jan-Apr

Notes:
[a] Source: Evans and Nichols (1984)
[b] Source: SIG (Unpublished Data)
[c] Source: Baitfish Research Project

using the experimental bouke-ami technique are included.

These tables are the pooled results of all samples taken during the year. In every case the engraulid anchovies make up the predominant part of the catch, with *Stolephorus heterolobus* and *S. devisi* the two most numerous species. The families of Dussumieriidae, including the species *Spratelloides lewisi, S. delicatulus* and *S. gracilis,* and Clupeidae, the predominant species being *Herklotsichthys quadrimaculatus,* are of secondary importance, with the families of Atherinidae, Apogonidae, Scombridae, Caesionidae and Leiognathidae comprising smaller parts of the catch. The 'Others' in the tables refer to all other fish caught and not only those too small for positive identification.

The predominance of *Stolephorus* anchovies in the bait catch is also recorded from Papua New Guinea (Kearney et al., 1972; Lewis, 1977; Dalzell and Wankowski, 1980), Palau (Wilson, 1977), and Hawaii (Uchida, 1977).

There was a marked decrease in the importance of *S. heterolobus* in the bait catch at both Munda and Tulagi in 1988 and 1989. This was coupled with an increase in importance of *S. devisi, Spratelloides* and *Herklotsichthys* species. This change in species composition can be partly attributed to fishing effort (see Rawlinson and Nichols, these Proceedings) but the influence of environmental factors such as rainfall and therefore run-off cannot be exlucded. Wetherall (1977) observed an inverse relationshp between increased stream discharge and abundance of *Stolephorus purpureus,* and this species has similar habitat preferences to *S. devisi* and *S. heterolobus* (Dalzell, 1986). The effects of fishing effort on stocks of baitfish are reported by Dalzell, 1984. He states that the continued removal of fish affects the equilibrium biomass of a fishing ground to the detriment of some species but to the benefit of others. The continual removal of baitfish from Ysabel Passage, Papua New Guinea may have benefited the 'other species' component of the catch as a whole by reducing predation of baitfish feeding on fish eggs; the removal of potential competitors for food; and/or the removal of baitfish leading to a decline in the abundance of larger predators. The situation in Solomon Islands seems to be that stocks of *S. heterolobus* suffer under high fishing pressure but with *S. devisi* and *Spratelloides* species becoming more numerous in its place (see Rawlinson and Nichols, these Proceedings).

The use of the small-scale experimental technique for the capture of some samples may have had an effect on the species composition of the catches. All samples collected from Vona Vona were caught using the experimental technique and samples were primarily composed of *S. devisi* (see Fig. 2). During 1988 and 1989 a larger number of the samples from Munda and Tulagi were collected using the same technique. *S. heterolobus* may have been able to avoid this smaller gear more quickly than other species. Smith (1977) noted that *S. heterolobus* will encircle a dimmed

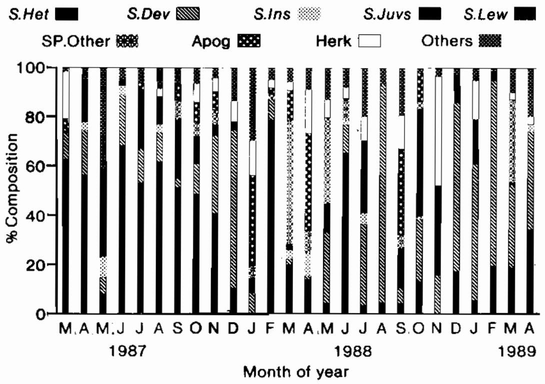

Figure 2. Baitfish Percentage Catch Composition by Numbers for Munda, 1987–89.

Key: S.Het — *Stolephorus heterolobus*
S.Dev — *Stolephorus devisi*
S.Ins — *Stolephorus insularis*
S.Juvs — *Stolephorus* juveniles
S.Lew — *Spratelloides lewisi*
Sp.Other — *Spratelloides delicatulus* and *S. gracilis*
Apog — Apogonidae Sp.
Herk — *Herklotsichthys* Sp. and *H. quadrimaculatus*
Others — All other fish not included above

Table 3. Species list of fish taken during baitfish sampling in Solomon Islands March 1987–May 1989.

Species	Munda	Tulagi	Vona Vona
ENGRAULIDAE			
° *Stolephorus devisi*	*	*	*
° *Stolephorus heterolobus*	*	*	*
Stolephorus indicus	*	*	*
Stolephorus insularis	*	*	*
Stolephorus punctifer	*	*	*
Thryssa baelama	*	*	*
DUSSUMIERIIDAE			
Dussumieria sp *A*	*	*	*
Dussumieria sp *B*	*	*	*
° *Spratelloides delicatulus*	*	*	*
° *Spratelloides gracilis*	*	*	*
° *Spratelloides lewisi*	*	*	*
CLUPEIDAE			
Amblygaster clupeiodes		*	*
Amblygaster sirm	*	*	*
° *Herklotsichthys quadrimaculatus*	*	*	*
° *Herklotsichthys* sp	*	*	*
Pellona ditchela	*	*	*
Sardinella melanura	*	*	*
Sardinella sp		*	
Clupeidae Unidentified sp		*	*
SCOMBRIDAE			
Rastrelliger brachysoma	*		
Rastrelliger faughni	*	*	*
Rastrelliger kanagurta	*	*	*
Scomberomorus commerson	*	*	
Scombridae Unidentified sp		*	
APOGONIDAE			
Apogon bandanensis	*		
Apogon compressus	*		
Apogon fraenatus	*		
Apogon marmoratus	*		
Apogon sp	*	*	*
Archamia lineolata	*	*	*
° *Archamia zosterophora*	*	*	*
Cheilodipterus macrodon	*		*
Cheilodipterus quinquelineata	*		
Cheilodipterus sp		*	
Pseudamia gelatinosa		*	
Pseudamia polystigma	*		
° *Rhabdamia cypselurus*	*	*	*
Rhabdamia gracilis		*	
Rhabdamia sp		*	
Siphamia sp	*		*
Apogonidae Unidentified sp	*		
CAESIONIDAE			
Caesio caerulaurea	*	*	*
Dipterygonotus balteatus	*	*	*
Gymnocaesio gymnopterus	*		
Pterocaesio diagramma	*	*	
Pterocaesio pisano	*	*	*
Pterocaesio tile	*		
Pterocaesio sp	*		
Caesionidae Unidentified sp	*	*	
ATHERINIDAE			
Atherinomorus duodecimalis	*		
Atherinomorus endrachtenis	*	*	*
Atherinomorus lacunosus	*	*	
Atherinomorus sp		*	
Hypoatherina barnesi		*	

Table 3. Species list of fish taken during baitfish sampling in Solomon Islands March 1987–May 1989.

Species	Munda	Tulagi	Vona Vona
Hypoatherina ovalaua	*	*	*
Hypoatherina temminckii	*		
Hypoatherina valenciennesi		*	
Hypoatherina sp		*	*
Stenatherina panatela	*	*	*
LEIOGNATHIDAE			
Gazza minuta	*	*	*
Leiognathus bindus	*	*	*
Leiognathus equulus	*		
Secutor insidiator	*	*	*
CARANGIDAE			
Atule mate	*	*	
Carangoides hedlandensis		*	
Caranx sexfasciatus	*		
Decapterus macrosoma		*	
Selar boops	*	*	*
Selar crumenophthalmus		*	
Selaroides leptolepis	*	*	*
Scomberoides lysan		*	
Scomberoides tol		*	*
Scomberoides sp	*	*	
Carangidae Unidentified sp	*	*	*
SPHYRAENIDAE			
Sphyraena barracuda	*	*	
Sphyraena chrysotaenia	*	*	
Sphyraena flavicauda	*	*	*
Sphyraena forsteri		*	
Sphyraena jello		*	
Sphyraena obtusata	*	*	
Sphyraena putnamiae			*
Sphyraenidae Unidentified sp	*	*	*
LUTJANIDAE			
Lutjanus biguttatus	*		
Lutjanus duodecimalis	*		
Lutjanus fulvus	*		
Lutjanus kasmira	*		
Lutjanus lutjanus	*		
Lutjanidae Unidentified sp	*	*	*
HOLOCENTRIDAE			
Myripristis adusta	*	*	
Myripristis leiognathus	*		
Sargocentron diadema	*		
Sargocentron spiniferum	*	*	*
Sargocentron sp		*	
Holocentridae Unidentified sp		*	*
MULLIDAE			
Mulloides flavolineatus	*		
Mulloides vanicolensis	*	*	
Upeneus sp		*	
Mullidae Unidentified sp	*		
SYNODONTIDAE			
Saurida gracilis	*	*	
Saurida undosgamis		*	
Syanodus variegatus	*		
Syanodus sp	*		
Synodontidae Unidentified sp			
SIGANIDAE			
Siganidae Unidentified sp	*	*	*
ACANTHURIDAE			
Acanthuridae unidentified sp	*	*	*

Table 3. Species list of fish taken during baitfish sampling in Solomon Islands March 1987–May 1989.

Species	Munda	Tulagi	Vona Vona
ALUTERIDAE			
Aluteridae unidentified sp	*		
CORIDAE			
Stethojulis strigiventer	*		
Coridae unidentified sp	*		
POMACENTRIDAE			
Abudefduf bankieri		*	
Abudefduf sp	*		
Pomacentridae Unidentified sp			
SYNGNATHIDAE			
Corythoichthys intestinalis waitei	*		
Syngnathidae Unidentified sp	*	*	
CANTHIGASTERIDAE			
Canthigasteridae unidentified sp	*		*
DIODONTIDAE			
Diodontidae unidentified sp	*	*	*
HEMIRAMPHIDAE			
Hemiramphidae unidentified sp	*		
NEMIPTERIDAE			
Pentapodus caninus	*		
Nemipteridae unidentfied sp	*		
ANGUILLIDAE			
Anguillidae unidentified sp	*		
BALISTIDAE			
Balistidae unidentified sp	*	*	
BOTHIDAE			
Bothidae unidentified sp	*		
TETRADONTIDAE			
Tetradontidae unidentified sp	*	*	
SERRANIDAE			
Epinephelus sp	*	*	
FISTULARIIDAE			
Fistularia commersonii	*		
Fistularia unidentified sp	*	*	
PRIACANTHIDAE			
Priacanthus cruentatus	*	*	
Priacanthus sp		*	
NOMEIDAE			
Ariomma indica	*	*	
BREGMACEROTIDAE			
Bregmaceros nectabanus		*	*
CHAETODONTIDAE			
Chaetodon trifasciatus	*		
Chaetodontidae Unidentified sp			*
TRICHIURIDAE			
Trichiurus sp		*	*
OSTRACIIDAE			
Rhynchostracion nasus		*	
GOBIIDAE			
Gobiidae unidentified sp	*	*	
LAGOCEPHALIDAE			
Lagocephalus sceleratus		*	
MUGILIDAE			
Mugilidae unidentified sp		*	
BLENNIDAE			
Petroscirtes mitratus	*		
Blennidae unidentified sp	*		
LETHRINIDAE			
Lethrinus haematopterus	*		
Lethrinidae Unidentified sp	*		
CHROMIDAE			
Chromis sp	*		

Table 3. Species list of fish taken during baitfish sampling in Solomon Islands March 1987–May 1989.

Species	Munda	Tulagi	Vona Vona
CARAPIDAE			
Carapidae unidentified sp			
F. SCARIDAE			
Scarus ghobban	*		
Scaridae unidentified sp	*		
PLATICIADAE			
Platax sp	*		
CHIROCENTRIDAE			
Chirocentrus dorab	*		
POMACANTHIDAE			
Chaetodontoplus mesoleucus	*		

° Species targeted for baitfish

baitlight endlessly so presumably they would be caught just as well as the other species present. There is no hard evidence the data are not representative of the actual situation but the use of the experimental gear must be taken into consideration.

A total of over 147 taxa representing 47 families were recorded from the three sites during the sample period. These fish are listed in Table 3 and the site each taxa occured marked with an asterisk. Kearney et al. (1972) identified over 190 species belonging to 60 familes from a survey of baitfish resources in Papua New Guinea and Lewis (1977) reports over 300 species having been taken in lift-net catches from the same country. It is considered that with further sampling in Solomon Islands a larger variety of species of fish would be identified from the bait catch.

A good time series of data to show the change in species composition by month for one particular baitground had not been available in Solomon Islands until the start of the BRP. Figures 2, 3 and 4 detail the percentage composition of the major baitfish species by numbers taken during sampling from Munda, Tulagi and Vona Vona respectively. Data shown include samples taken from both commercial catches and those taken using the experimental fishing gear. The number of samples taken and number of fish sampled during each month at each site are detailed in Table 4.

The predominance of *Stolephorus heterolobus* and *Stolephorus devisi* in the bait catches is indicated in Figures 2, 3 and 4. A large variation in species composition from month to month is evident. This is probably due to effects of fishing effort and changes in environmental factors as discussed above.

These data, which in many cases consist of one or two samples taken per month are, however, not considered sufficient to represent the overall situation at a baitground for that month. Three to four samples taken at Munda within an hour of each other from different vessels produced great variation in species composition. A far more intensive

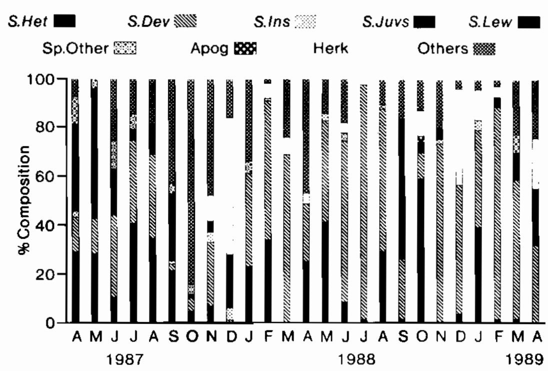

Figure 3. Baitfish Percentage Catch Composition by Numbers for Tulagi. 1987–89.
Key: As for Figure 2.

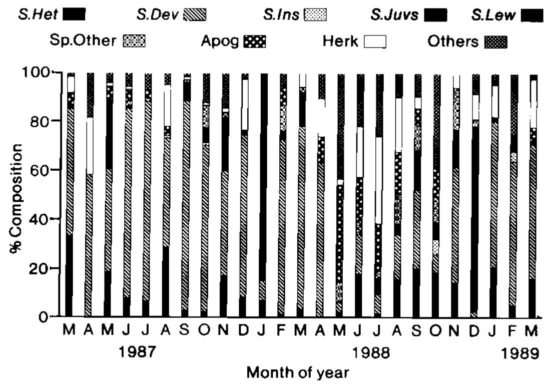

Figure 4. Baitfish Percentage Catch Composition by Number for Vona Vona, 1987–89.
Key: As for Figure 2.

Table 4. Sample sizes by site during Baitfish Research Project.

	Munda		Tulagi		Vona Vona	
	Samples	Fish	Samples	Fish	Samples	Fish
1987						
March	1	660	—	—	1	362
April	3	1778	2	1106	1	329
May	2	309	2	1390	1	461
June	3	1615	5	1728	1	725
July	2	2445	2	995	1	628
August	2	1632	3	2278	1	297
September	3	2813	5	2542	1	885
October	8	7548	2	1001	1	456
November	2	1330	1	427	1	524
December	1	768	1	296	1	284
1988						
January	1	564	2	610	1	1227
February	1	996	1	502	1	882
March	1	165	1	446	1	427
April	2	313	2	423	1	255
May	2	1960	2	625	1	221
June	1	427	3	825	1	428
July	1	366	1	529	1	167
August	1	601	1	583	2	371
September	1	457	3	2607	1	480
October	2	1111	1	531	2	839
November	1	834	1	108	1	563
December	1	556	1	466	2	786
1989						
January	2	2588	1	752	1	496
February	1	1536	1	805	2	511
March	2	2069	1	217	1	420
April	2	564	1	213	—	—
Totals	49	36005	46	22005	29	13024

sampling program than has been reported here would be required to give complete representation of the actual monthly situation.

Importance of by-catch species

Species considered as baitfish are those of the families Engraulidae, Dussumieriidae, Clupeidae, Atherinidae, Apogonidae, Caesionidae, Scombridae, Leiognathidae and Carangidae (*Selar boops* and *Selar crumenopthalmus* only) as described by Lewis et al. (1983). Other species caught are considered as by-catch.

Large predatory fish, particularly members of the families Carangidae and Trichiuridae are often caught in the commercial bait catches in Solomon Islands (Evans and Nichols, 1984). The capture of such large pelagic fish as diverse as *Sphyraenidae* spp, *Chirocentrus dorab* and *Scomberomorus commerson,* as well as the bottom living species *Lutjanus fulvus,* and coral reef fish such as *Scarus ghobban* and *Platax* sp., have also been noted in the catches. The by-catch species included in this study are those occurring in the random samples taken with the small fine meshed net which excludes these larger fish.

Local residents of baitgrounds have often remarked on the capture of adult fish in the baitnets, especially when pole-and-line operations began in Solomon Islands in 1971. Details of levels of the catch of adult fish from these early days of the industry are not available. Although numbers of adult fish caught in one haul of the bait-net are not usually large, totals over a whole season in a heavily baitfished area could be quite substantial and this is an area worthy of further study.

Lewis (1983) reports the capture of large predators (*Scomberomorus, Sphyraena, Caranx*) using baited lines around bait lights as an important source of coastal fish production. This method for capture of fish is also used by rural fishermen in Solomon Islands (Evans and Nichols, 1984) but was not seen as an important activity during this study.

Crustacea (prawns, shrimps, and crabs) and Cephalapoda (squid and octopus) are also taken in commercial bait catches in Solomon Islands. They are predominantly juveniles and occasionally occur in large numbers. These have also been excluded from the by-catch data.

McCarthy (1985) reported the occurrence of Crustacea and Cephalopoda in the commercial bait catch from Tarawa Lagoon, Kiribati.

The species recorded as by-catch and their mean fork lengths in millimetres from each site are listed in Table 5. Maximum and minimum lengths of species collected are recorded, as well as the standard deviation from the mean length. The majority of the fish were larval or juvenile stages.

The larvae of a number of species of tropical coastal fishes have been described as positively phototactic or habitually schooling near the water surface (Johannes, 1978). This would explain the reason for the larval stages of fish being attracted to the underwater lights and finally caught in the bait catch.

The list of species taken and their percentage composition by numbers of the total catch for the three years of this study are detailed in Tables 6, 7 and 8 for Munda, Tulagi and Vona Vona respectively. The frequency of occurrence is expressed as a percentage of the number of months that a species appeared in catches divided by the number of months of the year sampled.

The Tables show that a wide diversity of species are captured but they make up a very small proportion of the total catch composition by numbers. The highest yearly total was at Tulagi in 1987 when by-catch species made up 2.67% of the total catch composition and the lowest was at Vona Vona in 1987 when the level was only 0.12% of the catch.

The fish include a mixture of pelagic and reef-associated species. There are no species which occurred in the catches at all sites during all years and in a number of cases a species is represented by one individual collected on one sampling occasion (e.g. *Lutjanus biguttatus, Lutjanus duodecimalis* and *Lutjanus lutjanus*). Fish from the families Siganidae, Sphyraenidae, Carangidae and Holocentridae and the species *Scomberomorus commerson* and *Priacanthus cruentatus* appear most regularly in the baitfish catches from year to year.

Other authors have identified these species in bait-catches from other parts of the world. Kikawa (1977) reported many species collected at night-light stations of larval and juvenile fish which were too small to be used as baitfish during a survey in Papua New Guinea in 1968. During a second survey in 1969 he noted the following families in fairly large numbers in collections made using a stick-held lift net, scoop nets and night-lights: Myctophidae, Holocentridae, Mugilidae, Scombridae, Sphyraenidae, Carangidae, Mullidae, Apogonidae, Blenniidae, Pomacentridae, Acanthuridae and Siganidae. Only the larvae or juveniles were caught as the adults did not aggregate in schools around the light.

In Fiji, *Caranx* sp., 6.3 to 8.5 cm. in length, were taken in small quantities while night-lighting (Lee, 1973). *Scomberoides tol* are also reported to be taken in Fiji (Lee, 1973); *Scomberoides lysan* were reported in bait catches in Hawaii (June and

Table 5. By-catch species from baitfish sampling during BRP. The number of fish (N) measured; the mean, maximum and minimum fork lengths recorded and the standard deviation (SD) away from the mean are recorded for each species by site.

	Munda					Tulagi					Vona Vona				
Species	N	Mean	Max.	Min.	SD	N	Mean	Max.	Min.	SD	N	Mean	Max.	Min.	SD
Abudefduf bankieri	—	—	—	—	—	1	17.0	—	—	—	—	—	—	—	—
Abudefduf sp	1	38.0	—	—	—	—	—	—	—	—	—	—	—	—	—
Acanthuridae unidentified sp	5	27.6	32	21	3.9	5	38.8	44	29	5.3	2	31.5	35	28	3.5
Aluteridae unidentified sp	1	27.0	—	—	—	—	—	—	—	—	—	—	—	—	—
Anguillidae unidentified sp	1	192.0	—	—	—	—	—	—	—	—	—	—	—	—	—
Ariomma indica	4	13.2	24	8	6.4	5	14.6	21	10	4.2	—	—	—	—	—
Atule mate	—	—	—	—	—	1	107	—	—	—	—	—	—	—	—
Balistidae unidentified sp	1	31.0	—	—	—	2	16.5	32	12	15.5	—	—	—	—	—
Bothidae unidentified sp	1	30.0	—		—	—	—	—	—	—	—	—	—	—	—
Bregmaceros nectabanus	—	—	—	—	—	13	38.9	73	18	13.3	2	39.0	49	29	10.0
Canthigasteridae unidentified	2	65.5	—	—	—	—	—	—	—	—	3	22.3	25	19	2.5
Carangidae unidentified sp	16	29.6	47	15	9.1	11	39.9	65	18	13.2	6	44.6	56	25	11.4
Carangoides hedlandensis	—	—	—	—	—	1	147.0	—	—	—	—	—	—	—	—
Caranx sexfasciatus	7	75.0	81	68	4.5	—	—	—	—	—	—	—	—	—	—
Coridae unidentified sp	2	34.0	55	13	21.0	—	—	—	—	—	—	—	—	—	—
Decapterus macrosoma	—	—	—	—	—	1	82.0	—	—	—	—	—	—	—	—
Diodontidae unidentified sp	2	31.5	45	18	13.5	2	27.0	39	15	12.0	1	12.0	—	—	—
Epinephelus sp	2	21.5	23	20	1.5	3	17.3	22	15	4.0	—	—	—	—	—
Fistulariidae unidentified sp	1	127.0	—	—	—	1	125.0	—	—	—	—	—	—	—	—
Gobiidae unidentified sp	—	—	—	—	—	4	33.0	48	18	12.2	—	—	—	—	—
Hemiramphidae unidentified sp	1	74.0	—	—	—	—	—	—	—	—	—	—	—	—	—
Holocentridae unidentified sp	—	—	—	—	—	12	26.8	47	19	8.0	1	31.0	—	—	—
Lutjanidae unidentified sp	2	29.0	30	28	1.0	9	20.4	26	11	4.3	—	—	—	—	—
Lutjanus biguttatus	1	130.0	—	—	—	—	—	—	—	—	—	—	—	—	—
Lutjanus duodecimalis	1	36.0	—	—	—	—	—	—	—	—	—	—	—	—	—
Lutjanus lutjanus	1	85.0	—	—	0.0	—	—	—	—	—	—	—	—	—	—

Mullidae unidentified sp	2	67.0	85	49	18.0	—	—	—	—	—	—	—	—	—	—
Mulliodes flavolineatus	7	46.6	78	39	12.9	6	30.1	48	24	8.4	—	—	—	—	—
Myripristis adusta	1	28.0	—	—	0.0	5	26.4	35	17	7.0	—				
Myripristis leiognathus	1	35.0	—	—	—	—	—	—	—	—	—	—	—	—	—
Pomacentridae unidentified sp	1	38.0	—	—	—	—	—	—	—	—	—	—	—	—	—
Priacanthus cruentatus	5	63.6	70	58	4.2	3	41.3	46	38	4.2	—	—	—	—	—
Rhynochostracion nasus	—	—	—	—	—	2	10.0	10	10	0.0	—	—	—	—	—
Sargocentron diadema	1	108.0	—	—	—	—	—	—	—	—	—	—	—	—	—
Sargocentron spiniferum	8	30.7	35	26	2.8	1	31.0	—	—	—	3	33.0	33	33	0.0
Saurida gracilis	1	106.0	—	—	—	3	63.3	77	53	10.1	—	—	—	—	—
Saurida undosquamis	—	—	—	—	—	1	81.0	—	—	—	—	—	—	—	—
Scolopsis sp	1	31.0	—	—	—	—	—	—	—	—	—	—	—	—	—
Scomberiodes lysan	—	—	—	—	—	2	51.0	57	45	6.0	—	—	—	—	—
Scomberoides tol	—	—	—	—	—	4	48.8	53	46	2.6	1	54.0	—	—	—
Scomberoides sp	1	51.0	—	—	—	3	29.3	30	28	0.9	—	—	—	—	—
Scomberomorus commerson	1	34.0	—	—	—	5	36.4	45	20	8.7	1	40.0	—	—	—
Scomberomorus sp	—	—	—	—	—	5	29.8	38	25	4.6	—	—	—	—	—
Selaroides leptolepis	47	57.0	140	20	22.0	7	38.4	69	29	12.9	5	125.2	160	62	34.5
Siganidae unidentified sp	38	20.0	25	13	3.7	114	23.4	37	10	3.9	6	25.7	47	19	9.7
Sphyraena barracuda	3	42.6	45	38	3.3	2	56.0	60	52	4.0	—	—	—	—	—
Sphyraena chrysotaenia	1	169.0	—	—	—	7	80.3	167	62	35.5	—	—	—	—	—
Sphyraena flavicauda	6	56.5	69	48	7.3	15	62.9	236	35	48.3	3	61.3	69	50	8.2
Sphyraena forsteri	—	—	—	—	—	3	108.6	207	58	69.5	—	—	—	—	—
Sphyraena obtusata	12	162.4	227	50	64.0	12	83.0	184	42	49.1	—	—	—	—	—
Sphyraena putnamiae	—	—	—	—	—	—	—	—	—	—	1	68.0	—	—	—
Sphyraenidae unidentified sp	6	45.5	66	22	13.3	11	41.8	58	31	6.5	1	15.0	—	—	—
Stenthojulis strigiventer	1	60.0	—	—	—	—	—	—	—	—	—	—	—	—	—
Syngnathidae unidentified sp	12	33.9	37	27	2.6	1	50.0	—	—	—	—	—	—	—	—
Tetrodontidae unidentified sp	1	16.0	—	—	—	5	31.0	59	12	—	—	—	—	—	—
Trichiurus sp	—	—	—	—	—	1	100.0	—	—	—	1	142.0	—	—	—
Upeneus sp	—	—	—	—	—	2	37.0	38	36	1.0	—	—	—	—	—

Table 6. By-catch species recorded from baitfish sampling from Munda during BRP. The percentage composition (% N) by numbers of the total annual sample, and the occurrence in monthly samples as a percentage of the months sampled (% F) for each species by year are shown.

Species	1987		1988		1989	
	% N	% F	% N	% F	% N	% F
Abudefduf sp	—	—	0.012	6.67	—	—
Acanthuridae unidentified sp	0.014	11.11	0.036	20.00	—	—
Aluteridae unidentified sp	0.005	3.70	—	—	—	—
Anguillidae unidentified sp	0.005	3.70	—	—	—	—
Ariomma indica	0.005	3.70	0.048	26.67	—	—
Balistidae unidentified sp	—	—	0.012	6.67	—	—
Bothidae unidentified sp	—	—	0.012	6.67	—	—
Canthigasteridae unidentified sp	0.010	5.41	0.012	6.67	—	—
Carangidae unidentified sp	0.048	14.81	0.012	6.67	0.074	57.14
Caranx sexfasciatus	—	—	0.072	13.33	0.015	14.29
Coridae unidentified sp	0.005	3.70	0.012	6.67	—	—
Diodontidae unidentified sp	0.005	3.70	0.012	6.67	—	—
Epinephelus sp	—	—	0.024	6.67	—	—
Fistulariidae unidentified sp	—	—	0.012	6.67	—	—
Hemiramphidae unidentified sp	0.005	3.70	—	—	—	—
Lutjanidae unidentified sp	0.005	3.70	0.024	6.67	—	—
Lutjanus biguttatus	0.005	3.70	—	—	—	—
Lutjanus duodecimalis	0.005	3.70	—	—	—	—
Lutjanus lutjanus	—	—	—	—	0.015	14.29
Mullidae unidentified sp	0.010	7.41	0.012	6.67	—	—
Mulloides flavolineatus	0.019	3.70	—	—	0.089	28.57
Myripristis adjusta	—	—	—	—	0.015	14.29
Myripristis leiognathus	—	—	0.012	6.67	—	—
Pomacentridae unidentified sp	0.005	3.70	—	—	—	—
Priacanthus cruentatus	—	—	—	—	0.074	28.57
Sargocentron diadema	0.005	3.70	0.180	26.67	0.030	28.57
Saurida gracilis	0.005	3.70	—	—	—	—
Scolopsis sp	0.096	3.70	0.012	6.67	—	—
Scomberoides sp	0.014	3.70	—	—	—	—
Scomberomorus commerson	0.005	3.70	0.012	6.67	—	—
Selaroides leptolepis	0.225	37.04	—	—	—	—
Siganidae unidentified sp	0.077	11.11	0.778	40.00	0.059	28.57
Sphyraena barracuda	0.014	3.70	—	—	—	—
Sphyraena chrysotaenia	0.005	3.70	—	—	—	—
Sphyraena flavicauda	0.005	3.70	0.048	13.33	—	—
Sphyraena obtusata	0.010	7.41	0.012	6.67	0.133	14.29
Sphyraenidae unidentified sp	0.019	11.11	0.012	6.67	0.015	14.29
Stenthojulis strigiventer	—	—	0.012	6.67	—	—
Syngnathidae unidentified sp	0.057	11.11	—	—	—	—
Tetrodontidae unidentified sp	—	—	0.012	6.67	—	—
Other Fish (unidentified)	0.100	25.93	0.395	26.67	—	—
Total number of by-catch fish	146		150		35	
Total number of by-catch species	30		5		10	
Total % N	0.785		1.796		0.518	
Total number of fish sampled	20898		8350		6757	
Total number of samples	27		15		7	

Reintjes, 1953). Juveniles of *Priacanthus* sp. are noted by Cleaver and Shimada (1950) as having been used as skipjack tuna bait in Ponape and Truk. Juveniles of the barracuda *Sphyraena obtusata* were captured with night-light and lift net but not in great numbers (Marukawa, 1939). Cleaver and Shimada (1950) noted the use of this species in the "south seas" and Domantay (1940a, 1940b) reported its use in the Philippine fishery.

Kearney et al. (1972) reported the capture of many of the species considered to be by-catch in this paper from Papua New Guinea and McCarthy (1985) noted some of them in catches from Tarawa Lagoon, Kiribati.

Table 7. By-catch species recorded from baitfish sampling from Tulagi during BRP. The percentage composition (% N) by numbers of the total annual sample, and the occurrence in monthly samples as a percentage of the months samples (% F) for each species by year are shown.

	1987		1988		1989	
Species	% N	% F	% N	% F	% N	% F
Abudefduf bankieri	—	—	0.012	5.26	—	—
Acanthuridae unidentified sp	0.008	4.00	0.024	5.26	0.050	25.00
Ariomma indica	0.008	4.00	—	—	0.151	50.00
Atule mate	—	—	0.012	5.26	—	—
Balistidae unidentified sp	0.015	8.00	—	—	—	—
Bregmaceros nectabanus	0.092	20.00	0.024	5.26	—	—
Carangidae unidentified sp	0.077	24.00	0.036	5.26	—	—
Carangoides hedlandensis	—	—	0.012	5.26	—	—
Decapterus macrosoma	0.008	4.00	—	—	—	—
Diodontidae unidentified sp	0.008	4.00	—	—	—	—
Epinephelus sp	0.015	4.00	—	—	0.050	25.00
Fistulariidae unidentified sp	—	—	—	—	0.050	25.00
Gobiidae unidentified sp	0.008	4.00	—	—	0.050	25.00
Holocentridae unidentified sp	0.015	8.00	0.061	15.79	—	—
Lagocephalus sceleratus	—	—	0.012	5.26	—	—
Lutjanidae unidentified sp	0.069	16.00	0.012	5.26	—	—
Mugilidae unidentified sp	—	—	0.012	5.26	—	—
Mulloides flavolineatus	—	—	0.097	0.04	0.050	25.00
Myripristis adusta	—	—	0.048	10.53	0.050	25.00
Priacanthus cruentatus	0.015	4.00	0.024	5.26	0.050	25.00
Rhynochostracion nasus	0.015	8.00	—	—	—	—
Sargocentron spiniferum	—	—	0.012	5.26	0.050	25.00
Saurida gracilis	0.015	4.00	0.012	5.26	—	—
Saurida undosquamis	—	—	0.012	5.26	—	—
Scomberoides lysan	—	—	0.024	10.53	—	—
Scomberoides tol	—	—	0.048	5.26	—	—
Scomberoides sp	—	—	0.036	5.26	—	—
Scomberomorus commerson	0.039	12.00	0.048	10.53	0.050	25.00
Selaroides leptolepis	0.054	8.00	0.012	5.26	—	—
Siganidae unidentified sp	1.263	36.00	—	—	0.403	50.00
Sphyraena barracuda	—	—	0.024	10.53	—	—
Sphyraena chrysotaenia	0.054	8.00	—	—	—	—
Sphyraena flavicauda	0.046	12.00	0.109	15.79	—	—
Sphyraena forsteri	—	—	0.036	10.53	0.050	25.00
Sphyraena jello	0.023	4.00	—	—	—	—
Sphyraena obtusata	0.015	8.00	0.109	21.05	—	—
Sphyraenidae unidentified sp	0.085	20.00	0.012	5.26	—	—
Syngnathidae unidentified sp	0.008	4.00	—	—	—	—
Synodontidae unidentified sp	0.023	8.00	—	—	—	—
Tetraodontidae unidentified sp	0.031	8.00	—	—	0.050	25.00
Trichiurus sp	0.008	4.00	—	—	—	—
Upeneus sp	—	—	—	—	0.101	25.00
Other Fish (unidentified)	0.655	52.00	—	—	—	—
Total number of by-catch fish	348		77		5	
Total number of by-catch species	26		27		14	
Total % N	2.673		0.884		1.208	
Total number of fish sampled	12983		8255		1987	
Total number of samples	25		19		4	

Site differences in the species and number of by-catch

The most noticeable difference between sites was that at Vona Vona the diversity of species and numbers of by-catch species caught was much less than at Munda and Tulagi.

All samples were collected from Vona Vona using the experimental fishing technique so the sampling method may be the main reason for the lower by-catch from this area. Sample sizes are also generally smaller and this seems to have a significant effect on the numbers of species recorded (see below).

Table 8. By-catch species recorded from baitfish sampling from Vona Vona during BRP. The percentage composition (% N) by numbers of the total annual sample, and the occurrence in monthly samples as a percentage of the months sampled (% F) for each species by year are shown.

	1987		1988		1989	
Species	% N	% F	% N	% F	% N	% F
Acanthuridae unidentified sp	—	—	0.015	6.67	—	—
Ariomma indica	—	—	—	—	—	—
Bregmaceros nectabanus	0.020	10.00	0.015	6.67	—	—
Carangidae unidentified sp	0.020	10.00	—	—	0.140	33.33
Canthigasteridae unidentified sp	—	—	0.060	13.33	—	—
Chaetodontidae unidentified sp	—	—	0.030	6.67	—	—
Diodontidae unidentified sp	—	—	0.060	20.00	—	—
Holocentridae unidentified sp	—	—	0.015	6.67	—	—
Lutjanidae unidentified sp	—	—	0.120	6.67	—	—
Sargocentron spiniferum	—	—	0.045	6.67	—	—
Scomberoides tol	—	—	0.015	6.67	—	—
Selaroides leptolepis	0.020	8.00	0.015	6.67	—	—
Siganidae unidentified sp	—	—	0.316	33.33	—	—
Sphyraena flavicauda	—	—	0.030	13.33	—	—
Sphyraena putnamiae	—	—	0.015	6.67	—	—
Sphyraenidae unidentified sp	—	—	0.030	13.33	—	—
Trichiurus sp	—	—	0.015	6.67	—	—
Other Fish (unidentified)	0.061	20.00	0.075	13.33	—	—
Total number of by-catch fish	6		58		2	
Total number of by-catch species	4		16		1	
Total % N	0.121		0.873		0.140	
Total number of fish sampled	4951		6646		1427	
Total number of samples	10		15		4	

Secondly, Tulagi has a higher proportion of the by-catch made up of pelagic species, both in numbers and variety. This is to be expected due to the greater depth of water at Tulagi and because bait-fishing does not occur in such close proximity to coral reefs as it does in Munda.

Seasonal/monthly patterns in species and numbers of by-catch

Figures 5a and 5b, 6a and 6b, and 7a and 7b show the number of species and numbers of fish taken by month for Munda, Tulagi and Vona Vona, respectively. The number of fish sampled and the number of samples (for Fig. 5a, 6a and 7a only) taken per month are also plotted on the graphs. The 'others' category represents one taxon in the compilation of the graph.

The Figures show that for all sites there are peaks in the numbers of species of by-catch and numbers of by-catch fish caught around March and April, and September and October. The exception to this is at Vona Vona at the com-

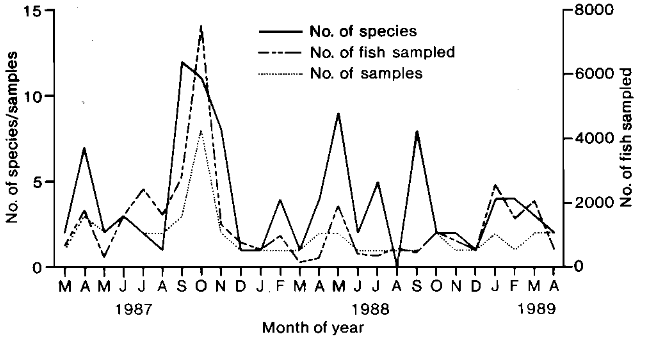

Figure 5(A). Munda Baitfish By-Catch.
Key: No. of Species — Number of taxa of by-catch species recorded in baitfish samples for a particular month.
No. of Fish Sampled — Number of fish in the monthly samples.
No. of Samples — Number of samples collected during a particular month.

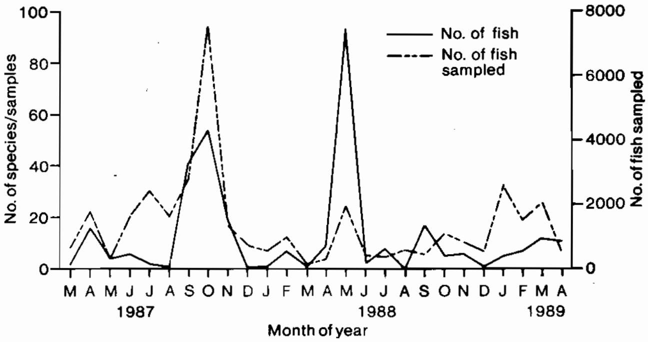

Figure 5(B). Munda Baitfish By-Catch
Key: No. of Fish — Number of individual fish which are by-catch species, recorded in baitfish samples for a particular month.
No. of Fish Sampled — Number of fish in the monthly samples.

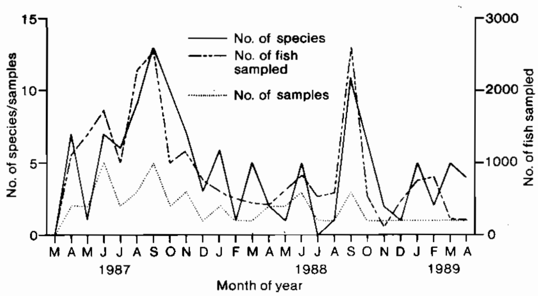

Figure 6(A). Tulagi Baitfish By-Catch
Key: As for Figure 5(A)

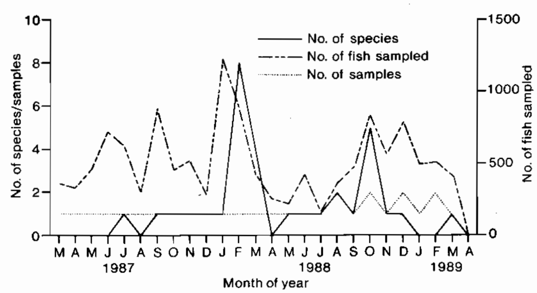

Figure 7(A). Vona Vona Baitfish By-Catch
Key: As for Figure 5(A)

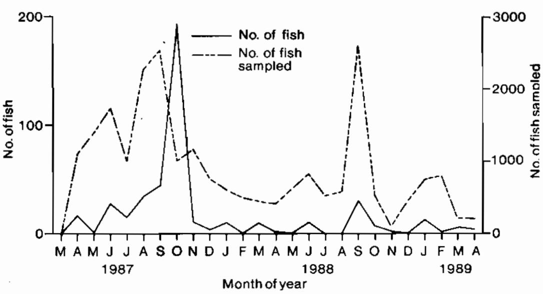

Figure 6(B). Tulagi Baitfish By-Catch
Key: As for Figure 5(B)

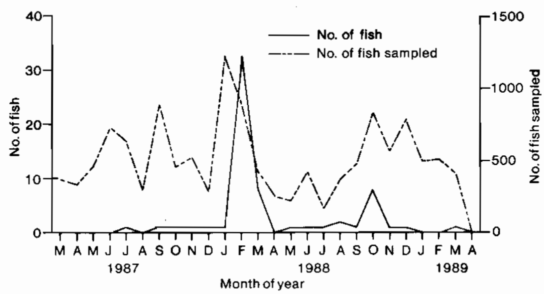

Figure 7(B). Vona Vona Baitfish By-Catch
Key: As for Figure 5(B)

mencement of sampling for this study in March and April 1987. Smaller peaks do occur during other months of the year but they are not as pronounced as those of March/April and September/October.

In general, reproduction of coastal marine fishes takes place the whole year around but there are certain times of the year when unusually large numbers of species and individuals within species, reproduce. These periods are referred to as collective spawning peaks (Johannes, 1978). In a number of instances there have been two collective spawning peaks identified within one year from different areas e.g. Madagascar (Fourmanoir, 1963); Mandapam, Southeast India (Bapat, 1955; Prasad, 1958); Hawaii (Watson and Leis, 1974); Curacao (Luckhurst and Luckhurst, 1977); Barbados (Powles, 1975) and the Tigak Islands, Papua New Guinea (Mohiba, 1989). In all cases the two peaks fall in between the months of March to May and August to November. It is likely therefore coastal marine fishes in Solomon Islands also have two collective spawning peaks giving rise to the two peaks in by-catch during March and April, and September and October as most of the by-catch consists of juvenile and larval fish. Russell et al. (1977) state however, that differences in larval life histories make interpretation of breeding times from juvenile recruitment data difficult and so analysis of the data on a species-to-species basis should be carried out.

The general pattern of collective spawning peaks is influenced by temperature, plankton productivity, rainfall and speed of prevailing currents and winds (Johannes, 1978). All these factors should be looked at to try and understand the exact timing of spawning and hence the abundance of larval fishes within baitfish grounds.

It is important to note that the numbers of by-catch species and fish are closely related to the numbers of fish sampled and numbers of samples taken per month. Most peaks in the numbers of by-catch coincide with peaks in the sample sizes. However, there is no direct relationship between size of the peaks and the size of the samples and so the occurrence of the peaks can not be solely attributed to sample size.

Importance of by-catch species in the subsistence fishery

Indications from Blaber et al. (1990) and what is known about the subsistence fishery in Solomon Islands are that species from the families Acanthuridae, Balistidae, Carangidae, Lethrinidae, Lutjanidae, Scombridae, Serranidae and Sphyraenidae make up a major proportion of the catch. A number of fish from these families have been caught as by-catch species of the baitfishing operations and are listed in Tables 9 and 10 for Munda and Tulagi, respectively. Those species which have only occurred in the catches on one sampling occasion have been removed from the list. As no commercial baitfishing takes place at Vona Vona the extraction of by-catch species other than from sampling is not considered.

Numbers of by-catch species important in the subsistence fishery taken in commercial catches

Dalzell (1984) found no significant difference between the mean annual percentage composition by numbers and the mean annual percentage weight composition of different species in bait catches in Papua New Guinea. Therefore in order to estimate the number of by-catch species being taken by commercial baitfishing operations, values of the percentage composition by numbers for each species were multiplied by the total catch made for that year from that site. At Munda 200 507 and 34 111 buckets of bait, and at Tulagi 82 449 and 129 725 buckets of bait were caught by the commercial pole-and-line fleet in 1987 and 1988 respectively. These numbers were used to convert the percentage by numbers values for each taxon into the total catch by taxa in buckets. A bucket of bait in Solomon Islands weighs 2.2 kilograms (Evans and Nichols, 1984) and this factor was used to convert the bucket totals to weights. For each of the by-catch taxon an estimation of the maximum and minimum weight of an individual over the size range recorded has been made. These estimations were from direct measurements of weights of individuals of a particular taxon whose size was close to the limits of the range. The weights have then been used to give a maximum and minimum number of individuals of each by-catch taxon, by dividing them into the total weights caught for each taxon. These figures are listed in Tables 9 and 10.

The numbers for some taxa are very large, between 422 160 and 1 055 401 individuals for Carangidae unidentified sp. from Munda in 1987, and between 251 481 and 628 703 individuals for Lutjanidae unidentified sp. from Tulagi in 1987. It is beyond the scope of this paper to discuss what effect the extraction of such numbers of larval/juvenile fish from an area would have on the adult population of a particular taxon. However, it is an area requiring more detailed study.

Conclusions

Large numbers of larval and juvenile fish are captured in the commercial bait catches in Solomon Islands, some are species which form an important part of the subsistence fishery of the local people who live in close proximity to the bait-ground. Adult fish and invertebrates are also caught in the bait catch but from this study it has not been possible to estimate to what extent.

The capture of non-target species in the bait catch may have a detrimental effect on the subsistence fishery in commercial baitfishing areas. It has not been possible to assess the level of impact of the extraction of this estimated number of larval and juvenile fish, but it is certainly an area which should be investigated further.

If these levels are significant then a reduction in commercial baitfishing effort or a completely closed season during the periods of peak reef-fish recruitment would appear to be the most practicable answer to decreasing the mortality of larval and juvenile fish. From the data presented in this paper this period would be between March and April and September and October.

Table 9. Estimated numbers of individuals of by-catch species important in subsistence fisheries caught in baitfishery at Munda by year.

Species	Approx. Weight (g)		1987				1988			
			% N	Catch	Catch (Numbers)		% N	Catch	Catch (Numbers)	
	Min.	Max.		(kg)	Min.	Max.		(kg)	Min.	Max.
Acanthuridae unidentified sp	0.50	0.60	0.014	63.32	105 540	126 648	0.036	26.96	44 937	53 924
Balistidae unidentified sp	0.10	0.20	—	—	—	—	0.012	8.99	44 937	89 873
Carangidae unidentified sp	0.20	0.50	0.048	211.08	422 160	1 055 401	0.012	8.99	17 975	44 937
Carnax sexfasciatus	8.00	10.00	—	—	—	—	0.072	53.92	5 392	6 740
Epinephelus sp	0.10	0.20	—	—	—	—	0.024	17.97	89 873	179 747
Lutjanidae unidentified sp	0.20	0.50	0.005	21.11	42 216	105 540	0.024	17.97	35 949	89 873
Scomberoides sp	0.90	1.30	0.014	63.32	48 711	70 360	—	—	—	—
Scomberomorus commerson	0.40	0.60	0.005	21.11	35 180	52 770	0.012	8.99	14 979	22 468
Sphyraena barracuda	0.30	0.50	0.014	63.32	126 648	211 080	—	—	—	—
Sphyraena chrysotaenia	40.00	60.00	0.005	21.11	352	528	—	—	—	—
Sphyraena flavicauda	1.00	2.00	0.005	21.11	10 554	21 108	0.048	35.95	17 975	35 949
Sphyraena obtusata	40.00	60.00	0.010	42.22	704	1 055	0.012	8.99	150	225
Sphyraenidae unidentified sp	0.50	1.50	0.019	84.43	56 288	168 864	0.012	8.99	5 992	17 975

Table 10. Estimated numbers of individuals of by-catch species important in subsistence fisheries caught in baitfishery at Tulagi by year.

Species	Approx. Weight (g)		1987				1988			
			% N	Catch	Catch (Numbers)		% N	Catch	Catch (Numbers)	
	Min.	Max.		(kg)	Min.	Max.		(kg)	Min.	Max.
Acanthuridae unidentified sp	0.50	0.70	0.008	13.97	19 959	27 942	0.024	69.14	98 778	138 290
Balistidae unidentified sp	0.10	0.20	0.015	27.94	139 712	279 424	—	—	—	—
Carangidae unidentified sp	0.20	0.60	0.077	139.71	232 853	698 559	0.036	103.72	172 862	518 586
Epinephelus sp	0.10	0.20	0.015	27.94	139 712	279 424	—	—	—	—
Lutjanidae unidentified sp	0.20	0.50	0.069	125.74	251 481	628 703	0.012	34.57	69 145	172 862
Scomberoides lysan	0.90	1.30	—	—	—	—	0.024	69.14	53 188	76 828
Scomberoides tol	0.90	1.30	—	—	—	—	0.048	138.29	106 377	153 655
Scomberoides sp	0.40	0.60	—	—	—	—	0.036	103.72	172 862	259 293
Scomberomorus commerson	0.40	0.60	0.039	69.86	116 426	174 640	0.048	138.29	230 483	345 724
Sphyraena barracuda	1.00	2.00	—	—	—	—	0.024	69.14	34 572	69 145
Sphyraena chrysotaenia	4.00	5.00	0.054	97.80	19 560	24 450	—	—	—	—
Sphyraena flavicauda	1.50	2.50	0.046	83.83	33 531	55 885	0.109	311.15	124 461	207 434
Sphyraena forsteri	6.00	10.00	—	—	—	—s	0.036	103.72	10 372	17 286
Sphyraena obtusata	4.00	5.00	0.015	27.94	5 588	6 986	0.109	311.15	62 230	77 788
Sphyraenidae unidentified sp	0.50	1.50	0.085	153.68	102 455	307 366	0.012	34.57	23 048	69 145

In order to carry out further study a more comprehensive sampling program would need to be undertaken. Sampling during this study was not specifically designed to address this particular area, therefore deficiencies in the sampling structure are evident and the following methods should be incorporated into any future program:

- standardise the sample size,
- standardise the sampling technique,
- more regular sampling at constant stations within the research site,
- more detailed information concerning the sampling station i.e. water depth at station, proximity to reef, bottom substrate, whether fishing takes place from a permanent mooring etc.,
- monitor the level of fishing effort that takes place at each particular sampling station.

It is also very important that each individual fish caught is properly identified to species level and detailed information of the life-histories of each species is obtained.

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