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Tuna Baitfish and the Pole-and-line Industry in Kiribati

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Summary

Tuna are fished throughout the tropical and temperate waters of the world using three main methods: purse-seining, long-lining, and pole-and-line fishing. The pole-and-line fishery is a low-cost, high-employment fishing technique compared to the purse-seine method. The move to high-capital, low-employment and high-technology resources of purse-seiners has increased in the American and to a lesser extent the Japanese tuna fishing fleet. Most of the tuna catch of Solomon Islands, Maldives, Kiribati, and Fiji is made using the traditional pole-and-line method. This technique cannot operate without a regular and adequate supply of suitable baitfish species. These are small fish which are thrown live into the sea to attract tuna schools within fishing range of the boat. The tuna industry is vital in Solomon Islands, Maldives, Kiribati and Fiji where it provides a major source of food, much employment and high export earnings.

The ACIAR-funded Tuna Baitfish Research Project coordinated by CSIRO Division of Fisheries began in 1986 in Solomon Islands and Maldives. Results of value to the fishery were available by 1988. At this time the Republic of Kiribati had a pole-and-line fleet of six vessels. The viability and further development of this fleet were constrained by inadequate and variable supplies of baitfish. With the aim of addressing this problem, and in response to requests by the Government of Kiribati, their Fisheries Division joined the Baitfish Research Project late in 1988 with financial assistance from the Australian International Development Assistance Bureau (AIDAB). They became a full part of the ACIAR project in 1989. A CSIRO scientist was stationed in Kiribati in 1990 and with staff of the Fisheries Division carried out the fieldwork necessary for the project. This was completed early in 1991. The results of this work, together with summaries and reviews of all past baitfish research in Kiribati, form the basis for this Report. The current status of the baitfishery is described with particular reference to stock assessment. New information from the project on mortality rates and catch-per-unit-effort has made possible reasonable estimates of maximum sustainable yield, and also the number of vessels that could be supported by the fishery. Research on the biology of baitfish in Kiribati highlights the migratory nature of these species in an atoll environment. This and their reproductive patterns contribute to the variability in catches experienced by the pole-and-line fleet. Natural predation and predation on baitfish around bouke-ami lights are described and the importance discussed in relation to artisanal fisheries.

In addition to research on baitfish, the project looked at methods to improve the overall efficiency and viability of baitfishing and thus of the pole-and-line fleet as a whole. Ways to change the timing of fishing, alternative sites and bait, and improvements to baitfishing techniques likely to lead to a more profitable industry are described. If viability problems persist in the commercial tuna fishery in Kiribati, then the introduction of an artisanal tuna fishery, as exists in Maldives, may be a real possibility for such atoll nations.

Previous Baitfish Studies in Kiribati

The references for a number of studies undertaken and reports written about baitfish and baitfishing in the waters of the Republic of Kiribati are listed in the Kiribati Fisheries Bibliography (Gillett et al. 1991). This section covers two different topics: firstly, research that has concentrated on assessments of the tuna and baitfish resources necessary for the development of a pole-and-line fishery; and, secondly, work which has concentrated on the biology and the fishery dynamics of some of the most important wild baitfish species.

It is vital in planning future research and development to be aware of the work that has already been undertaken on baitfish in the Republic of Kiribati. This section of the report details the most relevant and important aspects of each of the reports.

Assessment of Tuna and Baitfish Resources

This section includes the development of the pole-and-line fishery in the Republic of Kiribati.

Earliest reports

The first reports on baitfish resources in the Republic of Kiribati concern the Line Islands area. Smith and Schaefer (1949) found bait in the lagoon at Christmas Island and also reported large quantities of mullet and goatfish, but no fish of the silverside (Atherinidae), anchovy (Engraulidae), or herring (Clupeidae) families. They found some silverside just offshore of the island during night-light baiting operations. The bait catch at Christmas Island consisted of 30 scoops (about 4.5 kg baitfish per scoop) of 15-cm mullet (Mugilidae) and a few goatfish (Mullidae) of similar size. Other early reports of the resources of the Line Islands were made in the early 1950s (June 1951; June and Reintjes 1953). June and Reintjes (1953) reported that species suitable for use as supplemental live bait were available in the lagoon at Fanning Island, and that Christmas Island was potentially the most important baitfish source in the Line Islands.

Gibson (1977) details catches of skipjack tuna (*Katsuwonis pelamis*) by a commercial fishing company, the Teikaraoi Fishing Company, during 1975. The vessel was designed to operate as a tuna vessel employing trolling and pearl jig techniques. From April to December 1975, the vessel undertook 137 operational days fishing for a total catch of 63 848 kg skipjack tuna, an average of 466 kg for each fishing day.

The Government of Kiribati (or the Gilbert Islands, as it was at that time) set up a Fishery Survey Unit and under an agreement with an American tuna company initiated a joint survey program, mainly in the area of the central Gilbert group, to identify the economic viability of a tuna fishing industry (FAO 1983). The first operations of this venture indicated that, although large stocks of tuna existed in the area surveyed, the supply of suitable bait for pole-and-line fishing was limited. Unfortunately, this survey had to be abandoned when the three survey vessels were lost during a hurricane in October 1972. From this survey it was recognised that urgent steps were necessary to provide for sufficient supplies of baitfish so that any large-scale commercial tuna fishing venture would be economically viable (Gopalakrishnan 1974). A project was initiated to investigate the feasibility of aquaculture in lagoons, with special reference to culture of baitfish.

FAO

Based on the successful results obtained during 1974–1976 from the feasibility surveys and investigations, and the pilot farm established at Ambo (South Tarawa), the expanded project on 'Tuna and Baitfish Resources Evaluation' was established (FAO 1983).

The primary objectives of this project were defined as follows.

1. Development of fish cultivation practices for the production of milkfish (*Chanos chanos*) in quantities suitable for use as live bait in pole-and-line tuna fishing.
2. Demonstration of the commercial viability of pond culture of milkfish on South Tarawa and to develop the most effective program for pond culture.
3. Survey the atolls of the Republic of Kiribati and identify sites where commercially viable milkfish culture facilities could be established.
4. Survey the naturally occurring baitfish stocks in Kiribati and evaluate the sufficiency of these stocks for commercial pole-and-line fishing operations and develop the most effective methods for capturing and handling wild baitfish.
5. Index the surface tuna stocks available to pole-and-line fishing gear in the Republic of Kiribati and evaluate the performance of cultured milkfish fingerlings and species of naturally occurring fish as bait for pole-and-line fishing.
6. Train national personnel in all aspects of baitfish culture and commercial pond management, pole-and-line fishing and natural bait collection, bait handling and transport, bait utilisation, etc.

The project began in 1977 and concluded on 30 September 1982. A purpose-built vessel *Nei Manganibuka* was used for the fishing operations and two fish farms, at Ambo and Temaiku, were constructed.

The success of the baitfish culture depended on a regular supply of milkfish fry. On Tarawa, fry occur from late December to early February, and from May to September, with a fall in abundance in August. Fry were available throughout the year, however (Wainwright 1982).

Production rates from the pilot farm were very good in the first series of experiments and were obtained without special fertilisation and supplementary feeding. Production rates were increased in the second series of experiments by the introduction of pelleted food to the ponds (FAO 1983).

After setting up the ponds and achieving satisfactory production rates, the work focused on a suitable species to be produced as baitfish. Milkfish were identified as the best candidate due to their availability throughout the year, their satisfactory growth rates, their adaptability to sudden changes in salinity and temperature conditions, their virtual absence of parasites and diseases, and the fact that they possess characteristics suitable for effective live bait for pole-and-line fishing. The fry could be reared to sizes suitable for bait (7–10 cm) in 8–10 weeks (FAO 1983).

Problems arose with the collection of milkfish fry due to land ownership and traditional rights. These did not allow the establishment of milkfish fry collection centres. Furthermore, the use of government workers for such a scheme appeared to be unproductive. A system whereby villagers were encouraged to collect fry and were paid on a catch-to-cash basis was then set up and became popular. However, in 1980 the villagers began to demand unrealistically high prices for the fry, which led to a situation where the fry requirements of the two farms could not be met. In 1981, after efforts to explain the importance of fry collection, and some public relations work, the fry collection system by the villagers was once again able to function. In certain centres of North Tarawa, villagers were able to earn regular cash incomes from this industry (FAO 1983).

Milkfish surveys were also carried out at Butaritari, Abaiang and Maiana with encouraging results, and if the requirement for fry had increased, it would have been possible to set up a fry collection industry at these islands.

At the larger Temaiku fish farm which had a size limit of an 80–hectare complex it was considered that there would be sufficient availability of milkfish fry to stock the farm. It was estimated that approximately 50% of future fry requirements could be met by natural influx through the sluice gates and from any surplus at the Ambo farm. The balance would need to be met by expanding the fry collection program. It was estimated that with this supply of fry and if regular harvesting was carried out (this could be achieved by a regular demand for bait from the commercial vessels), then average production rates of 1500 kg/ha/yr could be achieved.

The project fishing vessel *Nei Manganibuka* started operations on 14 February 1979 and the program was completed on 24 October 1980. Average tuna catches in 1979 and 1980 were 906 kg/day and 649 kg/day, respectively. During the survey the highest monthly catches were during the months of June, July and August for both years. The highest monthly catch rate was in June 1987 with an average of 2200 kg/day. Lowest catches were during October and February.

Skipjack tuna (*Katsuwonis pelamis*) dominated catches during both years and accounted for 81% of the total yield. The average weight of skipjack during 1979 was 3.14 kg and 2.92 kg in 1980. Yellowfin tuna (*Thunnus albacares*) made up 14% of the catch. Their average weight was 3.7 kg in 1979 and 2.44 kg in 1980.

The main fishing area was the waters around Butaritari, Abaiang, Tarawa, Maiana, Abemama, Aranuka and Kuria Islands. The general indication was that the average size of the catch in the northern fishing grounds was bigger than in the southern fishing grounds, and that the number of schools in coastal waters was higher than in inshore waters. Biting tendency, however, was generally poorer in coastal waters.

In general terms, the best fishing season was from May to August. However, the information available on tuna catches indicates no marked seasonality and good catches can be expected at all times of the year, provided weather conditions are favourable. The highest mean catches per school were in the 28.0–29.9°C temperature range for surface seawater. Catch rates decreased with higher temperature and only averaged 19 kg/operation above 31.5°C. Detailed information on these results is in other reports by FAO (Walczak 1982; FAO 1983).

During 1979 a total of 91 days was spent scouting and fishing for bait with beach-seine gear. The trials were conducted in the lagoons of Butaritari (34% of total days), Tarawa (42%), Abaiang (18%) and Abemama (6%). A total of 7361 buckets (22 063 kg) of natural bait were caught, with an average of 80.9 buckets/day (243 kg/day). *Herklotsichthys quadrimaculatus* dominated the catches, comprising 86–100% of the samples. Atherinids of the species *Atherinomorus lacunosus* and *Hypoatherina ovalaua* formed the rest of the catches. Goatfish, carangids and gerreids were observed.

In 1980, the day bait catch dropped to 63 kg/day. Natural bait in the beach-seine collections was almost non-existent from April to October, except in Abemama. The percentage of sampling efforts were: Butaritari 13%; Tarawa 22%; Abaiang 30%; and Abemama 35%. The total catch in 1980 was 415 buckets (3.5 kg each) and the number of operational days was 23. The species composition was similar to that of 1979.

The pattern of appearance of *Herklotsichthys quadrimaculatus* differed in each of the four lagoons. Seasons of peak abundance are not identical. Furthermore, while the catches were good in 1979, the schools scarcely appeared in 1980, except in Abemama.

Bouke-ami operations started after March 1980. A total of 946.5 buckets was collected in 74 sets in 43 nights during the period April to October 1980. This gave an average of 12.8 buckets/set or 22 buckets/night. The species composition of the catches was: *Spratelloides delicatulus* 87.7%; *Atherinomorus lacunosus* and *Hypoatherina ovalaua* 7.3%; *Herklotsichthys quadrimaculatus* 1.4%; *Dussumieria acuta* 1.4%; *Amblygaster sirm* 1.4% and *Rhabdamia cypselurus* 0.8%. Several other species occurred in very small numbers. The average lagoon catch per operation was 25.3 buckets in Butaritari, 10.9 buckets in Abaiang, 10.3 buckets in Tarawa, and 2 buckets in Abemama (only two sets).

In 1979 the ratio of bait chummed to tuna caught was 1:9.8. This improved to 1:14.5 in 1980. For the different types of bait used the most noticeable observation was that milkfish had the highest total average ratio among the four bait types chummed from the project vessel.

One of the project's main conclusions was that the natural bait resources in the lagoons are erratic and cannot be relied upon. The bait trials conducted by the project in 1979 and 1980, as well as the results obtained earlier from two Japanese International Cooperation Agency (JICA) surveys, South Pacific Commission (SPC) surveys (see below), and reports received from trials in 1981 and 1982 clearly indicate that milkfish is an effective live bait for pole-and-line fishing operations for tuna. The high survival rate of milkfish in bait wells gives a high overall efficiency for this species (FAO 1983).

An economic report (the FAO Investment Centre Report No. 46/80) stated that the catch rate of 1 kg of bait to 15 kg of catch obtained during the exploratory fishing operations was too low, and that Japanese pole-and-line vessels are expected to obtain a bait to catch ratio of 1:90. It was therefore recommended that the 'I-Kiribati' fishermen need more training and experience in catching tuna and bait, but especially in the proper use of live bait. This economic report also stated that if a 100 GT class of pole-and-line vessel, operated by local crews, could obtain a catch rate of 750 t/vessel/yr, the exercise would have been profitable under the 1980 price structure. However, due to economic conditions in 1983, FAO considered this no longer a realistic figure. The initial commercial trials showed that the bait necessary for the 1980 level of operations may be available from the lagoons and the existing fish farms with a projected catch of 4500 t/yr. However, the report concluded that if more bait were needed there was little hope for an economically viable operation.

It was concluded that the future development of pole-and-line fishing in Kiribati would be possible only if the commercial trials were considered satisfactory. However, the entire scope of the venture depended on high market prices for tuna as well as high catch rates per unit bait expended. It was considered that both these essential requirements were unlikely to be achieved in the next 5–10 years (FAO 1983).

JICA

The Japanese International Cooperation Agency (JICA) undertook a survey of the skipjack and baitfish resources of the Gilbert Group of the Republic of Kiribati using the pole-and-line vessel *Daini Kyoryo-Maru* (59.98 ton) from 7 November 1977 to 5 March 1978 (JICA, 1978). A summary of their findings follows.

(a) The islands that have adequate passages to allow access of the survey vessel into the lagoons for baitfish are Tarawa, Abaiang, Butaritari, Abemama, Nonouti and Tabiteuea, but during periods of seasonal easterly winds, it would be difficult for the vessel to enter the lagoons of islands other than Tarawa and Butaritari.

(b) The lagoons of islands open to the sea from the western side are adversely affected during periods of westerly winds. The swells stir up the sand and mud increasing the water turbidity in the lagoon, during which periods the schools of baitfish are less frequent in their appearance.

(c) The fish species that could be used for baitfish caught in the lagoons were: *Herklotsichthys quadrimaculatus*, *Atherinomorus lacunosus*, *Spratelloides delicatulus*, *Archamia* sp. and *Decapterus* sp. Observations concerning these species follow.

Herklotsichthys quadrimaculatus — This was the most important baitfish in the area of the survey, the majority being caught in Tarawa and the northern islands of Abaiang and Butaritari, while few were caught in the southern islands of Maiana, Aranuka and Abemama, and none in islands further south. These results were qualified by stating that these figures should be considered indicative only of the period surveyed. They formed large schools in shallow water, making them available to capture by beach-seine net (referred to as purse-seine in the report). During periods of strong winds when the water becomes turbid the schools of baitfish become harder to observe and therefore more difficult to catch. The frequency of appearance of schools is generally higher at spring tides. It was speculated that spawning took place between November and December. Although *Herklotsichthys quadrimaculatus* will form schools around lamps at night, they are not strongly attracted to the lights. They did not approach the area around the centre of an underwater light but swam irregularly at a distance away from it.

When immediately transferred to the bait wells the mortality rate of *H. quadrimaculatus* was about 30% in the first 12 hours but decreased thereafter. Fish over 6 cm in body length have a higher degree of durability, depending on shock and sea conditions. This species could be kept in a well maintained bait tank for one week to one month, depending on water circulation patterns.

After undertaking holding experiments in anchored pens it was considered feasible to hold *H. quadrimaculatus* in a large bait pen for extended periods if feeding was carried out. The pens would have to be protected, however, against attack from large predators such as sharks.

Due to their availability, durability, size (30 mm to 95 mm recorded) and motion when cast into the sea, *H. quadrimaculatus* were considered most suitable as a baitfish for skipjack fishing. Their only defect was lack of resistance to scale-loss after capture.

It was noted that *H. quadrimaculatus* was an important source of food for local people. Hence, if they were caught in large quantities to be used as baitfish to support a commercial fishery, this might cause a shortage of food for the people. It was therefore necessary to study the ecology of *H. quadrimaculatus*, especially their migratory routes and spawning activity, and the possibility of continuous reproduction has to be confirmed before developing a pole-and-line fishery based on the use of this species.

Atherinomorus lacunosus — This species was observed mixed with schools of *Herklotsichthys quadrimaculatus* and on occasions formed discrete schools of its own. It was attracted more readily to lamps than *H. quadrimaculatus*. The size range was 30–75 mm.

Spratelloides delicatulus — Schools of this species were not observed in the daytime but were attracted to lights so could be caught using a stick-held dip net (bouke-ami) at night. This species was thought to occur in lagoons throughout the Gilbert group. Body length ranged 20–60 mm.

Dussumieria sp. — This species was not observed during the day but was caught in the stick-held dip net at night using lights. They occurred in Tarawa and Abaiang. Size ranges were 120–190 mm.

Apogonidae unidentified species — Very few specimens from this family were caught in the stick-held dip net during the night. They were thought to live in lagoons surrounding the entire Gilbert Group.

Decapterus sp. — This species was caught on one occasion in Tarawa lagoon using the stick-held dip net at night.

As well as using the wild-caught species listed above, tests were made using milkfish (*Chanos chanos*) supplied from the FAO–UNDP Milkfish Culture Centre at Ambo on Tarawa Island. This species had an extremely high rate of survival. Their death rate during transportation by boat was about 5% and those which die within 12 hours after being transferred to the live-bait well account for only 5%. It was stated that no fish die after this period. Milkfish could be kept in the wells with natural water exchange, without being fed, for six days. It was envisaged that with the right conditions and the right feeding strategy, milkfish could be kept in the vessel for a period of over one month. The size ranges used were between 5 cm and 15 cm. The tests showed that, although this species' movements are mild when dispelled into the water, they will form a school and follow the boat and therefore act as extremely effective baitfish for skipjack fishing. Gut content analysis of tuna showed that milkfish accounted for a higher proportion of the chum eaten than other species.

Results of catching methods used

Stick-held dip net — Because the main target species, *Herklotsichthys quadrimaculatus*, was not caught in great numbers using this method, it was used only on a limited basis. It was noted that if the lamp is illuminated for a long time, larger fish will gather and disperse the bait, so the net should be hauled after 2 to 3 hours of the lamp.

Beach-seine — This method accounted for over two-thirds of the bait captured during the survey and was considered most suitable for the capture of *H. quadrimaculatus*.

A second survey was carried out by the pole-and-line vessel *Hatsutori Maru No. 3* (79.37 tons) on the skipjack and baitfish resources in the Gilbert Group of the Republic of Kiribati for 163 days from 19 May 1978 to 28 October 1978 (JICA 1979).

During this survey it was ascertained that *Herklotsichthys quadrimaculatus*, *Spratelloides delicatulus*, *Hypoatherina ovalaua*, *Apogonidae* unidentified species, *Amblygaster sirm*, *Dussumieria* sp., *Caesio caerulaureus* and *Carangidae* unidentified sp. were available for use as bait for pole-and-line fishing and were distributed in the lagoons of Tarawa, Abemama and Butaritari islands. The survey showed that *H. quadrimaculatus* and *S. delicatulus* were particularly effective baitfish. Both species were abundant and could be easily caught in large quantities with either a bouke-ami net or a beach-seine. *H. quadrimaculatus* were more abundant in Tarawa and *S. delicatulus* in Abemama. Average catch rates by bouke-ami net during the course of the survey was 28.4 buckets per haul with *H. quadrimaculatus* comprising the major component of the catch and *S. delicatulus* a further 34.5%. For the beach-seine, average catch rates were 25.1 buckets per haul with *H. quadrimaculatus* accounting for 96% of the catch. (In this survey a bucket held 3 kg of baitfish.)

H. quadrimaculatus was excellent for durability and could be held in bait pens with varying success depending on the method of capture and transport and the size of the fish. *Spratelloides delicatulus* were not as durable (or hardy) and were not suitable for holding in pens. *Herklotsichthys quadrimaculatus* was also more active and effective as a bait than than *S. delicatulus*.

SPC

The Skipjack Survey and Assessment Programme of the South Pacific Commission undertook three visits to the Gilbert Islands Group of the Republic of Kiribati during the periods 5–25 July 1978, 22 November–1 December 1979 and 9–11 July 1980, as well as one visit to the Phoenix group from 2–5 December 1979 (Kleiber and Kearney 1983). Interim presentation of results from all but the last visit to the Gilbert Group have been given by Kearney and Gillett (1978) and Hallier and Kearney (1980). A summary and analysis of the results for all visits is given by Kleiber and Kearney (1983).

Baitfishing operations during these surveys were limited to the lagoons of Tarawa and Butaritari. Catch rates realised during bouke-ami operations were 69 kg/haul and 19 kg/haul for the first and second surveys, respectively. For beach-seine operations catches were 347 kg/haul and 24 kg/haul, respectively.

The final conclusions of these surveys were that the baitfish obtainable in the Gilbert Group can be used effectively to catch skipjack and other tunas. However, the results of the Skipjack Programme implied that good supplies of natural bait are variable in the Gilbert Group. Therefore supplementing the natural bait supplies with cultured baitfish may be essential for supporting a sustained local commercial pole-and-line operation. The surveys go on to comment that whether this is an economically viable prospect remains to be proven (Kleiber and Kearney 1983).

Kristjonsson and Stone, and MacInnes

In 1980 a two-man team of consultants, following a request from the Government of Kiribati, undertook a study to advise on the feasibility of establishing a locally-based skipjack tuna fishing industry (Kristjonsson and Stone 1981).

With reference to past survey results (e.g. JICA, SPC and UNDP/FAO), this study estimated that at least 50 buckets/night could be caught by bouke-ami net. The study noted that this figure was based on limited survey results with only one vessel. No indication of the effects of fishing pressure on the bait stocks could be obtained from these results. It was also noted that caution should be exercised when planning for the expansion of fishing effort on these bait stocks as very little is known of the biology of *Amblygaster sirm* and *Herklotsichthys quadrimaculatus* in atoll environments. It was suggested that the effects of fishing effort be closely monitored.

This team estimated that with the ponds available in Tarawa (40 ha), it would be possible to produce 60 000 kg of baitfish per year by 1981–82. This would be equal to 20 000 buckets of bait (3 kg/bucket). Given the high survival rate of the milkfish (*Chanos chanos*) in the bait wells, it was estimated that only 35–50 buckets of bait would be required per vessel per day. It was therefore concluded that the 60 000 kg of bait would sustain two to three vessels for a year. With the 140 000 kg estimated production for 1983–84, by which time the pond size was to be doubled and brought to full production, it was considered that it would be possible to sustain four to five vessels per year (200 days each).

The recommendations of this report were that, initially, skipjack/tuna fishing in the Republic of Kiribati should be by the pole-and-line live-bait fishing method, and the fish should be exported frozen. It was thought that there were no limiting marine resources factors to affect the establishment of a small, locally-based commercial skipjack/tuna fishing industry. The skipjack resources were stated to be abundant for most of the year (for 8 to 9 months) and that young yellowfin were present in coastal waters during the skipjack off-season.

The report stated that the availability of live bait is not a problem for a small fishery consisting of, say, 6 to 8 vessels. During the gradual build-up of such a fishery, experience would be gained which would be a guideline to fleet expansion.

In February 1981, Te Mautari Limited was created as the National Fishing Corporation of the Republic of Kiribati. The recruitment of the General Manager, funded by the United Nations Development Programme, was effected on 17 July 1981. Prior to that date the Company was under local caretaker management.

The commercial fishing operations grew from a single experimental pole-and-line vessel, *Nei Manganibuka*, at the conception of Te Mautari Limited to four vessels by March 1983. Two other vessels of a similar size, *Nei Arintetongo* and *Nei Kaneati*, started commercial operations in February 1982 and March 1983, respectively. A smaller vessel, *Te Tiaroa*, also joined the fleet in March 1983.

Two other vessels, *Nei Baeao* and *Nei Moaika*, arrived at the end of November 1988 and started fishing operations in 1989 (Tekinaiti 1990). The first *Nei Manganibuka* has since proved uneconomic and has been taken out of service (MacInnes 1990).

Since 1981, Te Mautari Limited has been a financial failure (MacInnes 1990). MacInnes attributed this failure to a variety of reasons including the fact that the original 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. He stated that the planners had made the assumptions that:

(a) both tuna and wild bait were not seasonal, and

(b) sufficient bait could be supplied by the development of milkfish culture ponds.

MacInnes said that in nine years of operation Te Mautari Limited had not clearly established fishing patterns both seasonally and annually. Experience had 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 Gilbert Group. Records also show that these are the best months for wild bait. He said that from October until February the winds blow sporadically from the west, resulting in a disruption of bait capture.

MacInnes also made a number of comments about the effectiveness of the baitfish species available. Concerning *Spratelloides delicatulus*, he stated that they could survive in the bait well for three days if only a few buckets were loaded, but with 20 buckets, the bait (both juvenile and adult) die within 15 hours and the largest percentage within nine hours. He added that the all-important *Spratelloides delicatulus* is the mainstay of the Te Mautari Limited fleet, and should they get the maximum sustainable yield of that species wrong and hit it too hard, then they would have economic problems ahead for some time.

MacInnes claimed that *Amblygaster sirm*, the species with gold spots, make up 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). However, neither of these species lives longer than 15 hours in the bait wells. It is also noticeable that the larger fish (100–150 mm) are dead within six hours, whereas smaller fish are hardier.

For *Herklotsichthys quadrimaculatus*, he claimed that this species makes an excellent bait, but only represents 5% of the catch. It will, however, live in the bait wells for up to three days.

MacInnes stated that 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 are therefore effective for chumming only up to a maximum of nine hours or 90 nautical miles from the baiting lagoon. His personal observations indicated that vessel crews are aware of the importance of keeping wild bait alive and active for chumming, and take all the necessary steps to ensure careful handling.

In conclusion, MacInnes stated that the problem that Te Mautari Limited encountered starting the pole-and-line operation was the economics of operating large, high-horsepowered vessels with a bait mass which suffered high mortality. However, they had now learned to match the vessel size and horsepower with bait mortality, and their latest vessels can operate with moderate efficiency within the constraints presented to them. Nevertheless, he considered it important to extend their area of operation by increasing the survival of the bait-mass. MacInnes considered that solving this problem was a matter of considerable priority.

Previous Studies of the Biology and Dynamics of Baitfish

Some of the earliest unconfirmed reports about the abundance of baitfish species in the lagoons of the islands of Tarawa and Butaritari pre-date the Second World War (Gopalakrishnan 1974). Prior to the war, *Herklotsichthys quadrimaculatus* were very abundant in these lagoons. During 1940–43 the Japanese used explosives to catch these fish, as a result of which this species almost completely disappeared during the years 1944–60. The species is then reported to have reappeared again in big schools, at intervals, from 1961 to 1972.

Randall

Randall (1955) studied the fish and native fishing methods in the Gilbert Islands and details the collection of specimens of *Spratelloides delicatulus* from the islands of Abemama and Marakei. In this bulletin he also gives details of the examination of the stomach contents of some of the fish species caught.

Cross

Cross (1978) collected biological information on fish species within Tarawa lagoon. He also tried to assess those species which could be used as baitfish for the development of a tuna pole-and-line fishery. He concluded that such a development would result in intensive fishing of the stocks of *Herklotsichthys quadrimaculatus*, which would lead to conflict with the interests of subsistence fishermen for whom it was an important source of food and bait for their handline fishery.

From his studies of *H. quadrimaculatus*, he proposed a theoretical life cycle for this species in Tarawa lagoon.

(a) Schools of juveniles enter the lagoon from the ocean at a total length normally between 30 mm and 40 mm;

(b) the lagoon provides richer feeding than the ocean and growth to maturity occurs;

(c) as the schools become sexually ripe they migrate out of the lagoon and spawn over the ocean reef;

(d) the eggs float and are carried into the ocean by currents, where they hatch and the larvae join the oceanic plankton and drift with ocean currents;

(e) after spawning, the adults either die or resume a pelagic life in the ocean — they do not return to shallow waters; and

(f) after the larvae metamorphose into juveniles, their behaviour pattern changes and they enter shallow coastal or lagoon water when the opportunity arises.

He concluded that intensive fishing of schools which are destined to leave the lagoon on reaching sexual maturity is likely to have little or no effect on future recruitment of juveniles into the lagoon. Cross also stated that with present knowledge it would be impossible to predict future recruitment of juveniles as it may depend on factors as yet unknown, beyond local control.

In his report, Cross also gives biological information, including length frequency data, on the potential baitfish species *Herklotsichthys quadrimaculatus*, *Spratelloides delicatulus* and *Atherinomorus lacunosus* in Tarawa lagoon.

Walczak

Walczak (1982) gives detailed information on the catch composition of the baitfishing by *Nei Manganibuka*'s operations of 1979–1980 during the course of the FAO project.

McCarthy

A study was undertaken by McCarthy between 1983 and 1984 of the wild baitfish species of Tarawa Lagoon. Catch-return data were collected from Te Mautari Limited, and from baitfish samples collected from the commercial catch (McCarthy 1985). This was the first major attempt to fulfil the recommendation of previous reports (Kristjonsson and Stone 1981) that any commercial development of the pole-and-line fishery should include a scientific study of the wild baitfish of Kiribati waters.

The information presented in the report is divided into two main parts. The first concerns the biological structure of the commercial baitfishery of Tarawa Lagoon and changes in this structure over time, and the second the biology of the major baitfish species in Tarawa Lagoon.

During 1983–1984 the baitfish catch was dominated by *Spratelloides delicatulus*, *Amblygaster sirm* and *Dussumieria* sp. B in roughly equal quantities. *Herklotsichthys quadrimaculatus* was occasionally abundant but mostly as small juveniles. Apogonidae, notably *Rhabdamia cypselurus*, were occasionally abundant. Atherinidae (principally *Hypoatherina ovalaua*), Caesionidae (*Caesio caerulaureus*) and Carangidae (principally *Selar crumenopthalmus*) were occasionally included in large quantities.

In agreement with previous surveys, McCarthy concluded that the species composition of the bait catch is unstable over relatively short periods of time. He stated that records show the abundance of *Herklotsichthys quadrimaculatus* may vary from dominance to almost absence from the bait catch over one or two years. *Amblygaster sirm* appeared to have risen from absence to prominence in the Tarawa bait catch over the four to five years prior to 1985.

McCarthy stated that the small size of the atoll environment and the reduced number of species found in such areas are associated with more pronounced variability where different families dominate bait catches several years apart and different species within one family alternate in dominance within the bait catch.

From his studies of the biology of some of the important species in the bait catch, McCarthy described the following life cycles of each group in Tarawa lagoon.

Spratelloides delicatulus — Most, if not all, of the life cycle of *S. delicatulus* may be spent in the lagoon. This species formed fairly discrete size classes which reduced the representative nature of the samples, causing problems for growth analysis that used modal length progression methods.

Both sexes of *Spratelloides delicatulus* showed first signs of sexual maturity at 40 mm standard length (at approximately 2.5 months of age), but most individuals did not mature until greater than 45 mm standard length. Females may reach sexual maturity and spawn when greater than 40 mm standard length but most ripe gonads were found in females above 50 mm standard length (at approximately 3.5 months of age). Males appeared to reach sexual maturity around 45 mm standard length and continued to be sexually active until maximum size (60 mm standard length, 5.5 months). Maximum size (female) and probable age in Tarawa samples from 1983 to 1984 was 68 mm standard length and approximately 9 months.

McCarthy concluded that the spawning of *Spratelloides delicatulus* is probably continuous and does not have a strong seasonal or lunar component. He considered that fecundity was about 2000 eggs but may possibly reach 4000 to 5000 in large females.

He postulated that fishing pressure is likely to have a strong effect on *Spratelloides delicatulus* and that recovery time after all parent stock above the minimum size (20 mm standard length) are caught is about four months.

Herklotsichthys quadrimaculatus — This species cycled between periods of great abundance and near absence in Kiribati and other waters. Such fluctuations in abundance appear to be a natural phenomenon but will certainly be aggravated by commercial fishing. Fishing pressure imposed by bouke-ami gear may be less than that imposed by seine or surround-nets, because the latter techniques employ active pursuit of the species, whereas bouke-ami capture relies on a passive technique of attraction to the net.

The majority of the specimens included in the 1983–84 samples were 20–27 mm in standard length and about 2 months old. Large and sexually mature individuals were rare. Juveniles recruited into the lagoon population for most of the sampling period, suggesting a lack of seasonality in spawning.

Herklotsichthys quadrimaculatus is likely to be strongly affected by overfishing. However, even in an unfished lagoon, recruitment is unpredictable since it probably occurs from ocean-based populations. Variation in abundance may therefore be related both to predictable local factors, such as fishing pressure, and unpredictable external factors.

McCarthy stated that *H. quadrimaculatus* was important to both commercial and subsistence fisheries in Kiribati.

Amblygaster sirm — McCarthy believed that *A. sirm* spends most of its life cycle outside the lagoon. He concluded this because of the absence of juvenile *A. sirm* in baitfish samples. He also found a possible seasonality of spawning.

McCarthy found that the abundance of *A. sirm* in Tarawa lagoon increased from an apparent absence in the late 1970s to one of the major species in the 1983–84 bait catch.

Ianelli

In 1986, in response to a request by the Government of Kiribati to study the impact of commercial baitfishing within its lagoons, the South Pacific Commission's Tuna and Billfish Assessment Programme assigned a scientist to address the following terms of reference:

(a) compile baitfishing data logged by both Te Mautari Limited pole-and-line vessels and by past baitfish surveys into a common format for analysis;
(b) design appropriate monitoring methods to assess the condition of the baitfish stocks; and
(c) perform analyses for gauging the impact of baitfishing operations on the lagoon ecosystem, the local fishing communities, and the future of the pole-and-line tuna industry within Kiribati.

The scientist spent two weeks, from 17 November to 3 December 1986, in Kiribati gathering data and other information. All available baitfishing data were compiled into a database format and analysed. They also provided a framework for future use by Fisheries Division. A total of five days was also spent on board one of the local pole-and-line vessels to observe baiting practices and data recording methods (Ianelli 1988).

Catch-rate patterns, from the analysis of the data compiled, did not show trends indicative of overfishing for all baitfish species combined. For individual species, compensating shifts of apparent abundance were noted between *Amblygaster sirm* and *Herklotsichthys quadrimaculatus*. In the early part of the pole-and-line baitfishery the catch rate of *A. sirm* was quite high and that for *H. quadrimaculatus* relatively low. A possible explanation for this phenomenon is that *H. quadrimaculatus* met with more favourable recruitment conditions while *A. sirm* met with increasingly poorer ones (Ianelli 1988).

Ianelli concluded that the practices of the pole-and-line baitfishery within Kiribati do not appear adversely to interact with local fishing methods by overfishing common food species (*Herklotsichthys quadrimaculatus*) or indirectly by depleting species that other food-fish eat. The impact of commercial baitfishing on the lagoon ecosystem was not possible to address explicitly using the data set available, but it was assumed that the incidental removal of juvenile and larval species of fish and invertebrates was likely to be low, based on detailed observations from other studies (e.g. Kleiber and Kearney 1983). The future of the pole-and-line fleet must still rely on cultured milkfish as bait due to fluctuations in natural bait catches. For these reasons it was not recommended that the size of the fleet be expanded unless the productivity of the milkfish farm was enhanced. Based on his observations and analyses Ianelli made the following recommendations:

(a) improve the quality and quantity of milkfish to enhance baitfish supply during periods of low natural bait catches;
(b) restrict beach-seining activities by commercial pole-and-line vessels in areas where local fishing communities regularly rely on catching *Herklotsichthys quadrimaculatus*; and
(c) encourage accurate collection of baitfishing details, particularly with regard to the number of sets during a given night, species composition of the catch, and the number of standard buckets loaded.

Stock Assessment

Summary

The most significant points from this section are:

- the main baitfish species are *Amblygaster sirm* and *Spratelloides delicatulus* and, to a lesser extent, *Herklotsichthys quadrimaculatus*;
- catch-at-age data for the three main baitfish species indicate that fishing mortality is quite high, especially for *A. sirm*;
- most natural baitfish are not in the effective length range for skipjack tuna;
- surplus production models of baitfish catch-and-effort suggest a maximum sustainable yield of 33 850 buckets/yr (102 t) for Tarawa;
- yield estimates based on primary productivity in each lagoon suggest much higher yields could be sustainable; and
- estimate of the baitfish requirements of the current Te Mautari fleet (5 vessels) for minimum viable returns (700 t/yr/boat) was 94 400 buckets (236 t) which is twice the highest annual baitfish catch.

Before populations of organisms can be managed effectively for rational exploitation, the status of the exploited population (stock) must be assessed. Despite the large number of studies of tuna baitfish in Kiribati in recent decades, only the recently published study of Ianelli (1992) has assessed the status of baitfish stocks or attempted to estimate the levels of fishing pressure these fish species will sustain. He estimated that there was an initial biomass of 18 500 buckets of *A. sirm* in Tarawa in 1982 and that the exploitation rate on this species was 4% per month, thus making this species lightly exploited. Other previous studies show that the major baitfish species in Kiribati are all clupeids: the sardine *Amblygaster sirm*, herring *Herklotsichthys quadrimaculatus* and sprat *Spratelloides delicatulus* (Cross 1978; McCarthy 1985). Clupeid fisheries are among the world's major fisheries and this group has been intensively studied in temperate regions. Clupeid populations are very susceptible to environmental changes and have little ability to modify their behaviour to compensate for changes in their environment (Cushing 1971). As a consequence, their numbers can fluctuate in response to environmental perturbations, thus making them vulnerable to overfishing.

This section assesses the current level of exploitation of the three major baitfish species in Kiribati by examining fishing mortality rates, commercial catch-and-effort and species composition data, and providing first estimates of the biomass of baitfish, maximum sustainable yields (MSY), and the optimal levels of fishing these stocks may sustain.

Mortality Estimates

In order to estimate the level of fishing effort baitfish stocks will sustain, we must first examine the impact of past fishing effort on the stocks. This enables us to determine whether the stocks have been lightly or heavily exploited.

Methods

Representative samples of *Amblygaster sirm*, *Herklotsichthys quadrimaculatus* and *Spratelloides delicatulus* were collected monthly from four sites in Kiribati between August 1989 and February 1991. All species were sampled from the commercial bouke-ami net catches (McCarthy 1984). In addition, *A. sirm* were caught by small-meshed gill-nets (see Predation section) and *H. quadrimaculatus* by cast net. All fish were measured (standard length in mm) then preserved in ethanol (70%) for further analyses in the laboratory.

In the laboratory, a subsample of fish was measured (standard length ± 1 mm) and dissected. Their sex was recorded and gonads, otoliths and stomachs removed for later analysis. Fish were aged by counting daily growth increments in otoliths. The von Bertalanffy growth parameters of the growth curve were estimated with an iterative non-linear regression procedure (SAS Proc NLIN) (Milton et al. 1992a). The MULTIFAN software package was used to estimate the best-fit growth parameters from the length-frequency data that were consistent with those obtained from the analysis of otoliths. Total mortality rates (Z) of each species were then estimated from the catch curve at each site and in those years where sufficient data were available.

Natural mortality (M) was estimated from three separate equations:

$$\log_{10}M = -0.0066 - 0.279\log_{10}L_\infty + 0.6543\log_{10}K + 0.4634\log_{10}T \quad (1)$$

where L_∞ (in cm) and K are the von Bertalanffy growth parameters that define the shape of the growth curve and T is the mean annual sea temperature (in °C) (Pauly 1980).

$$M = 3Ke^{-Kt}/1 - e^{-Kt} \quad (2)$$

where t is age at sexual maturity (in years) (Roff 1984) and

$$M = 1.521/(t^{0.72} - 0.155) \quad (3)$$

from Rikhter and Efanov (1976). The von Bertalanffy growth parameters and age at sexual maturity were obtained from Milton et al. (1992a,b).

Results

Amblygaster sirm

The mortality rates of the largest species, *A. sirm*, were similar to *Herklotsichthys quadrimaculatus* at the same site (Tables 1 and 2), but were lower than the smallest species, *Spratelloides delicatulus*. In Tarawa and Abaiang, fish were fully selected by the bouke-ami nets at one year of age (sexual maturity) and the catch curve (Figure 1) indicates that total mortality of these larger fish is very high for a fish of this size (Table 1). Total mortality estimates ranged from 6.8/yr in Abemama to 14.5/yr in Abaiang, but these differences were not statistically significant (P>0.10). All estimates of natural mortality were below 3.0/yr which indicates that large *A. sirm* are heavily exploited at all sites sampled.

Table 1. Age and size at full selection by bouke-ami nets, total mortality (Z), natural mortality (M) and exploitation rate (E = F/Z where fishing mortality F = Z – M) of *A. sirm* from three sites in Kiribati. Natural mortality was estimated by three methods: P = Pauly's (1980) empirical formula; R = Roff's (1984) mechanistic formula and R-E = Rikhter and Efanov's (1976) formula.

Site	Year	Age at selection (months)	Size at selection (mm)	Total mortality Z/year	Natural Mortality M/year P	R	R-E	Exploitation rate (E = Z – M)
Abaiang	1990	10	166	14.2±2.4				
	all	10	164	14.5±2.3	2.8			0.81
Tarawa	1990	12	184	13.1±1.6				
	all	12	184	13.1±1.7	2.9			0.78
Abemama	1989	5	96	7.4±1.2				
	all	5	96	6.8±1.3	1.5			0.78
all	all	10	165	11.7±1.8	2.4	1.7	2.0	0.79–0.87

Table 2. Age and size at full selection by bouke-ami nets, total mortality (Z), natural mortality (M) and exploitation rate (E = F/Z where fishing mortality F = Z–M) of *Herklotsichthys quadrimaculatus* from four sites in Kiribati. Natural mortality was estimated by three methods: P = Pauly's (1980) empirical formula; R = Roff's (1984) mechanistic formula and R-E = Rikhter and Efanov's (1976) formula.

Site	Year	Age at selection (months)	Size at selection (mm)	Total mortality Z/year	Natural Mortality M/year			Exploitation rate (E = Z–M)
					P	R	R-E	
Butaritari	1989	5	68	10.3±0.9				
	1990	3	47	9.6±2.6				
	all	5	68	11.0±1.1	5.3	4.9	4.6	0.52–0.58
Abaiang	1989	5	68	11.6±1.3				
	1990	5	68	9.4±1.3				
	all	5	68	10.9±0.9	6.3	4.2	4.9	0.42–0.61
Tarawa	1977[1]	4	59	11.2±2.3				
	1983[2]	1	20	10.0±1.8				
	1984[2]	2	36	8.6±0.7				
	1989	3	50	8.5±0.8				
	1990	5	68	9.0±0.5				
	1991	5	69	8.6±3.5				
	all	5	68	10.4±0.8	5.4	4.1	4.1	0.48–0.61
Abemama	1989	5	69	4.0±0.8				
	1990	5	68	6.4±1.4				
	all	5	68	5.3±0.8	4.4	4.8	4.1	0.09–0.23
all	all	5	68	10.8±0.5	5.0	4.7	4.7	0.54–0.56

[1] Calculated from length-frequency data in Cross (1978);
[2] calculated from length-frequency data in McCarthy (1985).

Herklotsichthys quadrimaculatus

There was little variation in the mortality estimates of *Herklotsichthys quadrimaculatus* from Kiribati (Table 2). Fish became fully selected by bouke-ami nets at 5 months of age (see Figure 2) and 68 mm. This length corresponds with first sexual maturity. Mortality estimates were lower than those for *Amblygaster sirm* and ranged 8.5–11.6/yr at Butaritari, Abaiang and Tarawa. Total mortality of *H. quadrimaculatus* was lower at Abemama than other sites ($P<0.05$). There were no significant differences in mortality between years at any site. Natural mortality was higher than that of *A. sirm* (Table 2) and the exploitation rates were lower. The data suggest that *H. quadrimaculatus* is being optimally exploited (F = M), except at Abemama.

Spratelloides delicatulus

There were no differences in total mortality between sites for *Spratelloides delicatulus* (Table 3) and mortality did not differ between years in Tarawa. Bouke-ami nets retained fish over 2–3 months old (see Figure 3). Fish also became sexually mature at this size. Natural mortality estimates were higher than for other species (Table 3). Exploitation rates were similar at each site and indicate that *S. delicatulus* is probably being exploited at an optimal level (F = M).

Table 3. Age and size at full selection by bouki-ami nets, total mortality (Z), natural mortality (M) and exploitation rate (E = F/Z where fishing mortality F = Z−M) of *Spratelloides delicatulus* from three sites in Kiribati. Natural mortality was estimated by three methods: P = Pauly's (1980) empirical formula; R = Roff's (1984) mechanistic formula and R-E = Rikhter and Efanov's (1976) formula.

Site	Year	Age at selection (months)	Size at selection (mm)	Total mortality Z/year	Natural Mortality M/year P	R	R-E	Exploitation rate (E = Z−M)
Butaritari	1989	3	45	17.3±0.2				
	1990	2	32	21.8±5.2				
	1991	2	32	26.2±5.8				
	all	2	32	18.9±3.5	5.8	12.4	11.4	0.34–0.70
Abaiang	1989	2	–	–				
	1990	2	32	28.7±6.2				
	all	2	32	26.2±5.2	10.8	8.8	12.3	0.53–0.66
Tarawa	1977[1]	2	36	16.0±3.1				
	1983[2]	2	32	13.3±1.2				
	1984[2]	2	30	16.7±4.1				
	1989	3	44	13.4±3.0				
	1990	3	45	24.5±5.4				
	1991	2	33	19.5±6.6				
	all	3	44	15.9±0.3	7.5	8.3	8.9	0.44–0.53
all	all	2	32	15.7±0.7	7.3	10.3	10.6	0.54–0.56

[1] Calculated from length-frequency data in Cross (1978);
[2] calculated from length-frequency data in McCarthy (1985).

Discussion

There are several important points that emerge from this analysis of catch-at-age data. Firstly, the results show that the catch rates on large *Amblygaster sirm* are very high and often irregular (see Catch composition section) suggesting that this species is extremely vulnerable to this method of capture. The size at full selection corresponds with sexual maturity, and other data (Milton et al. 1992b) show that *A. sirm* spawn in these lagoons. This species also makes inshore-offshore movements in other parts of its range following spawning (Dayaratne and Gjosaeter 1986). These findings strongly suggest that *A. sirm* regularly move into Kiribati lagoons to spawn. They appear to be very photo-positive and are readily attracted to underwater lights. Thus the Kiribati baitfishery is probably exploiting spawning aggregations of *A. sirm* which is reflected in the high total mortality estimates at all sites. Except for Abemama, there were few *A. sirm* less than 160 mm in our samples. Milton et al. (1992a) found larval *A. sirm* in Abaiang on a few occasions but few fish between 50 and 150 mm (2–9 months of age; see Figure1). This supports the idea that most juvenile *A. sirm* move offshore, only returning to spawn, and that fish move into and out of the lagoons prior to and after spawning (Chacko 1946; Cross 1978).

The catch-at-age data for the other important baitfish species indicate that they are probably fully exploited in these lagoons. Again, the baitfishery catches mainly adult fish of both *Herklotsichthys quadrimaculatus* and *Spratelloides delicatulus*. *H. quadrimaculatus* is particularly vulnerable during the day because it aggregates in

All the baitfish catch-and-effort data were compiled and analysed using the DBASEIII+ database computer package. Where baitfishing data were missing, especially species composition data, extrapolations have been made from available data to give estimated total catches and catches by species. Due to the inaccuracy of some of the raw data results could be analysed only on a yearly basis.

For the major part of this analysis the unit of effort is recorded as the boat night. The number of hauls of the bouke-ami net was often not recorded. The unit of catch is the bucket (average weight approximately 2–2.5 kg of baitfish (Ianelli 1988)). From observations made during the sampling work undertaken this weight will vary depending on the species being loaded. When the large sardine *Amblygaster sirm* was the predominant species in the catch during our survey the weight of a bucket was usually greater than 3 kg.

Project observers on board Te Mautari Limited vessels noted a certain amount of under-reporting of baitfish catches. During periods when large catches were made, captains of vessels tended to estimate what they considered to be a maximum catch for the vessel, usually about 80 buckets. However, well over that amount was caught, with approximately 150 buckets of bait loaded into the vessel and the remainder being kept for food. It is therefore considered that reported catches may well be underestimates of the total catches. The restriction of recording those species considered useful only as baitfish would also underestimate the total catches.

Results and discussion

Total use of baitfish from 1977–1990

The total amount and source of baitfish each year from 1977 to 1990 reveal that the catches before 1980 were low (less than 10 000 buckets; see Figure 4). From 1982, with the initiation of Te Mautari Limited and commercial fishing operations, the catches rose to a high in 1984. The amount of baitfish utilised during 1984 was between 100 and 125 tonnes. Catches dropped from 1985 to 1987 to between 30 000 and 35 000 buckets, and then to about 25 000 buckets in 1988 and 1989. The 1990 catch was much lower (approximately 6000 buckets) due to the Te Mautari vessels spending a large part of the year fishing in Fiji and Solomon Islands waters, and also being laid up due to poor tuna catches during the normal fishing season in the Republic of Kiribati.

The total baitfish used can be divided by its source and means of capture. During the surveys the predominant baitfishing method was the beach-seine which targeted schools of herring, *H. quadrimaculatus*. The use of cultured bait started in 1980 when milkfish, *Chanos chanos*, became available from fish ponds set up on Tarawa. The use of the bouke-ami method (stick-held dip net with underwater lights) became more important with the start of commercial operations in 1982, though the beach-seine and cultured milkfish made up a significant part of the bait used. From 1983, the use of the beach-seine decreased mainly because of concerns voiced by outer island councils that the beach-seine operations were depleting local stocks of *H. quadrimaculatus* available to artisanal fishermen (Ianelli 1988). This eventually led to a total ban on the use of the beach-seine technique for the capture of baitfish. Milkfish was used in varying amounts between 1983 to 1988 though never more than 4000 buckets were used in any one year. Although the graph does not show it, some milkfish were used in 1989 but the amounts were extremely small. In 1990 the commercial fishing vessels were totally reliant on the bouke-ami technique for their baitfish, except for the SPC tuna tagging vessel which used milkfish on a couple of occasions (see section Improvements to Fishery). The 'Other' gear refers to the use of a lift-net over coral heads which was tested as a method of increasing baitfish catches (Gillett 1986).

Total baitfish catches made by bouke-ami gear

The bouke-ami technique has been the most important for the capture of baitfish for the commercial pole-and-line vessels in the Republic of Kiribati. The extent of the catches since 1977 and details of the proportion of the catches coming from the different baitgrounds (lagoons) in Kiribati are shown in Figure 5.

During the early survey years catches using bouke-ami were small with effort being divided between Tarawa, Butaritari and Abemama. The onset of commercial operations in 1982 saw a dramatic rise in catches to a high in 1983 and 1984 with the majority of the bait coming from Tarawa Lagoon. From 1985 to 1987, catches dropped and the amount of bait coming from Tarawa was approximately equal to the combined totals from Abaiang, Abemama and Butaritari. During 1988 and 1989, more fishing effort was expended in Abaiang, with this baitground accounting for the highest proportion of the total catch. In 1990 the catches were below the levels of 1982 with most of the catch once again being taken from Tarawa (Fig. 5).

Catches rose very quickly from 1982 to the high of 1984 and have dropped since, apart from a slight rise in the 1987 catch over the 1986 figure (Fig. 6). The relationship between catch and effort is linear and a similar relationship has been observed in other baitfisheries in the Pacific — Papua New Guinea (Dalzell and Wankowski 1980), Fiji (Sharma and Adams 1990) and Solomon Islands (Rawlinson and Nichols 1990). Dalzell and Lewis (1988) state that the lack of pronounced curvature in the catch-per-unit-effort (CPUE) relationship may be due to the dynamics of the pole-and-line fishery, as baitfish are essential to the capture of tuna and fishermen will quickly leave a baitground when catches decline and try other locations for bait supply.

A line of best fit has been plotted through the points for the years from 1985 to 1990 inclusive (Fig. 6). The strongly linear relationship gives the average catch of baitfish in the Republic of Kiribati over this period as 38.8 buckets per night. A plot of the average CPUE by year, measured as the number of buckets per boat night, against the total fishing effort in boat nights for the corresponding year, is shown in Figure 7. Highest catch rates can be seen in the early years of the fishery from 1982 to 1984, with an overall trend of higher catch rates in years of higher effort.

The plots of catch against effort and CPUE for the individual bait sites of Butaritari, Abaiang, Tarawa and Abemama are shown in Figures 8 to 11 respectively.

In all cases there is a strong linear relationship between catch and effort. For Butaritari the average catch rate of 49.9 buckets per night varied little between years. Abaiang had an average catch rate of 40.5 buckets of bait per night with little variation between years. The average catch rate in Tarawa was 30.9 buckets per night (the regression was for the years from 1985 to 1990), with more variation between years than at Abaiang and Butaritari. Abemama had an average catch rate of 54.9 buckets per night with more annual variation than other sites (Fig. 11).

The average catch rates of Abemama and Butaritari are above the overall average catch rate of 39 buckets per night, with Abaiang's average being slightly above and Tarawa's below. Tarawa's catch rate has shown a distinct drop since the years of 1982, 1983 and 1984 (the early years of commercial fishing) when the buckets per night totals were 40.1, 54.1 and 45.5 respectively. Since then the catch rate has varied between a high of 36.6 buckets per night in 1990 and a low of 27.2 in 1987. Due to the importance of Tarawa as a baitfishing ground this decline is reflected in the overall catch rates for the Kiribati baitfishery (Figs 6 and 7).

During August and September 1991, the South Pacific Commission undertook tuna tagging work in the Republic of Kiribati using their vessel *Te Tautai* and one of the Te Mautari vessels, *Nei Kaneati*. Apart from one night's fishing in Tarawa that produced a negligible catch, *Te Tautai* caught 1671 buckets of bait from Abemama for 7 fishing nights (15 hauls of net), an average of 238 buckets per night and 111 buckets per haul. *Nei Kaneati* over the same period caught 1490 buckets in 12 nights from Abemama (average of 124 buckets per night), 340 buckets in 4 nights from Abaiang (average of 85 buckets per night) and 625 buckets in 9 nights from Butaritari (average of 69 buckets per night). At all sites the species was predominantly the sardine, *A. sirm*. These catch rates are higher than normally reported from these lagoons. This was either because the catches were being recorded by independent observers (normal records of Te Mautari activities are generally under-reported), or the size of the net of the *Te Tautai* being larger than those of Te Mautari vessels, or due to the low fishing effort of 1990 which allowed an increase in abundance of baitfish in these lagoons. Rawlinson and Nichols (1990) reported similar increased baitfish catch rates after a year of reduced fishing effort in Solomon Islands.

The importance of Tarawa as a baitfishing ground

Distribution of baitfishing effort is related to the proximity of productive fishing grounds, proximity of unloading points, weather conditions relative to baiting ground aspect and, more recently, the location of deployed fish aggregation devices (Lewis 1990).

As Betio on Tarawa atoll is the only base where the pole-and-line vessels unload their tuna catch and take on provisions, this lagoon has had a disproportionately high amount of baitfishing effort. Boats unload their catch and invariably remain at Tarawa for baitfishing. This situation changed during 1988 and 1989 when the majority of the fishing effort took place at Abaiang, the next closest baitfishing site to Tarawa.

No details are available of where the tuna fishing effort took place so it is not possible to assess whether the shift in the distribution of baitfishing effort was due to a direct shift in the distribution of the tuna schools. The fishing grounds known as the Maiana Banks to the south of Tarawa are an area where tuna are found at most times of the year and are an extremely important fishing ground to the subsistence fishermen of Tarawa. The regular occurrence of schools in this area also means that the pole-and-line vessels concentrate their effort in this area when schools cannot be found elsewhere. The closest baitfishing area to the Maiana Banks is Tarawa but boats will go to Abaiang to catch bait and steam back to the fishing grounds the next day if poor bait catches are expected from Tarawa.

Fish aggregating devices (FADs) have been deployed in the Republic of Kiribati, and at the end of May 1990 eight such devices existed in the waters of the Gilbert Group (Kiribati Fisheries Division 1989). However, data are not available to indicate whether their deployment since 1987 has had a significant effect on the distribution of fishing effort by the pole-and-line vessels. As most of the FADs have been deployed in positions close to the islands, in relatively shallow locations, for the benefit of the subsistence and artisanal fishermen (Kiribati Fisheries Division 1989), it is unlikely that they are in the best position for the pole-and-line vessels.

Declines in annual catch rates

Due to the importance of Tarawa for baitfishing, the overall decline in average catch rates for the whole baitfishery can be directly related to the decrease in catch rates from that lagoon. The reported decline in catch rates from Tarawa lagoon since the early years of the industry may be for two reasons.

1. Since the early years there may have been a depletion in the abundance of baitfish resulting in declines in catch rate.

Assuming that the fishing effort measures are valid and catch rates are unbiased, when fishing intensity is high enough for a decrease in catch rates to appear, management of fishing effort may be necessary and provisions for reducing effort would need to be formulated (Ianelli 1988).

Figure 10b shows the plot of CPUE against effort for Tarawa, and if the early years of 1982, 1983 and 1984 are excluded then a decrease in catch rates with increased fishing effort can be seen. Even though Ianelli (1988) considered that management of fishing effort in such a situation may be necessary, the effort by the fishing fleet has decreased of its own accord as vessels have moved to new baitfishing sites to improve their catch.

Figures 8, 9 and 11b show the plots for CPUE against effort for Butaritari, Abaiang and Abemama respectively. A decrease in CPUE with increased fishing effort is not apparent. Therefore any fluctuations of catch during the year at these sites is likely to be due to variables other than fishing effort.

2. The overall baitfishing operations of the commercial vessels may have become less efficient. This could be due to a number of factors.

(a) A decrease in the nightly baitfishing effort (the most accurate measure of bouke-ami fishing effort is the number of hauls of the net made each night) — no information is available on the number of hauls made from 1982 to 1986, but from 1988 to 1990 this information was recorded. The average number of hauls per night has been 1.72, 1.48 and 1.49 for the years of 1988, 1989 and 1990 respectively (Table 4).

Table 4. Commercial catch-and-effort data for four sites in Kiribati from 1988 to 1990 (bu = buckets, ha = hauls, nt = nights).

Site	Year	Catch (bu)	Effort (ha)	Effort (boat-nt)	CPUE (bu/ha)	CPUE (bu/nt)	Hauls/nt
Butaritari	1988	3 935	161	90	24.44	43.72	1.79
Abaiang		10 254	462	265	22.19	38.69	1.74
Tarawa		5 125	253	154	20.26	33.28	1.64
Abemama		4 600	187	109	24.60	42.20	1.72
Total		23 914	1 063	618	22.50	38.70	1.72
Butaritari	1989	3 184	94	76	33.8	41.89	1.24
Abaiang		13 857	488	330	28.40	41.99	1.48
Tarawa		4 610	246	149	18.74	30.94	1.65
Abemama		1 642	81	59	20.27	27.83	1.37
Total		23 293	909	614	25.62	37.94	1.48
Butaritari	1990	589	14	9	42.07	65.44	1.56
Abaiang		888	53	35	16.75	25.37	1.51
Tarawa		4 349	176	119	24.71	36.55	1.48
Total		6 000	251	168	23.90	35.71	1.49

If the average number of hauls being made on a nightly basis was greater (i.e. greater effort) than this during the early years then this would account for the higher average catches per night.

(b) A change in the size of vessels over the years. Larger vessels generally make higher bait catches because they use larger nets. In Kiribati smaller-sized vessels have been used recently as the larger vessels in the fleet have undertaken their operations in either Fiji or Solomon Islands for part of the year. This has often left the vessel *Te Tiaroa* to operate in Kiribati waters on its own. This vessel is the smallest in the fleet and has a bait-well capacity of only 9.09 m^3 compared with capacities of about 24 m^3 on larger vessels. With less bait requirements, less catching power and limited operational range (which generally means a lot of its fishing effort is concentrated around Tarawa), and most time spent fishing in Kiribati, compared to the larger vessels, lower average catch rates may have resulted.

(c) The fishing method has been changed in some way. The physical use of the net is not known to have changed so the only way the fishing method can be varied is by altering the power of the underwater lights. However, it is not known if such changes were made and, if they were, they would have been made only in an attempt to increase catches, not decrease them.

(d) The ability of the fishing masters is less than in the earlier years. As very little is known of the respective capabilities of the fishing masters on the vessels operating in Kiribati it is difficult to judge whether this could be a contributing factor to the declining catches. However, it should be noted that the success of pole-and-line vessel operations, both for the capture of baitfish and tuna, is extremely dependent on the abilities of the fishing master.

(e) The catchability of the baitfish has changed over the years. Bait catchability itself is influenced by a variety of factors including the lunar cycle (Kearney 1977), weather conditions (wind, current, turbidity), power of the light sources (and possibly its spectral composition) and other more subtle species-specific environmental factors (Lewis 1990).

During the CSIRO–ACIAR baitfish project, observations were made of commercial baitfishing operations in Tarawa lagoon. The water in the lagoon, throughout this period, was generally very turbid. In such a situation the effectiveness of the underwater lights for attracting baitfish is greatly reduced. Although no physical measurements of the water turbidity were taken during the survey, it is considered that this factor contributed strongly to the poor baitfish catches. The most recent record of this situation in Tarawa comes from the activities of the South Pacific Commission's tuna tagging vessel *Te Tautai*. The vessel undertook baitfishing operations in Tarawa lagoon during one night in August 1990. On that occasion the capture of baitfish was not possible and it was noted that constantly cloudy water must make the lagoon unproductive for baitfish (SPC, pers. comm.).

Increased turbidity in the lagoons affecting baitfish catches was first noted during an early survey by JICA (1978). It was stated that those lagoons open to the sea at their western edge would be affected during periods of westerly winds, as the large swells stir up the sand and mud in the lagoon, which leads to a lower frequency of occurrence of the baitfish schools.

Johannes et al. (1979) noted a large percentage of dead coral colonies along the western margin of the lagoon. One reason given for these mortalities was that a period of stormy weather, particularly from the west side of the lagoon, may have caused large-scale and long-term resuspension of abundant lagoon floor sediments, the scouring and smothering action of which can cause significant coral mortality. It was also noted that an unusually prolonged period of westerly storms created very choppy conditions in the lagoon in 1977, prior to the observations of the dead corals. MacInnes (1990) states that there was considerable change in the weather pattern during 1986–87 with the wind coming from the west for approximately 47% of the year. This dramatically affected the bouke-ami operations in respect of surface disturbance, turbid water, and disruption of bait schools. He states that the catcher boats were reduced to taking approximately 30–40 buckets from the bouke-ami instead of the expected 80–100 buckets and, to capture the bait, vessels had to move close inshore. Weather conditions around Tarawa during 1990 were fairly rough for much of the year. Heavy rainfall and strong, variable winds were typical and this may have accounted for the high levels of turbidity in the lagoon, which in turn led to low baitfish catches.

Consideration should also be taken of the construction activities on Tarawa during recent years. A causeway between Betio and Bairiki, the two western-most islets of Tarawa, was completed in 1987 by the Japanese International Co-operation Agency (Gilmour and Coleman 1990). Construction work of such a large project would have stirred up the reef flats and increased turbidity in an important area for baitfishing activities. Construction took place in 1986 during the time that catch rates of baitfish decreased.

During the CSIRO–ACIAR baitfish project in 1990 a bridge was built across the Tanaea passage at the eastern end of the island, close to the Fisheries Division headquarters. While construction was taking place the water in the passage and surrounding area was extremely turbid. A lot of sediment material was redistributed onto to nearby reef flats and was resuspended during periods of rough weather.

The high turbidity of the lagoonal water in Tarawa lagoon is certainly a major reason for the poor catches of baitfish during 1990 (see Fig. 10). Whether the cause for this high turbidity is due to the prevailing winds, general construction work or increased population pressure and its associated problems, or a combination of all of them, is not known, but while such conditions persist the capture of baitfish using underwater lights will be difficult.

Overall, it is likely that the high catches of 1983 and 1984, plus the changing physical conditions within the lagoon, are the major factors contributing to the decline in catch rates at Tarawa lagoon. This in turn has led to poorer overall catch rates for the whole of the fishery because of the importance Tarawa holds as a baitfishing site.

Higher catch rates with increased fishing effort

The trend of higher catch rates at higher levels of fishing effort can be attributed to the nature of baitfishing operations. While baitfish are plentiful and catch rates are good there is an extra incentive for the vessel's crew to keep baitfishing as they can expect a good catch of tuna the next day if they have plentiful supplies of bait. At the other extreme, if catch rates are very poor then vessels may not attempt to catch bait at all, as was the situation in 1990 when the whole fleet was laid off. Ianelli (1988) noted the same trend and discussed the problems of using baitfish CPUE data as an accurate index of abundance. Wetherall (1977) also outlined the problems of using this type of data from the Hawaiian baitfishery.

Variable catch rates

Catch rates were investigated on a monthly basis by Ianelli (1988). The rates over time were highly variable and plots of catch-per-unit-effort against time from 1982 to 1986 in Tarawa showed marked variation from month to month. The monthly data have not been looked at in this analysis since the data were not accurate enough to be representative. However, the coverage of catch statistics during 1988 was complete and the trends can be seen from looking at data from that year (Table 5).

Table 5. Monthly commercial baitfishing catch-per-unit-effort (CPUE) at four sites in Kiribati during 1988 ($CPUE^1$ = buckets/haul; $CPUE^2$ = buckets/night).

Month	Butaritari		Abaiang		Tarawa		Abemama	
	$CPUE^1$	$CPUE^2$	$CPUE^1$	$CPUE^2$	$CPUE^1$	$CPUE^2$	$CPUE^1$	$CPUE^2$
January					22.4	37.1	20.7	37.2
February	31.2	41.7	16.9	28.7	26.4	33.1	55.6	62.5
March					24.1	36.1	33.3	49.1
April			33.0	66.0	22.3	32.6	15.3	30.6
May	45.0	45.0	24.1	41.0	15.3	25.5	5.6	12.9
June	9.5	27.1	22.1	41.6	19.0	37.9	20.6	41.1
July	23.9	46.3	29.0	56.1	16.2	28.4	5.6	13.0
August	32.0	46.9	30.6	49.6	26.0	39.0	55.0	66.0
September	34.2	57.0	25.0	41.7	33.0	55.0	78.8	78.8
October	27.2	36.3	25.4	43.3	14.4	22.7	35.9	45.7
November	10.8	21.7	17.0	29.8	14.6	25.9	19.0	38.1
December	16.3	32.5	13.0	24.3	14.2	26.3	12.0	12.0
Total catch	3 935		10 254		5 125		4 600	
Total effort (hauls)	161		462		253		187	
Total effort (nights)	90		265		154		109	

Monthly catch rates during 1988 varied from 13.0 to 33.0, 5.6 to 78.8, 9.5 to 45.0 and 14.2 to 33.0 buckets per haul at Abaiang, Abemama, Butaritari and Tarawa respectively. Some months may represent only limited fishing effort and the catch rates recorded may not be representative of the overall situation. The range between upper and lower limits of these catch rates are least at the two most heavily fished sites of Abaiang and Tarawa. Lowest catch rates at all sites were generally at the end of the year and during the middle of the year, June and July. Highest catch rates were noted in August and September. Catch rates at the beginning of the years are difficult to interpret because limited fishing took place at Abaiang and Butaritari over these months. However, catches at Abemama and Tarawa were greater during February and March than during the middle of the year.

Baitfish production is seasonal in Papua New Guinea (Dalzell 1990) and Solomon Islands (Rawlinson and Nichols 1990) where highest CPUE figures were recorded during the months of peak reproductive activity. (Note: both these fisheries comprise predominantly *Stolephorus* anchovies.) Little is known of the spawning activities of baitfish in Kiribati, but McCarthy (1985) found no evidence of annual periodicity in sexual maturity in Tarawa lagoon for *S. delicatulus*. Whether the higher levels in CPUE during the 1988 season can be attributed to periods of increased spawning activity or recruitment is not known. It is worth noting that during the survey period in January 1991, a month not generally productive for baitfish, catches of *S. delicatulus* using experimental gear were extremely high and enormous amounts of baitfish were available. A commercial vessel operating during this period would have had little difficulty in catching enough to fill its bait wells in one night.

Species composition of bait from catch-and-effort data

From the data compiled from the pole-and-line vessels, it has been possible to estimate the species composition of the bouke-ami bait catches on a yearly basis. Figures 12 to 16 show the yearly bait catch species composition for Kiribati as a whole, Butaritari, Abaiang, Tarawa and Abemama.

The Kiribati baitfishery bouke-ami catches have comprised primarily three species: the blue sprat, *S. delicatulus*, the spotted sardine, *Amblygaster sirm*, and the gold-spot herring, *Herklotsichthys quadrimaculatus*. These three species made up at least 75% of the total catch each year from 1982 to 1990. However, the proportion of each species group in the catches has varied greatly from year to year. The species composition of Abaiang and Abemama between years is remarkably similiar, but Tarawa and Butaritari show differences from the other sites. Tarawa had a predominance of *S. delicatulus* followed by *H. quadrimaculatus*. However, during 1982 and 1990 *A. sirm* was the most abundant species. Butaritari also showed a predominance of *S. delicatulus* whereas Abemama and Abaiang show a much greater proportion of *A. sirm*. Generally, *H. quadrimaculatus* was the least important of the three species in Abaiang, Abemama and Butaritari.

McCarthy (1985) suggested that, based on catch return information from the Te Mautari fleet, Tarawa lagoon is predominantly a two-species baitfishery, comprising *S. delicatulus* and *A. sirm*. However, his analysis of baitfish samples and conversion of the number of each species to their volumetric equivalent suggested that during 1983 and 1984 *Dussumieria* sp. B was also important. He concluded that the data recorded on the pole-and-line vessels were only of species that were important baitfish (*Dussumieria* sp. B or the weak-herring dies quickly after capture and does not make an effective baitfish species). McCarthy (1985) also concluded that the species composition of the baitcatch may be unstable.

Ianelli (1988) stated that bouke-ami catches showed a definite species succession pattern for each area and that the change in species composition occurred over a wide geographic range indicating that recruitment may be independent of local lagoon-specific stock sizes. He also found that the greatest change in relative abundance was between *H. quadrimaculatus* and *A. sirm* for which he suggested several explanations. He concluded that the change in catch rates reflected a change in their abundance and explained the decline in the abundance of the sardine, *A. sirm*. He concluded that recruitment rates are variable and that harvest rates were not the major cause of the shifts in species composition. This change in species composition between *A. sirm* and *H. quadrimaculatus* has not been observed since in Tarawa (Fig. 19).

The level of the sardine catch in Tarawa since 1986 has remained low and the herring catch decreased until 1988 and 1989, when both species made up nearly equal proportions of the catch (Fig. 19). In 1990 herring catches continued to decline and sardine catches increased slightly. For the baitgrounds of Abaiang and Butaritari increased catches of sardine have occurred in the same years as increased catches of the herring. The peaks in catches of sardine were always greater than the peaks in herring catches. For Abemama the pattern is less clear as catches of herring are generally very low (Fig. 20). For the three sites of Abaiang, Abemama and Butaritari, annual catches of the herring by bouke-ami gear has never exceeded 2000 buckets (approximately 5 t) (Figs 17, 18, 20).

Herring are also captured by artisanal and subsistence fishermen using cast nets. As *H. quadrimaculatus* often forms tight schools in very shallow water they are easy target for local fishermen. This species is a favoured food fish as well as a good hook bait for the line fishing techniques utilised by these fishermen. Gibson (1977) reported weekly catches of 5415 lbs (approximately 2.5 t) of *H. quadrimaculatus* made by cast nets from Tarawa lagoon. From this weekly figure he obtained annual catch rates of 128 t, a figure greater than the annual total bait catch of the pole-and-line fleet. Gibson probably assumed that the herring occurs throughout the year and catch rates can be maintained every week, but this is not the case. However, estimates of 2.5 t in one week indicate the magnitude of the herring catches possible by cast nets when the fish are available.

As there are few details of exact amounts of herring taken in the artisanal and subsistence fishery the total amount of this species being extracted from the lagoons is unknown. *Herklotsichthys quadrimaculatus* are not attracted to underwater lights to the same degree as *S. delicatulus* and *A. sirm*. Hence it is difficult to judge shifts in the relative abundance of the sardine and the herring in the lagoons. In June 1990 large amounts of herring were available at the main fish market on Tarawa but at the same time the sardine was the main baitfish in the commercial bait catches from Tarawa lagoon, and the herring was absent.

When large schools of sardine aggregate around the underwater lights they are extremely active, swimming rapidly in and out of the illuminated area. Generally, if the school was large enough, this erratic movement seemed to scare other fish away from the light. Subsequently when the bait net is hauled the catch is predominantly sardines. Fishing masters therefore record the species composition of the catch as 100% sardine (Table 6).

Table 6. Total occurrence of species in nightly baitfish catches in 1988.

Details	Sardine	Sprat	Herring
Number of nights in catch	380	214	128
Number of nights recorded as 100% of catch	285	62	9
Percentage of nights recorded as 100% of catch against nights in catch	75.0	29.0	6.6
Average catch rate per night when recorded as 100% of catch (buckets per night)	44.4	37.4	25.9

From Table 6, 75% of the nights that the sardine occurred in the catch it was recorded as making up the total catch as opposed to 29% for sprat and 6.6% for herring. All the individual species have been recorded together. Regardless of whether it is inaccuracy in recording or because the aggregation of schools of sardine decreases the catchability of the other species, the use of the catch-and-effort data is unlikely to give an accurate measure of the abundance of the different species in the lagoons at any one time.

The herring is the only major baitfish species that is caught in large quantities by the subsistence and artisanal sectors. However, during the course of the CSIRO–ACIAR baitfish project local fishermen in Butaritari were observed also catching the sprat, *S. delicatulus*, with a hand-held dip net constructed of a wooden frame and mosquito netting. The fisherman wades into the lagoon at a depth up to about his waist. He positions himself near schools of sprats which can be seen being chased by predators. The net is immersed and the sprats are guided into it by the fisherman using his foot, as they swim past. The sprats are at their most vulnerable when escaping from a predator and will swim straight into the net if it is in their path. Catches of the sprat in one session were reported to be as much as one 25-kg rice bag full. However, this type of fishing is not commonplace and the quantities of *S. delicatulus* taken are assumed to be minimal in comparison to those taken by the pole-and-line fleet.

Influence of rainfall

Ianelli (1988) found that catch rates for sprats and sardines positively correlated with rainfall whereas those of herring were negatively correlated. The average annual rainfall pattern over Western Kiribati (taken from Burgess 1987) shows that Butaritari receives a much higher average rainfall (>3000 mm per year) than Abaiang, Abemama and Tarawa (between 1500 and 2000 mm per year) (Fig. 21). These three islands also show more variation in annual rainfall than Butaritari (Table 7).

The higher rainfall at Butaritari may explain the predominance of the sprat, *S. delicatulus*, in the catches. Years of the highest rainfall (1987 and 1990) for Butaritari also show a very high proportion of sprats in the species composition (>95%) (Fig. 13). The years when sprats predominate in the catch also are those with the highest catch rates (Fig. 8b).

Table 7. Details of the annual rainfall (mm) at each of the baitfishing sites since the importance of baitfishing has increased (supplied by the Meteorological Division, Kiribati; md = missing data).

Year	Abaiang	Abemama	Butaritari	Tarawa
1980	3 322	1 991	3 872	2 806
1981	md	1 492	2 950	2 145
1982	2 205	md	2 716	2 617
1983	1 563	md	2 661	1 898
1984	850	md	2 371	999
1985	md	md	1 970	744
1986	1 843	md	3 287	2 323
1987	3 535	md	4 657	3 843
1988	md	md	312	1 389
1989	md	430	2 206	920
1990	md	2 428	4 846	3 578

Conclusions

Variations in catches of baitfish are the result of complex interactions between previous fishing effort, prevailing weather and physical conditions within the lagoon and recruitment periods of the baitfish. The availability of the sardine *A. sirm* increases the catches by the pole-and-line boats and is the most important baitfish species for the pole-and-line vessels. It is also reported as the most desirable species by the fishing masters in Kiribati. Tarawa lagoon, which has been important for baitfishing operations because of the proximity of unloading facilities, has shown signs of overfishing. Decreased catch rates in Tarawa have necessitated utilising other sources of bait. Catches at the other sites of Abaiang, Abemama and Butaritari have not decreased since the start of commercial baitfishing.

One of the main difficulties for the pole-and-line industry in Kiribati is always going to be the unpredictable nature of baitfish catch rates. Reduction in fishing effort for a period of a year may result in higher catch rates, and limiting fishing effort at individual lagoons may help. The use of cultivated baitfish may be essential to maintain a viable tuna fishery.

Catch Composition

During the CSIRO–ACIAR baitfish research project in Kiribati (1989–91), it was hoped that samples could be collected monthly from the catches of the commercial pole-and-line vessels. However, there were many periods when no vessels fished in Kiribati waters. In 1990, many of the vessels moved to Fijian or Solomon Islands waters. For a period in mid-1990, the vessels returned to Kiribati waters but, because of very poor catches, they were tied up and did not fish. At the beginning of 1991 all tuna fishing operations in Kiribati ceased and the fishing company temporarily closed down.

Methods

Sampling

Baitfish samples were collected from the pole-and-line vessels by a research officer of the project who remained on the vessel for the duration of one fishing trip. In general at least two baitfishing grounds were fished during any one trip. However, during the periods when no commercial activities took place other methods were used to collect samples. Cast nets, small-meshed gill nets, beach-seine and small-scale bouke-ami type (see section Improvements to Fishery, Alternative Fishing Methods) gear were all utilised.

This section deals only with those samples taken from the catches of commercial vessels and those made with the small-scale bouke-ami technique. This method utilised the small-meshed bait netting (4-mm-square mesh) used by the commercial vessels and was undertaken at night with the use of artificial lights to attract the baitfish. The commercial bouke-ami fishing method undertaken in Kiribati is described by McCarthy (1984).

A fine-meshed hand-held scoop net was used to take a sample of the baitfish caught by these methods. This was not possible if the catches were either small and all the bait was required for the vessel's fishing operations, or non-existent. Samples of fish were preserved in either 10% formaldehyde or ethanol. Fish in these samples were sorted in the laboratory, identified to species level where possible, and measured (FL in mm). Individual weights of some specimens were taken using an electronic balance.

Results and discussion

Species composition

The species taken at the various sites are detailed in Table 8. A total of 26 374 fish were processed from 61 different sampling occasions. Over 120 taxa from more than 38 families were recorded from the four baitfishing (sampling) sites of Abemama, Abaiang, Butaritari and Tarawa.

Lewis et al. (1983) documented two species of herring, *Herklotsichthys quadrimaculatus* and *Herklotsichthys* sp., occurring in baitfish catches in the South Pacific Commission region. The former has two gold spots posterior to the operculum and the latter only one gold spot. Whitehead (1985), however, does not distinguish the fish with one gold spot as a separate species. Lewis (1990) identified *Herklotsichthys* containing clearly separate morphs which are likely to prove with

Table 8. Baitfish species composition (%) of samples collected in Butaritari between September 1989 and February 1991 (Sprat = *Spratelloides delicatulus*; Herring = *Herklotsichthys quadrimaculatus*; Sardine = *Amblygaster sirm*; Hardy 1 = *Hypoatherina ovalaua*; Hardy 2 = *Atherinomorus lacunosus*; Bait = other baitfish species; Non-bait = by-catch species).

Date	Time	Sprat	Herring	Sardine	Hardy 1	Hardy 2	Bait	Non-bait	Total
19 09 89	21.30	67.8	18.4	–	10.8	3.0	–	–	332
20 09 89	22.10	55.8	40.1	–	4.2	–	–	–	312
27 10 89	02.00	89.8	5.5	–	–	–	4.7	0.1	1 025
13 05 90	21.15	89.3	0.3	–	9.2	–	1.0	0.2	1 147
20 07 90	01.30	97.9	–	–	1.7	0.2	0.1	0.1	1 704
21 07 90	00.30	98.0	0.3	–	1.5	0.1	0.1	–	1 362
23 08 90	00.20	99.3	–	–	0.5	0.2	–	–	1 070
24 08 90	02.00	97.9	–	–	2.1	–	–	–	3 158
28 08 90	04.30	99.2	–	–	0.6	0.2	–	–	1 087
05 11 90	19.30	100.0	–	–	–	–	–	–	200
06 11 90	20.30	96.4	–	–	1.2	0.9	–	1.5	742
07 12 90	23.15	78.9	15.3	–	3.1	–	0.4	2.3	261
08 12 90	02.00	97.4	0.7	–	1.4	–	0.1	0.4	1 404
08 12 90	05.15	99.2	0.2	–	0.4	–	–	0.2	503
16 01 91	04.00	100.0	–	–	–	–	–	–	962
14 02 91	20.30	79.1	18.7	–	–	1.4	–	0.7	139
Sample size		14 639	326	–	321	28	65	29	15 408

further study to be sibling species, and their existence is suggestive of fine-scale habitat-partitioning. Herring of both types were identified in the baitfish catches in Kiribati but they have all been grouped as *Herklotsichthys quadrimaculatus* in this report.

Another point to note is that the silver sprat, *Spratelloides gracilis*, was collected from Butaritari on one sampling occasion. This particular species makes up an important component of the baitfish catches in Papua New Guinea (Dalzell and Wankowski 1980), Solomon Islands (Rawlinson 1990) and Fiji (Sharma and Adams 1990), and is considered an excellent bait, but needs careful handling (Lewis et al. 1983). This species has not previously been reported in baitfish catches from Kiribati and its geographical distribution (Whitehead 1985) has not included Kiribati.

The diverse species composition in night-time dip-net catches has been well documented from other Pacific Island countries; Papua New Guinea (Kearney et al. 1972; Lewis 1977), New Caledonia (Conand 1988), and Solomon Islands (Rawlinson 1990). There is a steady decline in species diversity eastward across the Pacific from Papua New Guinea (Dalzell and Lewis 1988), and the numbers of taxa found in Kiribati catches were less than in the above-mentioned more westerly countries.

Although a large number of taxa were taken during the sampling in Kiribati, only a few made a significant contribution to the catches and can be considered to be important as baitfish. These species will be dealt with separately and referred to as baitfish, as opposed to those which make up a much smaller proportion of the catch and will be considered as by-catch.

Table 9. Baitfish species composition (%) of samples collected in Abaiang between September 1989 and September 1990 (Sprat = *Spratelloides delicatulus*; Herring = *Herklotsichthys quadrimaculatus*; Sardine = *Amblygaster sirm*; Hardy 1 = *Hypoatherina ovalaua*; Hardy 2 = *Atherinomorus lacunosus*; Bait = other baitfish species; Non-bait = by-catch species).

Date	Time	Sprat	Herring	Sardine	Hardy 1	Hardy 2	Bait	Non-bait	Total
08 09 89	02.00	–	17.1	–	82.5	–	–	0.4	228
08 09 89	02.15	–	3.0	–	96.4	–	–	0.6	166
16 05 90	21.30	–	68.6	–	–	–	12.8	18.6	86
30 06 90	02.30	–	8.4	–	–	–	13.1	78.5	107
30 06 90	05.30	87.1	5.0	–	5.2	0.4	0.7	1.5	459
01 07 90	05.00	4.6	–	–	21.2	–	–	4.2	283
22 07 90	04.30	–	–	88.5	–	–	–	11.5	26
16 08 90	01.15	9.5	–	90.5	–	–	–	–	21
25 08 90	05.15	91.8	0.3	0.3	0.7	5.1	1.1	0.8	742
16 09 90	05.10	15.0	–	25.0	15.0	–	2.5	42.5	40
25 09 90	04.15	69.0	2.4	–	9.5	–	14.3	4.8	42
26 09 90	02.30	66.7	3.5	–	24.1	3.0	0.2	2.3	821
26 09 90	04.15	69.4	0.3	–	5.2	0.6	22.5	2.1	1 086
26 09 90	05.15	70.7	–	–	25.2	2.8	–	1.4	290
27 09 90	04.30	71.9	0.7	–	5.2	0.3	21.3	0.8	757
Sample size		3 380	175	54	813	81	450	201	5 154

Baitfish

Lists of the species composition of the baitfish samples from Abemama, Abaiang, Butaritari and Tarawa are shown in Tables 8 to 11 respectively. The percentage of the total number of fish identified in each group is detailed along with the total sample sizes. The column headings refer to the main baitfish species taken: Sprat (*Spratelloides delicatulus*), Herring (*Herklotsichthys quadrimaculatus*), Sardine (*Amblygaster sirm*), Hardy 1, the hardyhead (*Hypoatherina ovalaua*), Hardy 2, another species of hardyhead (*Atherinomorus lacunosus*). 'Bait' refers to other species which are considered useful baitfish species but only make occasional appearances in the catches, such as *Selar crumenopthalmus*, *Rhabdamia cypselurus* and other species from the families Apogonidae and Caesionidae. 'Non-bait' refers to those species which cannot be considered as useful baitfish, e.g. *Dussumieria* species which die quickly after being caught, and others which are too large in size, e.g. *Sphyraena* and *Caranx* species.

Due to the differences in sample sizes caused by the differences in size between species it has been necessary to calculate an index of relative abundance between the different species groups. The index is the sum of the percentage occurrence of each species in all the samples at one site divided by the total number of samples taken at that site. This gives a better representation of the relative occurrence of each species during the sampling period. These indices of relative abundance for each species from each site are given in Table 12.

Table 10. Baitfish species composition (%) of samples collected in Tarawa between August 1989 and February 1991 (Sprat = *Spratelloides delicatulus*; Herring = *Herklotsichthys quadrimaculatus*; Sardine = *Amblygaster sirm*; Hardy 1 = *Hypoatherina ovalaua*; Hardy 2 = *Atherinomorus lacunosus*; Bait = other baitfish species; Non-bait = by-catch species).

Date	Time	Sprat	Herring	Sardine	Hardy 1	Hardy 2	Bait	Non-bait	Total
23 08 89	23.15	7.1	69.0	–	10.7	1.2	8.3	3.6	84
01 09 89	04.15	58.0	11.4	–	–	–	2.3	28.4	88
01 09 89	05.30	86.9	11.1	–	1.3	0.7	–	–	306
29 09 89	05.45	83.3	–	–	4.9	2.4	9.4	–	371
22 10 89	02.30	–	5.8	–	61.2	30.6	1.7	0.8	121
23 10 89	02.30	1.3	31.3	–	42.5	23.8	–	1.3	80
07 03 90	03.35	57.5	4.9	0.4	7.1	19.0	1.3	9.7	226
07 03 90	05.40	17.1	29.3	9.8	4.9	26.8	–	12.2	41
26 03 90	23.50	4.9	8.1	–	65.9	16.3	0.8	4.1	123
27 03 90	03.25	17.5	17.5	–	38.6	12.3	–	14.0	57
05 04 90	05.30	2.7	6.8	–	58.1	29.7	–	2.7	74
04 05 90	04.45	2.4	17.9	–	34.9	44.8	–	–	212
04 05 90	05.30	1.7	4.3	–	59.8	34.2	–	–	117
13 06 90	06.00	–	–	100	–	–	–	–	46
28 06 90	02.30	74.1	–	4.3	–	8.6	0.9	12.1	116
29 06 90	05.30	86.0	–	0.2	8.4	0.9	0.5	4.0	1 862
15 09 90	04.00	–	–	100	–	–	–	–	13
10 10 90	22.00	–	8.2	–	–	–	88.7	3.1	355
12 10 90	05.00	–	–	–	–	–	52.2	47.8	69
06 01 91	21.00	97.8	–	–	1.1	–	–	1.1	180
27 02 91	00.40	–	–	0.3	–	–	–	–	310
27 02 91	05.20	100.0	–	–	–	–	–	–	161
Sample size		3 127	254	72	607	332	412	208	5 012

Using this index of relative abundance, the blue sprat, *Spratelloides delicatulus*, was the most abundant species taken in the bait catches at all sites apart from Abemama. The sardine, *Amblygaster sirm*, was most dominant in the catches at Abemama. However, the sardine was not collected on any occasion from Butaritari, the catches from this site consisting almost completely of *S. delicatulus*.

The hardyhead (Hardy 1), *Hypoatherina ovalaua*, was more predominant in the catches than the gold-spot herring, *Herklotsichthys quadrimaculatus*, at all sites except Butaritari. *H. quadrimaculatus* at the other three sites did not rank higher than fourth in relative abundance. The other species of hardyhead (Hardy 2), *Atherinomorus lacunosus*, made a significant contribution to the catch at only Abemama and Tarawa. Other effective baitfish species did not make up a significant part of the catch at any of the sites, except in two samples from the ocean side of Tarawa lagoon when *Encrasicholina punctifer*,

Table 11. Baitfish species composition (%) of samples collected in Abemama between August 1989 and October 1990 (Sprat = *Spratelloides delicatulus*; Herring = *Herklotsichthys quadrimaculatus*; Sardine = *Amblygaster sirm*; Hardy 1 = *Hypoatherina ovalaua*; Hardy 2 = *Atherinomorus lacunosus*; Bai t= other baitfish species; Non-bait = by-catch species.

Date	Time	Sprat	Herring	Sardine	Hardy 1	Hardy 2	Bait	Non-bait	Total
20 08 89	21.30	–	–	96.2	–	–	–	3.8	26
21 08 89	05.30	–	–	100.0	–	–	–	–	73
02 09 89	23.45	–	30.9	18.2	–	7.3	25.5	18.2	55
03 09 89	05.00	–	42.4	10.6	–	47.0	–	–	66
19 04 90	21.55	17.3	8.6	–	55.0	–	–	19.1	220
20 04 90	03.50	10.1	19.6	–	69.6	–	–	0.7	296
08 10 90	05.00	–	–	6.3	–	–	–	93.8	64
Sample size		68	122	119	327	35	14	115	800

Table 12. Index of relative abundance of baitfish species at each site (species abbreviations follow those given in the captions Tables 8–11).

Site	Sprat	Herring	Sardine	Hardy 1	Hardy 2	Bait	Non-bait
Butaritari	90.4	6.2	0.0	2.3	0.4	0.4	0.3
Abaiang	41.7	7.3	3.6	19.3	0.8	5.9	11.3
Tarawa	36.3	10.3	9.8	18.2	11.4	7.6	6.4
Abemama	3.9	14.5	33.0	17.8	7.8	3.6	19.4

the oceanic anchovy, made up 88.7% and 52.2% of the catch (see section Improvements to the Fishery). The non-baitfish component was relatively abundant in both Abemama and Abaiang, where the weak herring, *Dussumieria* sp., often made up a large part of the catch.

The importance of *Spratelloides delicatulus*, *Herklotsichthys quadrimaculatus*, *Amblygaster sirm*, *Hypoatherina ovalaua* and *Atherinomorus lacunosus* in the bouke-ami baitfish catches in Kiribati has been well documented (JICA 1979; FAO 1983; Kleiber and Kearney 1983; McCarthy 1984; Ianelli 1988; MacInnes 1990).

By-catch

A list of the species making only a minor contribution to the baitfish catches (referred to as by-catch), and the minimum, maximum and mean standard length and weight of each species in the bouke-ami catches are given together with the number of fish sampled, in Table 13.

Table 13. Species list of fish, not important as baitfish, collected during baitfish sampling in Republic of Kiribati, September 1989-February 1991. Minimum, maximum and mean length (mm) and minimum, maximum, and mean weight (g), and the number of each species collected (N) are given.

Family	Species	Length (mm)			Weight (g)			
		Min.	Max.	Mean	Min.	Max.	Mean	N
APOGONIDAE	*Apogon exostigma*	28.0	29.0	28.5	0.30	0.37	0.34	2
	Apogon fragilis	12.0	36.0	19.0	0.05	1.30	0.15	146
	Apogon kallopterus	64.0	64.0	64.0	7.0	7.0	7.0	1
	Apogon leptocanthus	19.0	19.0	19.0	0.20	0.20	0.20	1
	Apogon nigrofasciatus	30.0	30.0	30.0	0.60	0.60	0.60	1
	Apogon novemfasciatus	16.0	25.0	19.0	0.10	0.30	0.13	3
	Apogon savayensis	39.0	39.0	39.0	1.60	1.60	1.60	1
	Apogonichthys perdix	23.0	24.0	23.5	0.30	0.50	0.40	2
	Archamia fucata	16.0	52.0	31.2	0.10	4.60	0.95	69
	Archamia lineolata	19.0	50.0	32.5	0.10	3.70	0.99	69
	Cheilodipterus quinquelineata	24.0	42.0	33.8	0.30	1.50	0.76	8
	Foa brachygramma	20.0	2	0	22.0	0.40	0.33	3
	Pseudamia gelatinosa	41.0	74.0	53.8	0.90	5.70	2.56	5
	Pseudamia polystigma	47.0	70.0	58.5	1.30	6.20	3.75	2
	Rhabdamia cypselurus	18.0	44.0	33.6	0.10	1.30	0.71	42
	Rhabdamia gracilis	15.0	43.0	31.0	0.10	1.10	0.50	7
	Siphamia tubulata	24.0	34.0	29.8	0.50	1.10	0.85	4
	Siphamia versicolor	12.0	29.0	23.0	0.30	0.70	0.57	13
	Siphamia sp.	13.0	13.0	13.0	0.20	0.20	0.20	1
CAESIONIDAE	*Caesio caerulaurea*	23.0	88.0	31.9	0.10	9.24	0.85	49
	Pterocaesio chrysozona	44.0	62.0	49.1	1.30	3.40	1.88	13
	Pterocaesio diagramma	30.0	104.0	54.2	0.30	18.0	3.97	35
	Pterocaesio tile	26.0	38.0	34.0	0.16	0.61	0.41	8
CARANGIDAE	*Alectis indicus*	183.0	183.0	183.0	225.0	225.0	225.0	1
	Carangoides ferdau	365.0	365.0	365.0	1 550.0	1 550.0	1 550.0	1
	Caranx melampygus	62.0	515.0	353.7	3.79	3 150.0	1 523.1	24
	Caranx papuensis	61.0	435.0	186.0	4.50	2 000.0	669.70	3
	Caranx sexfasciatus	50.0	580.0	324.4	3.31	3 100.0	1 664.0	26
	Decapterus macarellus	230.0	230.0	230.0	300.0	300.0	300.0	2
	Decapterus russelli	83.0	83.0	83.0	7.19	7.19	7.19	1
	Gnathanodon speciosus	14.0	26.0	20.8	0.10	0.20	0.15	8
	Scomberoides lysan	28.0	415.0	83.1	0.40	700.0	101.6	11
	Selar crumenopthalmus	150.0	163.0	156.6	65.0	86.0	76.0	5

(Table continued on next page.)

Family	Species	Length (mm)			Weight (g)			
		Min.	Max.	Mean	Min.	Max.	Mean	N
ACANTHURIDAE								
	Acanthurus sp.	18.0	36.0	25.9	0.10	1.20	0.54	14
	Acanthurus lineatus	35.0	35.0	35.0	1.10	1.10	1.10	1
	Acanthurus triostegus	20.0	20.0	20.0	0.40	0.40	0.40	1
	Zebrasoma scopas	56.0	56.0	56.0	1.80	1.80	1.80	1
	Acanthuridae Unidentified sp.	21.0	32.0	26.5	0.30	0.70	0.50	2
BALISTIDAE	*Balistapus undulatus*	25.0	25.0	25.0	0.80	0.80	0.80	1
	Balistoides viridesens	23.0	28.0	24.5	0.45	0.82	0.56	4
	Balistidae Unidentified sp.	–	–	–	–	–	–	2
BELONIDAE	*Tylosurus* sp.	–	–	–	–	–	–	2
BOTHIDAE	*Bothus* sp.	30.0	35.0	32.3	0.47	0.70	0.55	8
BREGMACEROTIDAE								
	Bregmaceros nectabanus	30.0	40.0	36.1	0.10	0.37	0.28	17
	Bregmaceros rarisquamosus	37.0	37.0	37.0	0.30	0.30	0.30	1
CHAETODONTIDAE								
	Chaetodontidae Unidentified sp.	12.0	14.0	12.1	0.16	0.20	0.16	21
CHANIDAE	*Chanos chanos*	38.0	38.0	38.0	1.10	1.10	1.10	2
ECHENEIDAE	*Echeneis naucrates*	400.0	600.0	503.0	270.0	1 200.0	696.0	5
GERREIDAE	*Gerres oblongus*	14.0	32.0	15.4	0.10	0.50	0.13	23
	Gerres sp.	18.0	18.0	18.0	0.10	0.10	0.10	1
GOBIIDAE	*Amblygobius phaelena*	20.0	70.0	35.7	0.20	4.70	0.39	50
	Gobiidae Unidentified sp.	–	–	–	–	–	–	1

(Table continued on next page.)

Table 13. Cont'd

Family	Species	Length (mm)			Weight (g)			
		Min.	Max.	Mean	Min.	Max.	Mean	N
HOLOCENTRIDAE								
	Myripristis adusta	30.0	43.0	34.3	0.70	3.0	1.57	3
	Myripristis kuntee	28.0	53.0	38.0	0.40	3.40	1.65	19
	Myripristis pralinia	47.0	83.0	56.0	2.80	16.9	6.33	4
	Myripristis violacea	95.0	95.0	95.0	30.0	30.0	30.0	1
	Myripristis sp.	7.0	46.0	22.8	0.02	2.40	0.63	17
	Neoniphon argenteus	30.0	41.0	35.5	0.60	1.50	1.05	2
	Neoniphon sammara	28.0	34.0	30.8	0.40	0.90	0.63	19
	Sargocentron ittodai	35.0	49.0	39.4	0.90	2.20	1.30	7
	Sargocentron spiniferum	12.0	42.0	21.5	0.10	1.60	0.48	4
LABRIDAE	Coridae Unidentified sp.	–	–	–	–	–	–	1
	Stethojulis albovittata	73.0	73.0	73.0	6.70	6.70	6.70	1
	Stethojulis bandanensis	34.0	40.0	37.0	0.60	0.90	0.75	2
	Stethojulis strigiventer	43.0	58.0	51.5	1.40	3.60	2.48	36
LETHRINIDAE	Lethrinidae Unidentified sp.	15.0	18.0	16.8	0.10	0.20	0.18	5
LUTJANIDAE	*Lutjanus quinquelineatus*	25.0	25.0	25.0	0.30	0.30	0.30	1
	Lutjanus semicinctus	20.0	20.0	20.0	0.20	0.20	0.20	1
	Lutjanus sp. A	27.0	27.0	27.0	0.39	0.39	0.39	1
	Lutjanus sp. B	6.0	30	0	27.7	–	–	–
	Lutjanus sp.	27.0	27.0	27.0	0.20	0.20	0.20	1
MONOCANTHIDAE								
	Monocanthidae Unidentified sp.	35.0	35.0	35.0	0.88	0.88	0.88	1
MULLIDAE	*Mulloides flavolineatus*	34.0	34.0	34.0	0.50	0.50	0.50	1
	Mulloides samoensis	37.0	81.0	66.9	0.60	6.30	4.17	12
	Parupeneus barberinoides	35.0	56.0	49.9	0.60	2.80	2.11	7
	Upeneus vittatus	172.0	213.0	192.5	99.0	202.1	150.6	2
MYCTOPHIDAE	*Myctophum brachygnathum*	48.0	48.0	48.0	1.50	1.50	1.50	1
NOMEIDAE	*Ariomma indica*	11.0	15.0	12.8	0.11	0.20	0.16	4

(Table continued on next page.)

Family	Species	Length (mm)			Weight (g)			
		Min.	Max.	Mean	Min.	Max.	Mean	N
POMACANTHIDAE								
	Centropyge bicolor	13.0	37.0	21.7	0.10	2.0	0.77	3
POMACENTRIDAE								
	Chromis viridis	22.0	48.0	29.3	0.40	3.10	0.96	14
	Chromis sp.	25.0	25.0	25.0	0.53	0.53	0.53	1
	Dascyllus aruanus	18.0	22.0	20.0	0.30	0.50	0.40	3
	Pomacentrus pavo	6.0	52.0	24.2	0.01	-	0.47	52
	Pomacentrus sp.	25.0	25.0	25.0	0.40	0.40	0.40	1
	Pomacentridae Unidentified sp.	7.0	18.0	11.3	0.04	0.20	0.08	38
PRIACANTHIDAE								
	Heteropriacanthus cruentatus	31.0	75.0	35.7	0.85	1.80	1.22	45
	Parapriacanthus sp.	41.0	48.0	43.4	1.20	2.30	1.60	5
SCARIDAE	*Scarus* sp.	29.0	56.0	42.4	0.40	4.50	2.15	10
	Scaridae Unidentified sp.	36.0	50.0	43.4	1.20	2.40	1.87	7
SCOMBRIDAE	*Euthynnus affinis*	320.0	320.0	320.0	600.0	600.0	600.0	1
SERRANIDAE	*Epinephelus* sp.	32.0	32.0	32.0	0.56	0.56	0.56	1
SIGANIDAE	*Siganus argenteus*	34.0	49.0	44.0	0.50	1.50	1.08	9
	Siganus spinus	73.0	95.0	85.3	8.10	18.50	13.16	3
	Siganus sp.	24.0	40.0	30.3	0.39	1.00	0.60	17
SPHYRAENIDAE								
	Sphyraena flavicauda	157.0	165.0	161.0	27.20	32.7	29.9	2
	Sphyraena forsteri	86.0	555.0	433.9	5.30	1 450.0	726.0	117
	Sphyraena novaehollandiae	385.0	485.0	432.3	350.0	700.0	511.3	31
	Sphyraena sp.	54.0	68.0	61.0	0.71	1.53	1.12	2
SYNODONTIDAE								
	Synodus sp.	34.0	34.0	34.0	0.10	0.10	0.10	1

(Table continued on next page.)

Table 13. Cont'd

Family	Species	Length (mm)			Weight (g)			
		Min.	Max.	Mean	Min.	Max.	Mean	N
TETRAODONTIDAE								
	Arothron stellatus	640.0	640.0	640.0	–	–	–	1
	Canthigaster solandri	14.0	50.0	22.3	0.15	5.41	0.98	8
	Torquigener sp.	15.0	48.0	18.7	0.15	3.10	0.36	27
ANGUILLIDAE	Leptocephalus	45.0	98.0	62.8	0.20	0.60	0.29	13
CEPHALOPODA	*Octopus* sp.	–	–	–	0.10	1.40	0.72	14
ELOPIFORMES	Elopiform Larvae	35.0	37.0	36.0	0.11	0.16	0.14	2

It is important to note that some of the species included in this list are effective baitfish, e.g. *Rhabdamia cypselurus*, *Archamia lineolatus*, *Selar crumenopthalmus* and species from the family Caesionidae. These fish should probably not be referred to as by-catch but, because of their minor contribution to the baitfish catches during the overall sampling period, have been included in this list.

Crustacea (prawns, shrimps and crabs) and some cephalapoda (squid) are not included in this list but were taken periodically in the catches. The specimens taken from these groups were mainly juveniles, as also reported by McCarthy (1985), from Tarawa lagoon.

The composition of the by-catch can be divided into two groups, (1) larval and juvenile stages of coastal fish species, and (2) large predatory fish.

The majority of the by-catch species consisted of juvenile stages of coastal fish species. Fish from the Families Holocentridae, Carangidae, Sphyraenidae, Labridae, Gobiidae, Pomacentridae, Priacanthidae and Chaetodontidae were the most numerous. Species from the Families Sphyraenidae and Carangidae were the most numerous large predators in the by-catch. A few other predatory species were also taken: *Euthynnus affinis*, *Echeneis naucrates*, *Upeneus vittatus* and *Tylosurus* sp. These fish were actively feeding around the bait light before they were caught (see section on Predation).

A similar composition of larval and juvenile fish in the by-catch from bouke-ami operations was reported from Solomon Islands by Rawlinson (1990). Although the by-catch makes up a small proportion of the total baitfish catch, the number of individuals taken over a whole season may be large, especially if fishing effort is high. Unfortunately, from the limited data available, it is not possible to assess whether the numbers being removed are likely to have any effect on recruitment of these species into the artisanal and subsistence fisheries. However, it should be noted that mortality of the juvenile fish will be increased by predation due to larger fish that are attracted to the underwater lights (see section on Predation).

It is also difficult to assess the effects of removal of the large predatory fish due to limited data on their stocks in the lagoons in Kiribati.

Size composition

The length frequency distributions from all sites combined for the most important baitfish species, *Spratelloides delicatulus*, *Amblygaster sirm* and *Herklotsichthys quadrimaculatus* are shown in Figures 22 to 24 respectively.

Included in these figures are lines indicating the lower (50 mm) and upper (150 mm) size limits for a fish effective as baitfish. These limits depend greatly on the species being targeted and on the tuna fishing conditions (Kearney and Rivkin 1981), but are probably representative of the situation in Kiribati.

The majority of the sprats, *S. delicatulus*, and the sardines, *A. sirm*, taken in the bouke-ami catches during the sampling period were too small or too large, respectively, to be effective baitfish (Figs 22, 23). Only the catches of herring, *H. quadrimaculatus*, were composed of mainly fish of suitable size (Fig. 24). However, as the bouke-ami catches consist primarily of *S. delicatulus* and *A. sirm*, with *H. quadrimaculatus* only making up a small component, it is the size composition of these two species which is important.

Catch Rates and Composition: Implications for Fishing Performance

The composition of the catch from baitfishing operations is extremely important for the success of pole-and-line fishing activities for tuna. The characteristics of an effective baitfish species for the capture of surface schools of tuna using the pole-and-line method are well documented by Hester (1974), Baldwin (1977), Smith (1977) and Yuen (1977). They are summarised by Kearney and Rivkin (1981) as:

bright or silvery colour;

behaviour consisting of rapid movement, erratic motion in water, returning to boat after broadcast;

able to withstand handling and storage aboard ship for extended periods; and

size, generally thought to be important, although appropriate limits might vary between 3 and 15 cm, depending on fishing conditions.

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

Argue et al. (1987) measured the performance of six baitfish groups utilised in the Pacific Ocean, judged by the two criteria of how effectively baitfish stimulate tuna to bite the lures and how well they survive the effects of capture and confinement in bait wells. The indices used to measure fishing effectiveness were the tuna–bait ratio, the percentage of schools chummed that responded positively, the catch in kg per positive school, and the catch in kg per fishing day. The different baitfish group performances were analysed under a variety of fishing conditions. Conclusions included the following points.

(a) Fishing effectiveness differed significantly among baitfish groups.

(b) The amount of bait carried was the most important factor influencing the tuna catch per day and the tuna catch per positive school.

(c) There was a positive relationship observed between each fishing index and sea conditions when sardines were used. In comparison, fishing effectiveness dropped with worsening sea conditions (higher Beaufort measures) for remaining baitfish groups, i.e. the smaller baitfish species. Small baitfish were often carried well away from the vessel in moderate winds, and they were not as adept at swimming back to the vessel as were the larger sardines.

(d) Sea surface temperature bore a constant negative relationship to the indices of fishing effectiveness. This result is consistent with results received from Forsbergh (1980) who suggested that skipjack catches dropped off at water temperatures above 28°C.

(e) An important result of the study was how little of the total variability of the fishing effectiveness could be accounted for by the baitfish groups and independent variables such as water temperature, sea conditions, moon phase and age. A part of this unaccounted variability may have been due to daily fluctuations in tuna abundance, for which no reliable measure was available. Therefore it was concluded that the interactions among baitfish, tuna, pole-and-line gear, and the environment are very complex and could not be fully examined with the observational data available.

(f) Baitfish mortality in captivity was significantly affected by bait species, sea condition, and the amount of bait carried. Average daily baitfish mortality therefore differed significantly among baitfish species, both with respect to their differing relationships to independent variables, and with constant baitfish group effect.

(g) Overall, sardines and anchovies were marked the most effective of the baitfish groups, followed by milkfish, mollies, sprats, and hardyheads.

(h) There are situations where each of the baitfish groups can be used effectively, although it is questionable whether the groups that were least effective for fishing can produce consistent profitable catches.

One variable not included in this analysis was the average size of baitfish used. Although the size of the baitfish may be implied by the baitfish groups, as different groups attain different maximum sizes, the catch composition data included here (Figs 22–24) show that the size distribution of a species varies significantly on different fishing occasions. The average size of the baitfish used for a day's tuna fishing has a very important bearing on the effectiveness of the operations.

Another variable not mentioned in the report, though very difficult to measure, is the ability of the fishing master. It is not known whether this variable changed at all, e.g. change in fishing master during the collection of the data, but the skill and knowledge of the fishing master have a strong impact on the success of a vessel's operations.

Implications for Kiribati

Argue et al. (1987) showed that there are many different variables which affect the daily fishing performance of a pole-and-line vessel. Although data for such variables as abundance of tuna schools, sea conditions and water temperature are not available, an indication of the success of pole-and-line vessels in Kiribati is given by the size and composition of baitfish catches (Figs 22–24). The baitfish size distributions have the following implications for pole-and-line fishing.

Catch rates

The amount of bait carried is the most important factor influencing the tuna catch per day and tuna catch per positive school (Argue et al. 1987). The average baitfish catch made per night in Kiribati, which in most situations is the same as the amount of baitfish carried for the next day's fishing operations, has been estimated as 38.8 buckets between 1985 and 1990. This catch rate is low compared to those from other countries with active pole-and-line fisheries: approximately 130 buckets per night in Solomon Islands (Nichols and Rawlinson 1990) and 52.6 buckets per night in Fiji (Sharma and Adams 1990).

When comparing catches from Solomon Islands and Fiji with those of Kiribati it should be remembered that the first two countries comprise primarily high islands as opposed to the atolls which are found in Kiribati. Comparisons have been made between the baitfish catches from atolls and high islands (Tuna Programme 1984). It was reported that baitfish of seven families accounted for 90% of the average catch of 104 kg per haul from high islands, whereas baitfish in four families accounted for 96% of the average catch of 54 kg per haul from atolls. Species of stolephorid anchovies, which are among the most effective for tuna live-bait fishing, dominated (59%) the catch from high islands, but were absent from atoll catches. Other effective species from high islands were from the families Dussumieriidae, Clupeidae and Apogonidae. Together, species in these four families constituted 76% of the catch from high islands, but only 65% of the catch from atolls, thus increasing the discrepancy between atolls and high islands in terms of the effectiveness of the catch.

From repeat surveys at different times, undertaken at atolls and high islands, a two-way analysis of variance, taking into account unequal replication of hauls, was used to test whether variance in catch per haul was higher, between surveys, for atolls or for high islands. The variance in catch rates between survey periods for atoll sites was significantly higher than the variance between survey periods for high island sites ($P<0.01$). These results support the contention that atolls are less reliable sources of bait for pole-and-line fishing than high islands (Shomura 1977). Since atolls also produce lower average catches of less effective species, it is clear that atolls in general offer much less potential for commercial baitfish operations than high islands (Tuna Programme 1984).

Due to the inter- and intra-annual variability in baitfish availability, this average catch rate for vessels in Kiribati is often not always reached, and on other occasions the rates are well above this. When limited baitfish is available, tuna catches can be expected to be low even if abundant schools of tuna are available. When high catch rates of baitfish are possible, however, this does not mean that high catches of tuna can be assumed, as schools may not be present in the immediate area at the same time.

The pole-and-line fleet therefore have to make maximum use of those times when good supplies of both tuna and baitfish are present. Boats must maximise their fishing days during these periods. Reports by Te Mautari vessel skippers, of fishing being missed in 1989 due to the time taken to unload and then poor baitfishing catches from Tarawa Lagoon, all led to missed fishing days when the fishing situation was good. Whether sufficiently high catches can be made over these periods of good fishing to cover the costs of periods of poor fishing is not known.

During periods when schools of tuna are present but baitfish catches are low there are two main alternatives open to the pole-and-line vessels: increase the nightly baitfishing effort by increasing the number of hauls of the bait net each night, and use cultured milkfish available from the fish ponds at Tarawa to increase the amount of bait carried. Both these alternatives are discussed in the section on Improvements to the Fishery.

During periods when schools of tuna are not in the immediate vicinity of the main baitfishing lagoons, then the operational range of the vessels needs to be increased. This can only be achieved by extending survival of baitfish on board the vessels by:

(a) the use of cultured milkfish;

(b) adopting good handling practices of natural baitfish catches and ensuring good water circulation through the bait wells (which was not always the case on trips made on some of the pole-and-line vessels in Kiribati); and

(c) conditioning of the bait. Smith (1977) suggested that bait be held in the net until the portion of the bait most affected by netting had died. This usually means leaving the bait overnight in the net, alongside the vessel, then loading the remainder alive during daylight. This method relies on reasonably calm conditions otherwise the bait is 'washed' around in the net. However, increased survival rates of baitfish can be realised using such a technique, and if a large operational range for the next day's fishing is more important than getting to the fishing grounds at first light, this is certainly an approach that might be used.

Species composition

Of the main baitfish species available in Kiribati, it was concluded by Argue et al. (1987) that sardines are the most effective baitfish, followed by milkfish, sprats and hardyheads.

The most numerous species caught in Kiribati is the blue sprat (*Spratelloides delicatulus*), and although generally considered an excellent bait in the right conditions, it is often caught at only a small size in Kiribati. This will lead not only to higher mortality but also reduced effectiveness when used to 'chum' tuna schools. In strong wind conditions it may be very hard for such small fish to swim back around the boat, and although they may induce a positive feeding response from a school of tuna, the activity may be taking place outside the fishing area of the vessel. The smaller-sized bait, unless mixed with larger fish, is likely to be more effective at attracting small-sized tuna rather than the larger, more desirable fish sizes. The large size classes of sprats act very effectively in the right conditions, but the smaller ones are effective over a narrower range of conditions, e.g. in calm weather, when schools of small tuna are close to the baiting grounds.

The sardine group, which includes both *Amblygaster sirm* and *Herklotsichthys quadrimaculatus*, is the most effective group of baitfish, apart from anchovies which have not been caught by the Te Mautari fleet. In Kiribati, this group is primarily comprised of the sardine, *A. sirm*, with a much smaller proportion of the herring, *H. quadrimaculatus*. Usually only the adult size classes of the sardine are caught and during 1990 most of the fish were near the maximum size for this species (20 cm). However, smaller size classes are taken at certain times and these make a very effective baitfish. During a trip on board one of the Te Mautari vessels in August 1989, large numbers of good-sized (between 10 and 15 cm) sardine were caught from Abemama and catches of between 8 and 10 t/day of large-size skipjack tuna, *Katsuwonas pelamis*, were made. However, during 1990, when the sardine were much larger, a good chumming response could not be achieved and only a few large individual yellowfin tuna, *Thunnus albacares*, were caught. It is interesting to note also that during August 1991 the SPC Tuna Tagging vessel *Te Tautai* caught from Abemama large quantities of sardine with a mean length of between 12 and 13 cm, and made good catches of large skipjack and yellowfin tuna (Itano, pers. comm.).

McCarthy (1985) details monthly length-frequency distributions for *Amblygaster sirm* from Tarawa from June 1983 to May 1984. The majority of the fish were 50 to 150 mm in size. For *Spratelloides delicatulus*, the length distributions showed the majority of the fish measuring below 50 mm with larger size classes appearing in the catches during June, July and August 1983. The tuna-to-bait ratios in 1983 and 1984 were good during the period that this composition and size of bait were identified.

The herring caught in the bouke-ami nets are usually of the size classes considered effective, though some were on the small size (Fig. 24). If these species were caught in larger numbers then they would increase the overall effectiveness of the baitfish used in Kiribati. However, the catch-at-age data and mortality estimates (Table 2, Fig. 2) indicate that they are probably already fully exploited.

The hardyhead was the least effective of the baitfish groups and is not of any real use when caught on its own. However, mixed with other species, the hardyheads help to keep a school of tuna feeding around the boat.

Argue et al. (1987) suggested that the least effective baitfish groups were unlikely to produce consistently profitable catches of tuna. This was demonstrated in Kiribati, where the sprat is the mainstay of the Te Mautari fleet (MacInnes 1990).

The sardine, *A. sirm*, may therefore be the most important natural baitfish species for the success of future operations of the Te Mautari fleet. However, this species is variable in its availability and abundance so it is difficult to predict good catches from year to year. A problem also arises because the size classes available are sometimes too big to be effective baitfish.

With these larger baitfish, the concept of 'tails per bucket' is relevant when assessing the fishing value of a given quantity of bait (Lewis 1990). The principle of this is that there are smaller numbers of baitfish in one bucket with increasing size class of fish. In this situation, a number of buckets of medium-size fish is going to be far more effective than an equal number of buckets of large-size baitfish. A larger number of individual fish carried on the vessel is going to keep a larger number of tuna attracted to the boat for a longer period of time.

It is not possible for a fishing master to select the size classes of baitfish he catches using the bouke-ami technique, but the larger size classes can be excluded from the bait wells by placing appropriate netting over the opening of the bait well as buckets of bait are poured in. In some situations the large baitfish are a problem because they increase the mortality of the smaller-sized baitfish, and therefore are kept out of the bait wells. However, the vessels in Kiribati have the alternative of utilising the cultured milkfish if the size of the natural baitfish are not effective for the size of the tuna in the schools that are present at any one time. Milkfish can be graded from the ponds so that the appropriate size class of bait required could be made available.

The suggestions here regarding the use of cultured milkfish and increasing the nightly baitfishing effort would all have a financial price. Whether such an investment can produce the increased tuna catch to cover this extra expenditure and still produce a profit is not known. It would be imperative to carry out an economic appraisal of such practices taking into account the great variation in catches likely to be experienced.

Maximum Sustainable Yield: Number of Vessels the Baitfishery will Support

An estimate of the number of pole-and-line fishing vessels the available baitfish resources can support in Kiribati was first set at six to eight boats (Kristjonsson and Stone 1981). However, since the initiation of commercial pole-and-line operations the fleet size has not been larger than five vessels at any one time. The commercial operations of Te Mautari Limited failed and the principal constraint has been a lack of the hardy wild bait resource (MacInnes 1990).

The number of vessels the baitfishery can support is thus a vital question for the fleet size of Te Mautari to be set at an optimum level. Excluding all the economic implications, this involves an estimation of the levels of the baitfish resource available and an understanding of how this resource will react to fishing pressure.

In the section Analysis of catch-and-effort data, a link was found between the high fishing effort in the early years of commercial fishing and abundance of baitfish (measured as catch-per-unit-effort) in Tarawa Lagoon. The reduced catch rates were related to the high fishing effort of 1983 and 1984, although other factors may have played a major contributory role. No such relationship was found for Abaiang, Abemama and Butaritari.

The difficulties predicting a relationship between baitfish abundance and fishing effort were due primarily to the inaccuracy of available data, relocation of fishing effort when catches start to decline, variability of catches (both in abundance and species composition over both short and long timescales), and a lack of understanding of the recruitment of the major baitfish species, especially the sardine, *Amblygaster sirm*, into the lagoons of Kiribati. It is therefore considered inappropriate to try and predict optimal fishing effort from the catch-and-effort data for all sites.

Estimates of baitfish yield

Estimates of the potential sustainable yield from the baitfishery will be only 'guesstimates', at best, given an absence of a long time series of accurate catch-and-effort data for the fishery. However, the following analysis provides two independent estimates of the potential yields based on (1) surplus production models fitted to the available catch-and-effort data, and (2) an empirical method that uses literature values of carbon production of other coral atolls to estimate potential yield of a fishery that relies on that primary productivity. Both methods have unrealistic assumptions but give some indication of the potential for the fishery.

Method 1: Surplus production models

Schaefer (1954) developed a model which in its simplest form is a linear relationship between catch per effort and effort, and of the form:

$$C/f = a - bf$$

where C = catch, f = effort and a and b are constants.

Using this model for Tarawa the relationship between catch and effort is described by:

$$C/f = 35.1 - 0.0091 f$$

From Schaefer's model, maximum sustainable yield (MSY) and optimal fishing effort (f_{opt}) for Tarawa between 1985 and 1990 can be calculated from:

$$\text{MSY} = a^2 / 4b$$

$$f_{opt} = a / 2b$$

For Tarawa, therefore, MSY = 33 846 buckets/yr or 84.5 t/yr with an optimal effort of 1929 boat-nights/year. When converted to a yield per km^2, it becomes 0.256 t/km^2/yr. These figures must be treated with some caution because of the poor 'goodness-of-fit' for the relationship ($r^2 = 0.255$, degrees of freedom = 4). This would imply that the decrease in catch rate cannot be attributed to fishing effort alone and that there are other factors responsible for the trend. However, it does give an estimate of the magnitude of catches that may be sustainable. In both 1983 (37 303 buckets) and 1984 (37 755 buckets), this level of catch was exceeded. Pitcher and Hart (1982) stated that there will be a peak of catch in the early years of a fishery, even at the optimum fishing rate, that gives maximum sustainable catch. Such a high yield early in the exploitation of a new fishery can create management problems. From available information it appears that Tarawa Lagoon suffered from such high levels of exploitation of the baitfish resources in 1983 and 1984 that the equilibrium catch is now at a lower level than at the start of the fishery. (Equilibrium catch is defined as the catch (in numbers) taken from a fish stock when it is in equilibrium with fishing of a given intensity, and, apart from the effects of environmental variation, its abundance is not changing from one year to the next (Ricker 1975).)

Method 2: Empirical approach

An approach by Dalzell and Lewis (1988) which follows Marten and Polovina (1982) uses the empirical relationship between primary production and potential pelagic fish yield for tropical small pelagics. Given available primary production estimates in South Pacific waters are in the range 18–46 g carbon/m²/yr, potential yields in the range of 0.71 to 0.95 t/km²/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/km²/yr are obtained. These estimates could be applied to the known lagoon area in individual baitfisheries to obtain first order yield estimates (Lewis 1990).

Applying this approach to the lagoons used for baitfishing in Kiribati, the estimates of potential yields are shown in Table 14. For comparison, the MSY is also calculated for each site (assuming a similar productivity to that of Tarawa).

Table 14. Land and lagoon area of the four baitfish sites, their estimated MSY (assuming production of 0.256 t/km²/yr from surplus production model for Tarawa), minimum and maximum yields (based on potential production of 0.46–0.62 t/km²/yr) and the highest recorded baitfish catch at each site.

	Land area (km²)	Lagoon area (km²)	MSY (t/yr)	Min. yield (t/yr)	Max. yield (t/yr)	Highest catch (t/yr)
Abaiang	17.48	273.8	70.1	125.9	169.8	34.6(1989)
Abemama	27.40	144.5	37.0	66.5	89.6	23.1(1984)
Butaritari	13.49	254.3	65.1	117.0	157.7	25.4(1984)
Tarawa	30.00	330.0	84.5	151.8	204.6	94.4(1984)
Total yield			256.7	461.2	621.6	125.0(1984)

Sources of land area data: Abaiang — Taniera 1988; Abemama — Mees 1986; Butaritari — Mees 1985; Tarawa — Gilmour and Colman 1990.

Estimates of minimum yields of baitfish using either the surplus production or empirical approachs are much higher than the highest catches ever achieved by the pole-and-line fleet at each of the lagoons (Table 14). The results imply that higher catches of baitfish than are presently taken may be made from lagoons in Kiribati, without detrimental effects to the stocks. However, the mortality estimates (Tables 1–3) suggest that stocks of adult baitfish are being optimally exploited. Thus the lower MSY estimates (Table 14) are considered to be more realistic.

How much baitfish is required?

Kearney (1975) attempted to estimate the quantities of bait required to develop an export skipjack tuna fishery. Using data from the Papua New Guinea pole-and-line fishery in the early 1970s, Kearney was able to obtain indications of fluctuations in the relationship between bait and skipjack catches with variable skipjack abundance. Economic factors have to be considered when trying to predict the potential success of a fishing enterprise. Some of the economic variables identified by Kearney were: (1) the cost of catching the fish, (2) transportation expenses, (3) market prices, (4) efficiency of processing, and (5) labour costs. As the costs of these factors are not known it is difficult to assess the economic potential of a pole-and-line fishery in Kiribati, and remains outside the scope of this report. However, an attempt can be made to estimate the quantities of baitfish required to maintain the present fleet size of five vessels.

After the initial surveys of 1979 and 1980, an economic report (the FAO Investment Centre Report No. 46/80) estimated that if a 100 GT class of pole-and-line vessel operated by local crews could obtain a catch rate of 750 t/vessel/year, the exercise would be profitable under the 1980 price structure. Kearney (1975) also estimated catch rates of approximately 700–750 t/boat are required to cover costs. If these figures are used as a guideline to the catches required by each vessel then an annual catch of about 3500 t is required from a fleet of five vessels in Kiribati. One of the vessels in the Te Mautari fleet is distinctly smaller than the other four, and therefore the catch it requires to make each year would not be as high as the others. However, a target annual catch of 3500 t is reasonable for the purposes of this exercise. The highest annual catch to date was in 1984 when 2252 t tuna were caught.

Tuna-to-bait ratio

Table 15 details the tuna and baitfish catches made by the pole-and-line fleet in Kiribati from 1982 to 1989. The ratio of tuna caught per unit of baitfish caught is also given.

The average catch of tuna for every kg of baitfish was 14.8 kg during the period 1982 to 1989. This figure has varied each year with a low of 7.1 kg tuna to one of baitfish in 1987 and a high of 21.3 kg in 1989. It is interesting to note that a catch rate of 1 kg of baitfish to 15 kg of tuna was obtained during the early exploratory fishing operations, and even this rate was considered too low to hold any potential for the development of a pole-and-line fishery in Kiribati (FAO 1983).

The tuna-to-baitfish catch ratio from Solomon Islands (Nichols and Rawlinson 1990), was 12.07 from 1981 to 1988. This figure varied from a low of 9.9 in 1985 to a high of 15.0 in 1985. The pole-and-line fishery in Solomon Islands is much larger than that of Kiribati and had an annual catch in excess of 33 000 t and baitfish catches of 142 buckets per night in 1988 (Nichols and Rawlinson 1990). However, the average ratio of tuna to baitfish over roughly the same period of time is of the same magnitude and may be indicative of the operations of a fleet of medium-size pole-and-line fishing vessels working Pacific Islands waters.

The tuna-to-bait ratio is variable through the year during changing periods of good and poor fishing. Data for 1988 from Kiribati show this trend (Table 16).

During 1988 tuna-to-bait ratios were three to four times lower at the beginning of the year than during the second half of the year when the highest catches were made. MacInnes (1990) stated 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. His records also showed that these months are the best months for wild bait. The data for 1988 in Table 16 show that there is a period from July to December when catches of tuna were much greater than for the remainder of the year. The season for tuna in 1988, however, was later than MacInnes identified as normally the best time for fishing. Baitfish catches were higher during March to October with a decline in catch rates at the end of the year. Tuna-to-bait ratios during November and December were still high and if bait catches could have been higher, increased tuna catches may well have been realised.

If the figure of 14.8 kg of tuna caught for every kg of baitfish captured is used, then for an annual catch of 3500 t tuna, the requirement of baitfish would be 236 t (or 94 400 buckets) per year. This figure is almost double the maximum annual baitfish catch made in Kiribati (1984), and four times greater than that of 1989.

Using the estimates of potential yields from the baitgrounds in Table 14, this requirement of baitfish would be difficult to meet from the natural stocks of pelagic baitfish from the lagoons of Abaiang, Abemama, Butaritari and Tarawa. But in order to approach these catch levels, increased nightly fishing effort by each vessel would be required. The effort required would be even greater if most of the fishing effort were to take place away from Tarawa. Due to the variation in catch rates in Kiribati, it may not be possible to achieve this average annual requirement from natural stocks, and so it will be necessary to supplement from the cultured milkfish farms.

As these estimated yields have been produced from methods whose underlying assumptions are rarely met, it cannot be assumed that the natural baitfish stocks can sustain the increased fishing effort this analysis suggests is possible. It will therefore be vital to monitor on a regular nightly basis the catch and effort made by the pole-and-line boats. Such information can quickly indicate whether overfishing may be occurring. Due to the nature of baitfishing (and the relocation of fishing effort when declining catch rates occur), the fact that recruitment of the major baitfish species comes from an ocean-based pool and that the species are relatively short-lived (Milton et al. 1992a) and highly fecund (Milton et al. 1992b), it is unlikely that stocks could be completely decimated. The increased use of cultured baitfish could also take a considerable amount of fishing pressure away from the natural stocks.

It would therefore be unwise to increase the size of the present fishing fleet until increased catches by existing vessels are achieved. Extremely careful thought and consideration needs to be given to any increase in fleet size by Te Mautari Limited, and a lot of these decisions must be based on economic factors. However, once these have been taken into consideration and target catch rates have been set, the figures above should assist in assessing the amounts of baitfish required.

Table 15. Annual baitfish and tuna catches in Kiribati from 1982 to 1989 and their tuna-to-baitfish ratios (bu = buckets).

Year	Bait catch (bu)[1]	Tuna catch (t)	Tuna per unit of baitfish (kg)
1982a	16 913	549.89	13.01
1983a	45 513	1 868.52	16.42
1984b	50 586	2 252.00	17.81
1985b	35 329	826.00	9.35
1986c	29 636	1 360.00	18.36
1987d	32 896	584.00	7.10
1988e	24 274	875.70	14.43
1989f	23 241	1 242.80	21.30
Total	258 288	9 558.91	14.79

[1] 1 bu ≙ 2.5 kg

Sources of tuna catch data: a. Dalley 1984; b. Lawson 1991; c. Mees 1987; d. Mees 1988; e. raw data from South Pacific Commission; f. Kiribati Fisheries Division 1989.

Table 16. Monthly tuna fishing effort, tuna and baitfish catch, tuna-to- bait ratio and the amount of baitfish used daily by the pole-and-line fleet during 1988 (N = number of vessels; bkts = buckets).

Month	N	Fishing days	Bait catch (bu)[1]	Tuna catch (t)	Tuna to bait (kg)	Bait/day (bu)
January	2	42	1 560	26.4	6.77	37.1
February	2	42	1 535	20.8	5.41	36.6
March	1	25	1 149	26.0	9.05	46.0
April	1	22	735	18.9	10.29	33.4
May	1	26	788	16.1	8.15	30.3
June	3	59	2 283	23.0	4.03	38.7
July	3	60	2 682	105.2	15.69	44.7
August	3	65	3 182	156.6	19.68	49.0
September	3	80	3 939	165.5	16.81	49.2
October	3	64	2 592	122.6	18.92	40.5
November	4	74	2 250	137.4	24.41	30.4
December	4	64	1 579	70.1	17.77	24.7

[1] 1 bu ≙ 2.5 kg

Baitfish Biology

Summary

The main conclusions from this section are:

- the three main baitfish species spawn throughout the year with periods of more intense activity;
- *Amblygaster sirm* of effective baitfish size are absent from the lagoon and baitfishing catches only spawning adults;
- *Herklotsichthys quadrimaculatus* disperse from daytime aggregations after dark to feed and spawn and this may be the reason that this species is not attracted to the underwater lights in large numbers;
- predation of baitfish around underwater lights was higher than under natural conditions and there was an increase in the number of species preying on baitfish;
- there was some overlap in the predatory fish by-catch and the artisanal reef-fish fishery, but the effect of the interaction appears to be small.

Aspects of the biology that affect the catch rates of the three main baitfish species, *Amblygaster sirm, Herklotsichthys quadrimaculatus* and *Spratelloides delicatulus* are presented in this section.

Growth and Recruitment

As shown in the previous section on the size composition of the catch, most *A. sirm* and *S. delicatulus* in baitfish catches are too small or too large to be effective baitfish for skipjack tuna The seasonal changes in the length-frequency distribution of these species are influenced by the time at which fish recruit to the fishery. By having a better understanding of their recruitment patterns, the fishermen may be able better to predict when most fish of desirable size are in the population. They could also target areas where that species occurs in order to catch more bait of the most effective size.

The reproductive cycle of the three main species in Kiribati involves almost continuous spawning throughout the year (Milton et al. 1992b). However, the number of eggs produced each month varies in relation to food availability. The distribution of birthdates of each of the three species back-calculated from length-frequency samples (Figs 25–27) shows that some fish are born each month.

In 1989, *Amblygaster sirm* had a protracted spawning season during the middle of the year and most fish were born between March and October. These fish would reach the minimum preferred length for bait (5 cm) in 2–3 months (Fig. 25). Yet they rarely enter baitfish catches (Fig. 22). Most of the commercial catches of *A. sirm* were large adults involved in spawning (Milton et al. 1992b).

The distribution of birthdates back-calculated from length-frequency samples of *H. quadrimaculatus* from the four years examined was more even than for other species. Fish were fully selected by bouke-ami nets at five months of age (Table 2), when they approach sexual maturity (Milton et al. 1992b). Continuous spawning throughout the year by *H. quadrimaculatus* means that most of the *H. quadrimaculatus* population should be of a suitable length for baitfishing.

Herklotsichthys quadrimaculatus is not attracted to underwater lights as effectively as the other two species and does not form a significant part of the catch (Tables 7–10). During the day they form dense schools in shallow water where they are caught for local consumption. Their poor representation in baitfish catches may be because *H. quadrimaculatus* disperse during the night to feed (Milton et al., unpublished data). Density in baitlighting areas may be quite low and so few would be attracted to the lights. Both *A. sirm* and *S. delicatulus* feed during the day (Milton et al. 1990) and baitlights are probably attracting spawning fish (Milton et al., 1992b) that are aggregating in these areas.

The distribution of back-calculated birthdates of *Spratelloides delicatulus* varied among the four years examined (Fig. 27). Fish spawned throughout the year, but in each year there were two periods of increased activity. A similar pattern was found for this species in Solomon Islands (Milton and Blaber 1991). Only a small fraction of the length distribution of *S. delicatulus* is in the effective length range for skipjack tuna bait. This makes it difficult to predict at which time of the year these fish will be more prevalent. In 1989 and 1990, the largest length-classes were collected during the peak spawning period in June to August. This suggests that larger *S. delicatulus* may be more catchable at these times.

Predation on Baitfish

Previous work by the CSIRO–ACIAR baitfish research project in Solomon Islands and Maldives (Blaber et al. 1990a, b) addresses the question of biological interactions between baitfish and reef fish and the potential effects of baitfishing on artisanal and subsistence reef fisheries. Nothing is known of such interactions in Kiribati and hence as a first step predation by larger fish on baitfish was investigated. This predation takes two forms; firstly, natural predation by larger species, and, secondly, intense predation around baitlights at night. Information on both is necessary if we are to understand the trophic effects of baitfishing on reef fish communities.

Methods

During the course of sampling baitfish around the islands of Abemama, Abaiang, Butaritari and Tarawa, other fish were captured with a number of different types of fishing gear:

(a) monofilament gill-nets of varying mesh sizes: 25 mm, 33 mm, 50 mm, 75 mm and100 mm;

(b) the bouke-ami net (as by-catch of the baitfishing operations);

(c) trolling lines and lures towed from behind a small skiff;

(d) handlines (or droplines) (these operations took place around the underwater light used to aggregate baitfish as well as under natural conditions when no light was operating); and

(e) other methods including beach-seine, cast-net and fishing poles.

Most of the fishing gears were being used for the collection of baitfish samples or were incidental fishing operations while undertaking other activities. However, on one occasion a fishing competition was arranged specifically to sample non-baitfish species from Tarawa Lagoon (see Appendix 1).

After fish had been captured they were identified, measured (standard length) and weighed and the stomachs removed and preserved in 10% formalin. In the laboratory, the stomach contents were sorted, as far as possible, by species, and dried to constant weight at 60°C. The diets of each species are expressed in terms of the percentage contribution of each prey category to the total dry weight of stomach contents and its percentage frequency of occurrence.

Results

Species collected

A list of the different species that were collected from each site and examined for their stomach contents is given in Table 17. The numbers of each species and how they were caught are shown in Table 18.

Table 17. Species list of fish collected for dietary analysis during sampling in the Republic of Kiribati, September 1989–February 1991 (Ab = Abemama; Ag = Abaiang; Bu = Butaritari; Ta = Tarawa).

Species	Sites			
	Ab	Ag	Bu	Ta
BALISTIDAE				
Balistipus undulatus				*
Pseudobalistes flavimarginatus				*
Rhinecanthus aculeatus				*
Sufflamen chrysopterus				*
BELONIDAE				
Ablennes hians				*
Strongylura incisa	*	*	*	*
Tylosurus acus		*		
Tylosurus crocodilus			*	
Tylosurus sp.		*		
CAESIONIDAE				
Caesio caerulaureus			*	
CARANGIDAE				
Alectis indicus		*		
Carangoides ferdau				*
Caranx ignobilis			*	*
Caranx melampygus		*	*	*
Caranx papuensis			*	*
Caranx sexfasciatus			*	*
Decapterus macarellus				*
Decapterus macrosoma			*	
Scomberoides lysan	*	*	*	*
Selar crumenopthalmus		*	*	*
DUSSUMIERIIDAE				
Dussumieria sp. A		*		
ECHENEIDAE				
Echeneis naucrates	*			*
GERREIDAE				
Gerres argyreus				*
HOLOCENTRIDAE				
Myripristis murdjan		*		
Sargocentron spiniferum				*
LABRIDAE				
Choerodon anchorago				*
Thalassoma lunare				*

(Table continued on next page.)

Species	Ab	Ag	Bu	Ta
			Sites	
LETHRINIDAE				
Lethrinus elongatus			*	*
Lethrinus nebulosus			*	
Lethrinus ramak				*
Monotaxis grandoculus				*
LUTJANIDAE				
Aprion virescens		*		
Lutjanus bohar			*	*
Lutjanus fulvus			*	*
Lutjanus gibbus			*	*
Lutjanus kasmira			*	*
Lutjanus monostigma			*	
Lutjanus russelli			*	
Lutjanus semicinctus				*
MULLIDAE				
Upeneus vittatus		*		
NEMIPTERIDAE				
Nemipterus peronii			*	
SCOMBRIDAE				
Euthynnus affinis		*	*	
Grammatorcynus bilineatus			*	
Rastrelliger brachysoma			*	
SERRANIDAE				
Aethaloperca rogaa			*	
Cephalopholis argus				*
Cephalopholis cyanostigma			*	
Epinephelus cyanopodus			*	
Epinephelus fuscoguttatus				*
Epinephelus merra				*
Epinephelus tauvina			*	
Plectropomus areolatus			*	*
SPHYRAENIDAE				
Sphyraena barracuda				*
Sphraena flavicauda		*	*	
Sphyraena forsteri	*	*	*	*
Sphyraena novaehollandiae				*

Table 18. Number of fish collected for dietary analysis by method and species during sampling in the Republic of Kiribati, September 1989–March 1991 (BOU = bouke-ami catch; DLL = drop-line fishing around artificial light at night; DL = drop-line fishing away from artificial light; NET = gill-nets; TRL = trolling lures; OTH = other methods including beach-seine, cast-net, fishing pole; TOT = total numbers sampled).

Method Species	BOU	DLL	DL	NET	TRL	OTH	TOT
BALISTIDAE							
Balistipus undulatus	–	–	1	–	–	–	1
Pseudobalistes flavimarginatus	–	–	1	–	–	–	1
Rhinecanthus aculeatus	–	–	1	–	–	–	1
Sufflamen chrysopterus	–	–	2	–	–	–	2
BELONIDAE							
Ablennes hians	–	–	–	1	–	–	1
Strongylura incisa	–	–	–	21	–	–	21
Tylosurus acus	–	–	–	2	–	–	2
Tylosurus crocodilus	–	–	–	1	–	–	1
Tylosurus sp.	2	–	–	–	–	–	2
CAESIONIDAE							
Caesio caerulaureus	–	–	–	2	–	–	2
CARANGIDAE							
Alectis indicus	1	–	–	–	–	–	1
Carangoides ferdau	1	–	–	–	–	–	1
Caranx ignobilis	–	–	–	1	3	–	4
Caranx melampygus	21	–	–	29	52	1	103
Caranx papuensis	1	–	–	1	3	–	5
Caranx sexfasciatus	23	1	–	23	2	1	50
Decapterus macarellus	5	–	–	–	–	–	5
Decapterus macrosoma	–	–	–	1	–	–	1
Scomberoides lysan	2	1	–	128	–	–	131
Selar crumenopthalmus	5	1	–	7	–	–	13
DUSSUMIERIIDAE							
Dussumieria sp. A	4	–	–	–	–	–	4
ECHENEIDAE							
Echeneis naucrates	5	–	–	–	–	–	5
GERREIDAE							
Gerres argyreus	–	–	1	–	–	–	1
HOLOCENTRIDAE							
Myripristis murdjan	–	–	–	–	1	–	1
Sargocentron spiniferum	–	–	3	–	–	–	3
LABRIDAE							
Choerodon anchorago	–	–	1	–	–	–	1
Thalassoma lunare	–	–	1	–	–	–	1

(Table continued on next page.)

Species \ Method	BOU	DLL	DL	NET	TRL	OTH	TOT
LETHRINIDAE							
Lethrinus elongatus	–	–	4	–	2	–	6
Lethrinus nebulosus	–	–	–	5	–	–	5
Lethrinus obsoletus(ramak)	–	–	3	–	–	–	3
Monotaxis grandoculus	–	–	1	–	–	–	1
LUTJANIDAE							
Aprion virescens	–	–	–	–	1	–	1
Lutjanus bohar	–	–	–	–	6	–	6
Lutjanus fulvus	–	–	–	13	–	–	13
Lutjanus gibbus	–	–	5	8	2	–	15
Lutjanus kasmira	–	–	17	17	–	–	34
Lutjanus monostigma	–	–	–	1	–	–	1
Lutjanus russelli	–	–	–	1	–	–	1
Lutjanus semicinctus	–	–	1	–	–	–	1
MULLIDAE							
Upeneus vittatus	1	–	–	–	–	–	1
NEMIPTERIDAE							
Nemipterus peronii	–	–	–	1	–	–	1
SCOMBRIDAE							
Euthynnus affinis	1	–	–	–	4	–	5
Grammatorcynus bilineatus	–	–	–	2	7	–	9
Rastrelliger brachysoma	–	–	–	37	–	–	37
SERRANIDAE							
Aethaloperca rogaa	–	–	–	–	1	–	1
Cephalopholis argus	–	–	4	–	–	–	4
Cephalopholis cyanostigma	–	–	–	–	1	–	1
Epinephelus cyanopodus	–	–	–	–	5	–	5
Epinephelus fuscoguttatus	–	–	–	–	2	–	2
Epinephelus merra	–	–	6	–	–	–	6
Epinephelus tauvina	–	–	–	1	–	–	1
Plectropomus areolatus	–	–	–	–	8	–	8
SPHYRAENIDAE							
Sphyraena barracuda	–	–	–	–	2	1	3
Sphraena flavicauda	3	–	–	2	–	–	5
Sphyraena forsteri	123	1	–	20	4	–	148
Sphyraena novaehollandiae	31	–	–	–	–	–	31

Table 19. Percentage dry weight of prey consumed (Wt%) and percentage frequency of fish consuming prey type (F%) by species under natural conditions (no light) and artificially illuminated conditions (light) during sampling in the Republic of Kiribati, September 1989–March 1991.

Species	Prey type	No light Wt%	No light F%	Light Wt%	Light F%
BALISTIDAE					
Balistipus undulatus	Empty	–	100.00	–	–
Pseudobalistes flavimarginatus	Empty	–	100.00	–	–
Rhinecanthus aculeatus	Empty	–	100.00	–	–
Sufflamen chrysopterus	Empty	–	100.00	–	–
BELONIDAE					
Ablennes hians	Empty	–	100.00	–	–
Strongylura incisa	Atherinidae Unid. sp.	28.13	16.67	–	–
	Clupeidae Unid. sp.	38.86	16.67	–	–
	Empty	–	71.00	–	–
	Spratelloides delicatulus	11.88	16.67	–	–
	Spratelloides sp.	3.23	16.67	–	–
	Teleost remains	17.90	16.67	–	–
Total prey weight		5.453 g	–	–	–
Tylosurus acus	Empty	–	50.00	–	–
	Teleost remains	100.00	50.00	–	–
Total prey weight		0.026 g	–	–	–
Tylosurus crocodilus	Empty	–	100.00	–	–
Tylosurus sp.	Carid	–	–	0.46	50.00
	Empty	–	–	–	0.00
	Holocentridae Unid. sp.	–	–	59.09	50.00
	Myripristis sp.	–	–	4.58	50.00
	Ophicthiid Eel	–	–	10.95	5.00
	Spratelloides delicatulus	–	–	2.18	50.00
	Spratelloides sp.	–	–	8.97	50.00
	Teleost remains	–	–	13.77	100.00
Total prey weight		–	–	4.960 g	–
CAESIONIDAE					
Caesio caerulaureus	Empty	–	100.00	–	–
CARANGIDAE					
Alectis indicus	Carid	–	–	11.54	100. 00
Crab		–	–	53.85	100.00
Empty		–	–	–	0.00
Teleost remains		–	–	34.62	100.00
Total prey weight		–	–	0.260 g	–

(Table continued on next page.)

Table 19. Cont'd

Species	Prey type	No light Wt%	F%	Light Wt%	F%
Carangoides ferdau	*Apogon* sp.	–	–	100.00	100.00
	Empty	–	–	–	0.00
Total prey weight		–	–	0.478 g	–
Caranx ignobilis	Empty	–	50.00	–	–
	Teleost remains	100.00	50.00	–	–
Total prey weight		1.034 g	–	–	–
Caranx papuensis	Carid	–	–	24.36	100.00
	Clupeidae Unid. sp.	–	–	34.62	100.00
	Crab	19.96	25.00	–	–
	Decapoda	0.57	25.00	–	–
	Digested remains	1.00	25.00	–	–
	Empty	–	25.00	–	0.00
	Gerreidae Unid. sp.	78.47	25.00	–	–
	Sergestidae Unid. sp.	–	–	41.02	100.00
Total prey weight		18.080 g	–	0.078 g	–
Caranx melampygus	*Apogon* sp.	7.04	7.84	–	–
	Atherinomorus lacunosus	–	–	0.71	4.76
	Blenniidae Unid. sp.	0.07	1.96	–	–
	Brachyuran	–	–	0.10	4.76
	Caesionidae Unid. sp.	0.37	1.96	–	–
	Callionymidae Unid. sp.	0.03	1.96	–	–
	Carid	0.04	9.80	0.30	14.29
	Coral	7.72	1.96	4.18	4.76
	Crab	6.90	13.73	0.02	4.76
	Crustacea	0.04	1.96	<0.01	4.76
	Digested remains	0.10	1.96	–	–
	Empty	–	37.80	–	0.00
	Gerres oblongus	0.11	1.96	–	–
	Gobiidae Unid. sp.	0.74	1.96	–	–
	Hypoatherina ovalaua	–	–	2.97	14.29
	Isopod	–	–	0.11	4.76
	Monocanthidae Unid. sp.	–	–	0.11	4.76
	Myctophidae Unid. sp.	–	–	0.30	4.76
	Myripristis sp.	–	–	9.70	4.76
	Mysids	0.02	1.96	–	–
	Natantid	0.01	1.96	–	–
	Octopus sp.	–	–	0.04	4.76

(Table continued on next page.)

Table 19. Cont'd

Species	Prey type	No light Wt%	No light F%	Light Wt%	Light F%
	Pebbles	0.44	1.96	–	–
	Penaeid Prawn	0.03	1.96	–	–
	Penaeus sp.	1.09	1.96	–	–
	Plant matter	<0.01	1.96	–	–
	Pomacentridae Unid. sp.	0.54	1.96	–	–
	Priacanthidae Unid. sp.	–	–	0.75	4.76
	Rhabdamia sp.	0.41	1.96	–	–
	Scyllaridae Unid. sp.	–	–	0.64	14.29
	Sergestidae Unid. sp.	–	–	0.03	4.76
	Spratellodes delicatulus	6.55	7.84	13.03	14.29
	Spratelloides sp.	8.84	9.80	–	–
	Squilla sp.	–	–	0.18	14.29
	Stegastes nigricans	12.66	1.96	–	–
	Encrasicholina punctifer	1.13	5.88	66.20	71.43
	E. punctifer larvae	–	–	0.34	9.52
	Stomatopod	–	–	0.05	4.76
	Teleost larvae	–	–	2.02	4.76
	Teleost remains	45.13	84.31	6.94	4.76
Total prey weight		87.396 g		193.327 g	
Caranx sexfasciatus	Acanthuridae Unid. sp.	–	–	5.57	29.17
	Alphaeid	–	–	0.08	4.17
	Apogon sp.	–	–	1.08	4.17
	Balistidae Unid. sp.	–	–	1.04	16.67
	Crab	–	–	0.15	4.17
	Crustacea	–	–	0.02	8.33
	Empty	–	84.62	–	0.00
	Gerreidae Unid. sp.	52.56	25.00	–	–
	Herklotsichthys quadrim.	–	–	4.44	8.33
	Hypoatherina ovalaua	17.83	25.00	0.84	4.17
	Isopod	–	–	0.06	4.17
	Myctophidae Unid. sp.	–	–	2.37	20.83
	Myripristis sp.	9.61	25.00	9.44	33.33
	Panilurus sp.	–	–	0.04	4.17
	Pomacentridae Unid. sp.	–	–	0.29	4.17
	Priacanthus sp.	–	–	5.18	33.33
	Sargocentron sp.	–	–	0.34	4.17
	Scyllaridae Unid. sp.	–	–	0.42	4.17
	Sea grass	–	–	0.02	4.17
	Spratelloides sp.	6.65	25.00	-	-
	Squid	–	–	0.07	4.17
	Squilla sp.	–	–	0.38	4.17
	Encrasicholina punctifer	–	–	38.05	66.67

(Table continued on next page.)

Species	Prey type	No light Wt%	No light F%	Light Wt%	Light F%
	E. punctifer larvae	–	–	0.08	4.17
	Teleost remains	12.38	75.00	29.78	83.33
	Tetraodontidae Unid. sp.	–	–	0.26	4.17
	Unknown	0.98	25.00	–	–
Total prey weight		5.430 g			123.283 g
Decapterus macarellus	Empty	–	–	–	0.00
	Fish scales	–	–	23.00	20.00
	Spratelloides delicatulus	–	–	75.05	80.00
	E. punctifer larvae	–	–	1.94	20.00
Total prey weight		–	–	0.926 g	–
Decapterus macrosoma	Empty	–	100.00	–	–
Scomberoides lysan	Atherinidae Unid. sp.	0.52	2.04	–	–
	Carid	–	–	0.18	33.33
	Copepods	0.34	2.04	–	–
	Crab	0.02	2.04	–	–
	Crustacea	5.79	12.24	–	–
	Empty	–	61.72	–	0.00
	Fish scales	0.12	4.08	–	–
	Hypoatherina ovalaua	12.05	4.08	–	–
	Mysid	39.08	55.10	–	2.26
	Natantid	0.25	2.04	–	–
	Spratelloides delicatulus	–	–	97.56	66.66
	Spratelloides sp.	4.84	2.04	–	–
	Squilla sp.	3.23	6.12	–	–
	Stomatopod larvae	13.69	6.12	–	–
	Teleost remains	13.97	12.24	–	–
	Teleost larvae	0.69	2.04	–	–
	Zooplankton	5.41	8.16	–	–
Total prey weight		6.523 g		4.387 g	
Selar crumenopthalmus	*Apogon* sp.	–	–	8.40	33.33
	Carid	100.00	100.00	–	–
	Chaetodon sp.	–	–	4.58	33.33
	Crustacea	–	–	49.75	33.33
	Empty	–	85.71	–	50.00
	Mysid	–	–	37.27	33.33
Total prey weight		0.003 g		1.202 g	

(Table continued on next page.)

Table 19. Cont'd

Species	Prey type	No light Wt%	No light F%	Light Wt%	Light F%
DUSSUMIERIIDAE					
Dussumieria Sp. A	Carid	–	–	82.05	100.00
	Crab megalopa	–	–	15.90	100.00
	Empty	–	–	–	0.00
	Squilla sp.	–	–	1.03	25.00
	Stomatopod	–	–	1.03	25.00
Total prey weight		–	0.195 g		
ECHENEIDAE					
Echeneis naucrates	*Amblygaster sirm*	–	–	23.91	20.00
	Atherinomorus lacunosus	–	–	1.93	20.00
	Bregmaceros sp.	–	–	0.88	40.00
	Carid	–	–	3.38	100.00
	Empty	–	–	–	0.00
	Gobiidae Unid. sp.	–	–	4.92	40.00
	Hypoatherina ovalaua	–	–	4.81	40.00
	Crab megalopa	–	–	0.21	40.00
	Myripristis sp.	–	–	0.93	40.00
	Octopus sp.	–	–	2.64	20.00
	Plant matter	–	–	6.92	60.00
	Pomacentridae Unid. sp.	–	–	1.15	20.00
	Pomacentrus pavo	–	–	1.86	40.00
	Sergestidae Unid. sp.	–	–	0.66	40.00
	Spratelloides delicatulus	–	–	38.67	40.00
	Squilla sp.	–	–	2.85	20.00
	Encrasicholina punctifer	–	–	1.69	40.00
	E. punctifer larvae	–	–	0.95	40.00
	Teleost remains	–	–	0.29	40.00
	Teleost larvae	–	–	1.19	40.00
Total prey weight		–	30.255 g		
GERREIDAE					
Gerres argyreus	Empty	–	100.00	–	–
HOLOCENTRIDAE					
Myripristis murdjan	Brachyuran larvae	100.00	100.00	–	–
	Empty	–	0.00	–	–
Total prey weight		0.003 g	–		

(Table continued on next page.)

Table 19. Cont'd

Species	Prey type	No light Wt%	No light F%	Light Wt%	Light F%
Sargocentron spiniferum	Alphaeid	0.57	33.33	–	–
	Crab	4.39	66.66	–	–
	Digested remains	4.01	66.66	–	–
	Empty	–	0.00	–	–
	Gastropod	38.74	66.66	–	–
	Green algae	0.19	33.33	–	–
	Portunid crab	52.10	33.33	–	–
Total prey weight		0.524 g	–		
LABRIDAE					
Choerodon anchorago	Empty	–	100.00	–	–
Thalassoma lunare	Empty	–	100.00	–	–
LETHRINIDAE					
Lethrinus elongatus	Blennidae Unid. sp.	12.80	20.00	–	–
	Crab	2.96	20.00	–	–
	Crustacea	1.98	20.00	–	–
	Digested remains	4.01	60.00	–	–
	Empty	–	16.67	–	–
	Holothurian	3.29	20.00	–	–
	Natanid	0.16	20.00	–	–
	Pebbles	14.24	40.00	–	–
	Portunid crab	1.98	20.00	–	–
	Teleost remains	53.56	60.00	–	–
	Xanthid crab	1.48	20.00	–	–
Total prey weight		2.429 g	–		
Lethrinus nebulosus	Bivalve	48.58	50.00	–	–
	Empty	–	60.00	–	–
	Gastropod	51.42	50.00	–	–
Total prey weight		0.212 g	–		
Lethrinus ramak	Bivalve	20.83	100.00	–	
	Crab	2.60	100.00	–	–
	Digested remains	61.98	100.00	–	–
	Empty	–	60.00	–	–
	Polychaeta	14.58	100.00	–	–
Total prey weight		0.384 g	–		

(Table continued on next page.)

Table 19. Cont'd

Species	Prey type	No light Wt%	No light F%	Light Wt%	Light F%
Monotaxis grandoculus	Empty	–	100.00	–	–
LUTJANIDAE					
Aprion virescens	Empty	–	100.00	–	–
Lutjanus bohar	Crab	100.00	100.00	–	–
	Empty	–	83.33	–	–
Total prey weight		2.914 g	–		
Lutjanus fulvus	Carid	4.74	16.67	–	–
	Crab	62.38	50.00	–	–
	Crustacea	19.77	16.67	–	–
	Empty	–	53.85	–	–
	Teleost remains	13.10	33.33	–	–
Total prey weight		1.244 g	–		
Lutjanus gibbus	Anomuran	6.66	11.11	–	–
	Crab	49.29	55.56	–	–
	Empty	–	40.00	–	–
	Gastropod	27.62	44.44	–	–
	Portunid crab	2.69	11.11	–	–
	Sea grass	0.64	11.11	–	–
	Seed pod	0.21	33.33	–	–
	Teleost remains 0.14	11.11	-	–	
	Vegetable matter	0.07	11.11	–	–
	Xanthid crab	12.68	11.11	–	–
Total prey weight		1.412 g	–		
Lutjanus kasmira	Carid	0.31	10.53	–	–
	Crab	31.89	42.11	–	–
	Crustacea	12.46	26.32	–	–
	Digested remains	1.39	21.05	–	–
	Empty	–	44.12	–	–
	Fish scales	3.02	15.79	–	–
	Gobiidae Unid. sp.	10.53	5.26	–	–
	Isopod	0.23	5.26	–	–
	Hermit crab	0.54	5.26	–	–
	Stomatopod	3.25	5.26	–	–
	Teleost remains 28.64	15.79	–	–	
	Unknown	7.74	10.53	–	–
Total prey weight		1.292 g	–		

(Table continued on next page.)

Species	Prey type	No light Wt%	No light F%	Light Wt%	Light F%
Lutjanus monostigma	Empty	–	100.00	–	–
Lutjanus russelli	Crab	6.58	100.00	–	–
	Empty	–	0.00	–	–
	Teleost remains	94.67	100.00	–	–
Total prey weight		0.076 g	–		
Lutjanus semicinctus	Empty	–	100.00	–	–
MULLIDAE					
Upeneus vittatus	Empty	–	–	–	0.00
	Mysid	–	–	6.50	100.00
	Spratelloides delicatulus	–	–	93.50	100.00
Total prey weight		–	0.200 g		
NEMIPTERIDAE					
Nemipterus peronii	Alphaeid	22.49	100.00	–	–
	Carid	1.78	100.00	–	–
	Crab	18.34	100.00	–	–
	Crustacea	31.95	100.00	–	–
	Empty	–	0.00	–	–
	Teleost remains	24.44	100.00	–	
Total prey weight		0.169 g	–		
SCOMBRIDAE					
Euthynnus affinis	*Apogon* sp.	–	–	2.27	100.00
	Empty	–	25.00	–	0.00
	Herklotsichthys sp.	–	–	9.58	100.00
	Spratelloides delicatulus	–	–	88.15	100.00
	Spratelloides sp.	48.89	33.33	–	–
	Teleost remains	51.11	66.66	–	–
Total prey weight		9.457 g	7.922 g		
Grammatorcynnus bilineatus	Anomurans	0.05	14.29	–	–
	Empty	–	22.22	–	–
	Gobiidae Unid. sp.	10.08	14.29	–	–
	Spratelloides sp.	38.95	42.86	–	–
	Teleost remains	50.20	42.86	–	–
Total prey weight		3.807 g	–		

(Table continued on next page.)

Table 19. Cont'd

Species	Prey type	No light Wt%	No light F%	Light Wt%	Light F%
Rastrelliger brachysoma	Amphipod	0.34	18.18	–	–
	Digested remains	9.66	90.91	–	–
	Empty	–	70.27	–	–
Total prey weight		2.040 g	–		
SERRANIDAE					
Aethaloperca rogaa	Empty	–	0.00	–	–
	Teleost	100.00	100.00	–	–
Total prey weight		0.196 g	–		
Cephalopholis argus	Digested remains	33.33	66.66	–	–
	Empty	–	25.00	–	–
	Fish scales	66.66	33.33	–	–
Total prey weight		0.012 g	–		
Cephalopholis cyanostigma	Empty	–	100.00	–	–
Epinephelus cyanopodus	Empty	–	100.00	–	–
Epinephelus fuscoguttatus	Empty	–	100.00	–	–
Epinephelus merra	Empty	–	100.00	–	–
Epinephelus tauvina	Empty	–	100.00	–	–
Plectropomus areolatus	Empty	–	87.50	–	–
	Teleost	100.00	100.00	–	–
Total prey weight		2.540 g	–		
SPHYRAENIDAE					
Sphyraena barracuda	Empty	–	66.66	–	–
	Teleost remains	100.00	100.00	–	–
Total prey weight		0.710 g	–		
Sphraena flavicauda	Acanthuridae Unid sp.	10.27	50.00	–	–
	Empty	–	0.00	–	0.00
	Hypoatherina ovalaua	49.30	50.00	–	–
	Spratelloides delicatulus	–	–	79.75	33.33
	Teleost remains	40.43	100.00	20.25	66.66
Total prey weight		2.347 g	0.237 g		

(Table continued on next page.)

Species	Prey type	No light Wt%	No light F%	Light Wt%	Light F%
Sphyraena forsteri	Acanthuridae Unid sp.	–	–	4.83	19.17
	Acanthurus triostegus	–	–	0.07	1.67
	Alphaeid	0.30	10.00	0.01	0.83
	Anguilliform	–	–	0.13	0.83
	Ariomma indica	–	–	0.26	10.00
	Balistidae Unid. sp.	–	–	0.26	4.17
	Caranx sexfasciatus	–	–	0.26	0.83
	Caranx sp.	36.12	10.00	0.12	0.83
	Carid	–	–	0.21	12.50
	Chaetodontidae Unid. sp.	–	–	0.14	0.83
	Crab	–	–	0.03	2.50
	Digested remains	–	–	<0.01	0.83
	Eel	–	–	0.75	5.83
	Empty	–	58.33	-	2.44
	Epinephelus sp.	–	–	0.23	0.83
	Herklotsichthys sp.	–	–	0.04	0.83
	Herklotsichthys quadrim.	–	–	6.24	9.17
	Insect	–	–	<0.01	0.83
	Mulloides flavolineatus	14.33	10.00	–	–
	Mullidae Unid. sp.	–	–	1.28	2.50
	Myripristis sp.	–	–	4.64	24.17
	Octopus sp.	–	–	0.02	0.83
	Panilurus sp.	–	–	0.05	1.67
	Priacanthus sp.	–	–	2.41	9.17
	Rhabdamia cypselurus	–	–	0.05	0.83
	Sargocentron sp.	–	–	0.98	6.67
	Scyllaridae sp.	–	–	0.48	4.17
	Spratelloides delicatulus	1.13	10.00	0.01	0.83
	Spratelloides sp.	1.16	10.00	–	–
	Squid	–	–	0.16	1.67
	Squilla sp.	–	–	0.64	26.67
	Encrasicholina punctifer	–	–	61.30	80.83
	E. punctifer larvae	–	–	0.05	4.17
	Stomatopod	–	–	0.04	2.50
	Teleost remains	46.96	50.00	14.29	55.00
	Tetraodontidae Unid. sp.	–	–	0.02	0.83
Total prey weight		10.376 g	431.652 g		
Sphyraena novaehollandiae	Acanthuridae Unid. sp.	–	–	0.09	3.23
	Apogon sp.	–	–	0.66	3.23
	Ariomma indica	–	–	2.69	25.81
	Balistidae Unid. sp.	–	–	0.63	6.45

(Table continued on next page.)

Table 19. Cont'd

Species	Prey type	No light Wt%	No light F%	Light Wt%	Light F%
	Carid	–	–	0.03	3.23
	Crab	–	–	0.03	3.23
	Crustacea	–	–	0.02	3.23
	Myctophidae Unid. sp.	–	–	7.00	12.90
	Myripristis sp.	–	–	6.70	19.35
	Priacanthus sp.	–	–	1.13	3.23
	Squid	–	–	0.17	3.23
	Squilla sp.	–	–	0.10	6.45
	Encrasicholina punctifer	–	–	65.82	96.77
	E. punctifer larvae	–	–	0.04	3.23
	Teleost remains	–	–	14.89	58.06
Total prey weight		–	–	102.656 g	

The stomach contents of 719 fish of 56 taxa were analysed. The prey items consumed by each species are given in Table 19, which has been arranged to show those prey types consumed from fish collected under natural conditions (No light) and from those collected from around artificially illuminated conditions (Light), i.e. while using lights to attract baitfish.

Predation on Baitfish

The prey taxa considered as baitfish for this analysis are those from the families Clupeidae, Dussumieriidae, Atherinidae, Apogonidae and Engraulidae.

Predators of baitfish under natural conditions

From a total of 486 fish that were caught under natural conditions 254 (52.2%) had empty stomachs. Fish species identified as predators of baitfish collected under natural conditions and the percentage contribution by dry weight of baitfish species in their diets are shown in Table 20.

Under natural conditions no species in this study preyed on the sardine, *Amblygaster sirm*, or the herring, *Herklotsichthys quadrimaculatus*. The primary baitfish species in the diets were the sprat, *Spratelloides delicatulus*, and the hardyhead, *Hypoatherina ovalaua* (Table 19).

In a similar study in Solomon Islands (Blaber et al. 1990a) fish were classed as major predators (>10% baitfish in diet) and minor predators (<10% baitfish in diet). Using this method, *Strongylura incisa*, *Sphyraena flavicauda*, *Euthynnus affinis*, *Caranx melampygus* and *Scomberoides lysan* would all be classed as major predators of baitfish, with *Caranx sexfasciatus* and *Sphyraena* being classified as minor predators. In the Solomon Islands study, only two specimens of *Grammatocynnus bilineatus* were collected and they showed no signs of baitfish in their diets. Other species in the Solomon Islands study that were classed as baitfish predators, which were also analysed in this study, were *Tylosurus acus* (minor), *Tylosurus crocodilus* (major), *Caranx ignoblis* (minor), *Caranx papuensis* (minor), *Selar crumenopthalmus* (major), *Lutjanus fulvus* (major), *Lutjanus gibbus* (minor) and *Sphyraena barracuda* (major). In this study either the sample sizes of these species were small, or their stomach contents contained teleost fish remains which could

Table 20. The percentage of baitfish (by weight) in the natural diet of major predators in Kiribati.

Species	Baitfish in diet (%)
Strongylura incisa	82.11
Sphyraena flavicauda	49.30
Euthynnus affinis	48.89
Grammatocynnus bilineatus	38.95
Caranx sexfasciatus	24.48
Caranx melampygus	22.80
Scomberoides lysan	17.05
Sphyraena forsteri	2.29

not be identified to species level, or their stomachs were empty. It is therefore conceivable that these species may well be predators of baitfish in Kiribati but could not be identified as such from this study.

One point of interest was the appearance of the oceanic anchovy, *Encrasicholina punctifer*, in the diets of three individuals of the blue-fin trevally, *Caranx melampygus*. As the anchovy has never been recorded in baitfish catches made inside the lagoons of Kiribati it must be assumed that they do not enter them and were consumed on the ocean side of the islands. The trevallies that had eaten the anchovy were caught inside the lagoons which suggests movement of this predator into and out of the lagoons.

Predators of baitfish under artificial conditions

A total of 233 fish was caught around the artificial light. Only six (2.6%) had empty stomachs.

It should be noted that the sample sizes of some of the predators were small or consisted of only one specimen, e.g. *Carangoides ferdau* (Table 19).

Many of the above predators were captured in bouke-ami operations that took place on the ocean side of Tarawa Lagoon (see section on Improvements to Fishery) rather than inside the lagoon where commercial baitfishing operations usually take place. On this occasion, *Encrasicholina punctifer* were captured in large numbers and this species makes up a large component of the baitfish consumed by some of the predators, e.g. *Sphyraena forsteri*, *Sphyraena novaehollandiae*, *Caranx melampygus* and *Caranx sexfasciatus* (Table 21).

Another important point to note from fish caught under artificial conditions is the numbers of juvenile reef-associated fish species that are consumed. Juveniles of taxa from the families Acanthuridae, Holocentridae, Pomacentridae, Priacanthidae, Balistidae, Chaetodontidae, Serranidae and Mullidae were all found in the stomach contents of fish caught around the lights (Table 19).

Natural conditions versus artificial conditions

The percentage of empty stomachs in fish caught under natural conditions is far greater than in those caught under artificial conditions (52.2% and 2.6%) respectively. The underwater lights set up a situation where fish are attracted to the baitfish and other animals that have been aggregated and feed upon them voraciously.

Table 21. The predator species of baitfish collected under artificial light conditions and the percentage contribution by dry weight of baitfish species in their diets.

Species	Baitfish in diet (%)
Euthynnus affinis	100.00
Carangoides ferdau	100.00
Scomberoides lysan	96.60
Upeneus vittatus	93.50
Caranx melampygus	83.25
Sphyraena flavicauda	79.95
Decapterus macruellus	76.99
Echeneis naucrates	71.96
Sphyraena forsteri	66.57
Sphyraena novaehollandiae	66.52
Selar crumenopthalmus	61.70
Caranx sexfasciatus	44.44
Caranx papuensis	34.62
Tylosurus sp.	11.15

Although only a few species were caught under both natural and artificial conditions, comparison of the quantities of food taken under both conditions indicates the increased consumption of food that takes place around baitlights. The mean amount of food taken per species, calculated as total dry weight of food consumed divided by the number of fish sampled minus the number of fish with empty stomachs, from around light and from natural conditions, is shown in Table 22.

Table 22. Mean dry weight food items from stomach contents in fish from natural and baitlight feeding situations.

Species	Natural mean dry wt (g)	Baitlight mean dry wt (g)
Caranx melampygus	1.710	9.210
Caranx sexfasciatus	1.360	5.150
Scomberoides lysan	0.130	1.740
Selar crumenopthalmus	0.003	0.480
Euthynnus affinis	3.150	7.922
Sphyraena forsteri	1.038	3.630
Caranx papuensis	6.030	0.078
Sphyraena flavicauda	1.170	0.079

There was no significant difference in the size of fish sampled for each species between natural and artificial conditions. Apart from *Caranx papuensis* and *Sphyraena flavicauda*, for which sample sizes were small, the mean amount of food consumed around baitlights is at least two times greater than under natural conditions.

Possible effects of baitfishing on subsistence fisheries

The concern that commercial baitfishing causes a reduction in the amount of forage available for desirable predatory species is one that has been frequently voiced in Pacific Island countries where there have been active pole-and-line fisheries (Lewis et al 1983; Nichols and Rawlinson 1990). Te Mautari Limited encountered considerable antagonism while collecting wild tuna baitfish on many atolls and has been forced to pay fees (Zann 1983). One of the main concerns voiced by the outer island councils was that the commercial baitfishing activities deplete the source of food for larger species, thereby indirectly reducing the abundance of the larger species (Ianelli 1988).

From this study (although not comprehensive), the major predators of baitfish species, under natural conditions, are those from the families Carangidae, Sphyraenidae, Scombridae and Belonidae. Only the mackerel tuna, *Euthynnus affinis*, fed exclusively on baitfish; all other fish consumed other prey types in addition to baitfish. The general assumption and concern of local people are that if there is a reduction in baitfish numbers caused by baitfishing then predatory species might find a shortage of food and move to other areas in search of prey. This could have an effect on the subsistence fishery if these species were an important component of it. However, most piscivorous fish are essentially opportunistic (Lowe-McConnell 1987) and their diets are largely determined by prey availability and the size relationship between predator and prey (Alexander 1967; Kakuda and Matsumoto 1978; Davis 1985).

A number of fisheries surveys have been carried out in Kiribati to assess the levels of fishing, the composition of the fish catch, the areas fished, etc. A comprehensive list of these reports can be found in Gillett et al. (1991) under the Statistics section.

In a review of fisheries surveys carried out in South Tarawa from 1976 to 1987, Mees (1987) found that the species compositions of catches of marine resources by local fishermen and fisherwomen over this time period were similar. Mollusca (approximately 30%) tend to make up the single most important taxa, with species from the family Scombridae (approximately 20%). The scombrid catch primarily consists of skipjack tuna, *Katsuwonis pelamis*, and yellowfin tuna, *Thunnus albacares*, caught in oceanic waters. From the lagoon, species from the family Albulidae (bonefish) are the most important, followed by snappers and emperors (lutjanids and lethrinids) which each represent about 10% of the catch. Of the families of baitfish predators Carangidae made up less than 4% of the catches (except in one survey carried out in November 1986, when its contribution was estimated to be 12.1%); Sphyraenidae made up 0.1% of the catch at the very most; and Belonidae were not recorded making a contribution to the catches. More recent surveys of South Tarawa (Kiribati Fisheries Division 1989) concur with the fact that species from the families Belonidae, Carangidae and Sphyraenidae make up only a small proportion of the catch. Baitfish predator families are also only a small component of the local catches in the other important baitfishing sites: Butaritari (Mees 1985; Kiribati Fisheries Division 1989), Abaiang (Taniera 1988) and Abemama (Mees 1986; Kiribati Fisheries Division 1989).

From the evidence available it would seem that a reduction in the numbers of baitfish caused by commercial fishing operations, even allowing for a pre-conceived movement of predatory fish to other areas for forage, is going to have little effect on subsistence fishermen. The adult fish removed as a direct result of baitfishing as by-catch of the bouke-ami operations are also primarily from the same families. Therefore any reported reduction in catches of fish within the lagoons, unless directly referring to species from the families Carangidae, Sphyraenidae and Belonidae, and the species *Euthynnus affinis*, are likely to be more attributable to direct fishing effort or changes in physical conditions in the lagoons than to the extraction of baitfish or predatory fish by commercial pole-and-line vessels.

During the period of the survey large amounts of *Spratelloides delicatulus* were present in Butaritari lagoon. At the same time many large schools of fish were observed actively feeding on these sprats. The schools were primarily of *Euthynnus affinis* that proved extremely difficult to catch as the schools would dive as soon as the boat approached. Local fishermen in the area also reported problems in catching this species despite their abundance in the lagoon. At the same time schools of carangids (particularly *Caranx melampygus*) were observed feeding on baitfish and they were much more easily caught on trolling lines.

From a similar study in Solomon Islands (Blaber et al. 1990a), it was concluded that unless there is a marked increase in trolling (the towing of lures or baits on a line behind a boat) among subsistence fishermen, there is little likelihood of a significant direct trophic interaction between the subsistence fishery and the commercial tuna baitfishery. A 'snap-shot' of the relevance of this conclusion to the situation in Tarawa is shown in the results of a fishing competition held during the course of the project (see Appendix 1). Fish from the families Carangidae and Sphyraenidae, which have been identified as predators of baitfish in Kiribati, were also only taken using trolling lines.

Appendix 1

Tarawa Lagoon Fishing Competition

A fishing competition was held in Tarawa Lagoon on Saturday, 2 March 1991. The competition was arranged so that fish could be landed to a weighing-in area where they were identified, measured and weighed, and their stomachs removed and preserved for later analysis.

Methods

Advertisements of the competition were posted around Tarawa in banks, supermarkets and other public areas. Radio messages were also announced over Radio Kiribati. Every effort was made to encourage as many people as possible to join in the competition and make them aware of the prizes to be won.

Ten prizes of $25 worth of fishing gear were put on offer. Each prize was for a different section. The sections were divided by fishing method, sex of fishermen and age of fishermen, in an attempt to attract men, women and children to join the competition.

Entry forms were also left in banks, shops, etc. and included rules for the competition. Prospective competitors were encouraged to complete these forms before the event in order to assess the number of fishermen expected so that the appropriate manpower required to process fish at the weigh-in could be estimated. Entry forms were typed onto one sheet of A4 paper, one side written in English and the other in I-Kiribati.

The competition started at 06.00 hours on Saturday, 2 March 1991 and finished at 15.00 hours on the same day, by which time all fish were to be weighed-in at a central landing area, the Ambo Lagoon Club. Fishermen were trusted not to start before the given time and were to confine their fishing effort to Tarawa Lagoon itself and not go out into the ocean. The rules of the competition also stated that the only fishing methods allowed were hook and line, i.e. droplining and trolling. The use of gill-nets, longlines, etc. was prohibited.

Every fish landed was identified to species level, measured and weighed, and stomachs removed and preserved in 10% formaldehyde. Fish weighed-in after 15.00 hours were also processed in this way.

Results

A total of four motorised boats carrying fourteen men and one boy, and two paddle canoes with one man each were entered in the competition. Those fishermen in the motorised boats used both droplining and trolling techniques, whereas the men in the paddle canoes restricted themselves to dropline fishing. Seventy-five per cent of the entrants were I-Kiribati and the remainder expatriates.

The total number of fish caught was 132 with a total weight of 106.837 kg. Droplining accounted for 84.4% by numbers and 29.2% by weight of the catch (Table 23) with trolling acounting for the remaining 15.2% and 70.8% by number and weight respectively. *Lethrinus obsoletus (ramak)* and *Epinephelus merra* were the most dominant species caught by droplining and *Caranx melampygus* was the most numerous species caught by trolling.

Conclusions

The competition was successful because it encouraged fishermen to return their catch to a location for a weigh-in where stomachs could be removed for later analysis in an attempt to identify baitfish predators in Tarawa Lagoon. The number of entrants in the competition was, however, very disappointing and therefore the number of fish samples collected was limited. Although effort was made through posters and radio messages to advertise the competition this was obviously not sufficient to encourage large numbers of fishermen to enter. If the exercise is to be repeated then additional methods to publicise the event should be undertaken, e.g. announcements through the church, invitations to scout groups, etc. With larger numbers of entrants larger quantities of fish could be expected. Not only could this provide samples for dietary analysis but data from such an event would give a good indication of the importance of different species caught by the different fishing methods. Such details would be very useful to supplement the information collected through the questionnaire surveys carried out by Fisheries Division.

Table 23. The number and weight of each species caught during a fishing competition in Tarawa Lagoon on 2 March 1991 (Wt = weight in g).

Species	Dropline		Trolling		Total	
	N	Wt (g)	N	Wt (g)	N	Wt (g)
BALISTIDAE						
B. undulatus	1	1 460	–	–	1	1 460
P. flavimarginatus	1	360	–	–	1	360
R. aculeatus	120	–	–	1	120	
S. chryopterus	2	191	–	–	2	191
CARANGIDAE						
C. melampygus	–	–	12	28 380	12	28 380
GERREIDAE						
G. argyreus	1	350	–	–	1	350
HOLOCENTRIDAE						
S. spiniferum	4	685	–	–	4	685
LABRIDAE						
C. anchorago	1	76	–	–	1	76
T. lunare	1	50	–	–	1	50
LETHRINIDAE						
L. elongatus	6	7 555	–	–	6	7 555
L. obsoletus (ramak)	39	12 075	–	–	12	12 075
M. grandoculus	1	1 160	–	–	1	1 160
LUTJANIDAE						
A. virescens	–	–	1	1 250	1	1 250
L. bohar	–	–	1	4 850	1	4 850
L. gibbus	7	2 185	–	–	7	2 185
L. kasmira	18	1 300	–	–	18	1 300
L. semicinctus	1	240	–	–	1	240
SERRANIDAE						
C. argus	5	1 425	–	–	5	1 425
E. fuscoguttatus	–	–	2	15 950	2	15 950
E. merra	23	1 915	-	-	23	1 915
P. areolatus	–	–	2	2 460	2	2 460
SPHYRAENIDAE						
S. barracuda	–	–	2	22 800	2	22 800
Total	112	31 147	20	75 690	132	106 837
Percentage by method	84.4	29.2	15.2	70.8		

Improvements to the Fishery

Summary

The major areas where significant improvements in baitfishing are possible:

- major sources of lost fishing time are identified, including late arrival at fishing grounds due to navigational difficulties and lack of or poor survival of bait (ways to reduce these effects are suggested);
- suggested improvements to the baitfishing technique, including the use of generator boats, echo-sounders and improved baitfish handling (methods to achieve these aims are outlined); and
- a method involving artisanal fishermen to increase the catch of tuna is proposed, the current state of its development outlined, and future research directions suggested.

During the course of the Baitfish project fieldwork a number of trips were undertaken on board pole-and-line vessels operating for Te Mautari Limited as well as a vessel carrying out tuna tagging work for the South Pacific Commission in Kiribati waters. From observations made during these trips and from experience on commercial vessels operating in Solomon Islands and Fiji, some suggestions are made for the improvement of the operations of Te Mautari Limited vessels in Kiribati.

Timing of Fishing Activities

Fishing ground arrival times

Following a trip on the South Pacific Commission research vessel *Te Tautai*, 6–12 October 1990, records were compiled of the number of tuna caught at different times of day during the cruise (Fig. 28). The results showed that fish were caught throughout daylight hours. Most fish were caught between 15.00 and 16.00 hours but this was from one school which responded well to the chum and relatively large numbers of tuna were caught. The next most productive time was in the early hours of the morning between 06.00 and 08.00. Fishing success, measured by the number of schools spotted compared to number of schools from which fish were caught, was also greater at this time of day (Fig. 29).

The results of time of day fished versus mean catch per school during the two years of the survey undertaken by FAO on *Nei Manganibuka* showed that catches in Kiribati waters are not governed greatly by the time of day (Walczak 1982). The one exception is from 08.00 to 10.00, when there is a slightly higher per cent total catch compared to the per cent total effort. The mean catch per school chummed during both years of the survey was remarkably constant at 250 kg. Mean catches per school chummed remained close to this average during all the time intervals except during 08.00–10.00 when the mean catch per school averaged 326 kg. It is interesting to note that during this survey, greater fishing success depended neither on dawn nor sundown schools. In fact, the results obtained fishing the former were lowest with a resulting catch rate of 202 kg/school and sundown schools where the average was 252 kg/school.

It can be concluded, therefore, that as long as a vessel is carrying suitable amounts of live baitfish it is possible to catch tuna during any of the daylight hours. This implies that the more time spent on the fishing grounds, the greater the chance of catching fish. The early hours of the morning seem to hold better chance of success than later in the day.

From observations made during the course of the Baitfish Project, Te Mautari Limited vessels did not reach the fishing grounds until after 08.00, primarily due to difficulties of navigating out of the lagoons during darkness after completing baitfishing operations. The vessels usually completed their tuna fishing activities so that they were anchored back in the baitground by mid-afternoon. This was sometimes due to the fact that all the baitfish had been used or because there were no schools of tuna present in the area.

This loss of fishing time could be reduced by the following changes.

Early departure from baiting grounds

If vessels were able to navigate out of the lagoon during darkness then they could be on the fishing grounds at dawn and therefore maximise utilisation of daylight hours for searching and catching tuna. The navigation problem could be alleviated in two ways. Firstly, good navigational beacons could be placed to mark the passages of the lagoon as well as between the most commonly used baiting positions and the entrances/exits to the lagoons. All the passages to the lagoons commonly used for baitfishing were not clearly marked and the captains all expressed reluctance to pass through them in darkness. The positioning of beacons which could be picked up on radar or illuminated by the use of powerful searchlights on the boats would facilitate the movement of vessels in and out of lagoons during the night.

Secondly, advanced navigational equipment could be installed on the vessels. None of the Te Mautari vessels had operating radar systems during the trips undertaken so there were no operational electronic navigational aids to assist movement through the passages of the lagoons. A properly working system would obviously assist this situation. The Global Positioning Systems (GPS) that utilise satellite technology are now so accurate, if set up and used correctly in conjunction with normal navigational procedures, they would enable the captains to navigate through the passages of the lagoon during the night.

In conjunction with the optimisation of the use of the daylight hours for searching and fishing, not enough effort was expended in looking for schools of fish from the flying bridge of the Te Mautari vessels. During the cruise on the *Te Tautai* two men were employed looking for schools with the aid of binoculars. In Solomon Islands this was always the case and it was not uncommon for four or five men to be searching at any one time. Te Mautari vessels seemed to have only one man undertaking this duty, usually the captain, and this was not on a full-time basis. The use of more men over longer periods of time can only increase the chances of locating schools of fish.

Increasing the survival times of the baitfish in the bait wells

If baitfish can be kept alive for two to three days inside the vessel bait wells then there may not be the need to return to the lagoon every night to collect baitfish. This will mean that the vessel can either drift or anchor on the ocean side of the lagoon, weather permitting. This will allow the vessel to move to the fishing ground at first light, especially if fishing around fish aggregating devices. Increased survival of baitfish could be achieved by the use of the hardy milkfish bait or, not as easily, conditioning of the wild bait species as mentioned earlier. These methods could be employed as alternative strategies to the normal practices of the pole-and-line vessels of the Te Mautari fleet.

Alternative Baitfish Species and Sites

Use of milkfish as bait

Te Mautari pole-and-line vessels have used milkfish as bait on only a few occasions during the last two seasons primarily because (a) milkfish are considered not to survive well in baitfish tanks, (b) milkfish are not considered an effective bait as tuna are not attracted to the boat by them, and (c) milkfish are expensive to purchase.

The results of previous studies on the use of milkfish in Kiribati (FAO 1983) and observations during the current project show that milkfish will survive well in bait wells for in excess of 3–4 days and act as an effective baitfish for tuna.

During a trip on the *Nei Kaneati* in 1989 milkfish were carried on board the vessel from Tarawa to Abemama. These milkfish survived in the bait wells for over 4 days. These fish were too large (20–30 cm) and did not act as effective bait as they swam away from the boat and the tuna were seen following them.

Small milkfish (5–15 cm) were loaded onto the *Te Tautai* during the trip in October 1990. These fish could be seen swimming back towards the boat and acted as effective chum by attracting and inducing the tuna into a feeding frenzy. When the stomach contents of some of the tuna caught were examined, the size of chum eaten was in the length range of 6–9 cm. These smaller-size milkfish also survived well in the bait wells when handled correctly.

During a second visit of *Te Tautai* to Kiribati a total of 350 buckets of milkfish was loaded on the vessel at Tarawa on 19 August 1991. The vessel then proceeded south, fishing on the way, and on 22 August was able to tag and catch in excess of 1000 individual skipjack tuna, south of Arorae Island. This position is well to the south of the normal fishing grounds of the Te Mautari fleet. During two further uses of milkfish in September 1991, fishing was successfully carried out on one occasion south of Arorae, and on the other west of Banaba. During the trip to Banaba the milkfish bait was used to catch tuna six days after it had been loaded at Tarawa (SPC, pers. comm.). The milkfish bait in these instances was used successfully to increase the operational range of the vessel.

The recent experiences of the South Pacific Commission with the use of milkfish in Kiribati waters (Itano, pers. comm.) are that (a) the the milkfish can be effective if delivered in graded sizes less than 15 cm, but are best between 8 and 12 cm, (b) their habit of running away from the boat when chummed can be limited if the bait is squeezed by the chummer prior to broadcast into the sea, (c) they are extremely hardy and lasted over one week on the vessel, (d) a majority of the bait from the fish farm appeared starved, skinny and in a very weakened condition (some were big-headed, cadaverous runts which may have been starved — if milkfish were to be used on a regular basis the quality of these fish would need to be improved), and (e) dead milkfish were effective if pinned onto the hooks of the fibreglass poles during times when the tuna were not actively biting the artificial lures. This was especially effective for the capture of large yellowfin. All dead milkfish bait was kept and utilised when this situation arose.

In conclusion it was considered that milkfish should be able to realise a profit for Te Mautari vessels during times when wild baitfish are scarce, as long as correct and careful handling procedures are carried out, both during transport and delivery to the boat, and once the fish are in the bait wells.

These results indicate that milkfish can be an effective baitfish species, both in terms of survival and attractiveness to tuna, if the right size fish are used and handled correctly. If milkfish 5–15 cm can be produced at an affordable price, then the production of milkfish of the optimal size should be encouraged in order to provide an alternate source of baitfish for the Te Mautari fleet when any of the following conditions arise: (a) there are limited amounts of natural bait available, (b) when natural baitfish are difficult to catch during the full moon, and (c) when tuna schools cannot be found at the usual fishing grounds and the vessels need to increase their range.

Capture of anchovies

During the trip on the SPC research vessel *Te Tautai*, the vessel anchored in 40 m outside the entrance to Tarawa Lagoon when deck-lights were seen to attract schools of *Herklotsichthys quadrimaculatus*. Underwater lights were lowered and normal baitfishing operations started. When the net was hauled, the catch comprised approximately 80 buckets of *H. quadrimaculatus* and *Encrasicholina punctifer*. Two further hauls were made that night for a total catch of 200 buckets.

Encrasicholina punctifer have been found in the diet of skipjack tuna from Kiribati (Kleiber and Kearney 1983) and were found in the natural diet of 36% of the tuna caught during the SPC trip. These anchovies are highly prized as one of the most effective baitfish species. They work well as chum and during the SPC cruise lasted 2–3 days in the bait wells, indicating that they are hardier species than some of the coral reef lagoon baitfish species.

Encrasicholina punctifer are oceanic, do not enter the lagoons in Kiribati and little is known of their distribution in open waters. However, as lack of suitable baitfish is one of the prime causes of lost fishing time (MacInnes 1990) further effort under certain circumstances could be expended in trying to catch this species.

If a vessel has enough bait to carry out fishing operations the next day but the capacity to hold more bait, it may be worthwhile for it to anchor on the ocean side of the closest island and operate the baitlights. If baitfish aggregate then a haul of the net may allow the capture of extra bait which may make a significant difference to the success of operations next day. This situation could arise if milkfish bait is being used and schools of tuna are in close proximity to a lagoon that cannot be entered for baitfishing, e.g. the southern-most islands of the Kiribati group. If catches of *E. punctifer*, or another baitfish species, were possible, this could significantly extend the period of time available for fishing a productive school of fish.

Baitfishing effort should not be concentrated in these areas, rather, they should be considered as alternative sites. It must be remembered that bait may not be present at all at certain times in these ocean-side positions, as was the case when an underwater light was set from the fisheries research vessel *Nei Tewenei* during one of the baitfish sampling trips to Butaritari.

Technical Improvements to Baitfishing Techniques

Use of generator boats

One of the major limitations to successful pole-and-line fishing in Kiribati has been the lack of baitfish for the following day's fishing. One of the current inefficiencies of baitfishing in Kiribati is that each vessel hauls on average less than twice each night (Table 4). If the number of hauls each night could be increased, the number of days fishing lost due to inadequate baitfish supplies may be significantly reduced.

In Solomon Islands, vessels have generator boats which operate additional underwater lights that attract fish at the same time that the pole-and-line vessel is catching bait. This enables the vessel to move to the site where the generator boat is lighting, after hauling its own net, and quickly make an additional haul of the bait aggregated there. The use of generator boats enables up to five hauls per night to be made when necessary. The pole-and-line vessels in that country rarely have less than a full complement of bait.

The use of a generator boat was trialled on three occasions in Kiribati during July and August 1990. The generator boat was a small (5 m) dinghy with a Yamaha EF2500 generator which powered a one kilowatt underwater light similar to that routinely used on Te Mautari vessels. A marine plywood cover was constructed to house the generator and protect it from the rain.

Method

The generator boat was towed to the baitfishing grounds in Butaritari and Abaiang for each trial. It was anchored in a good location chosen by the fishing master and then the pole-and-line vessel chose its own fishing position and both started lighting as darkness fell. While the generator boat had only the single underwater light, the pole-and-line vessel also had two powerful overhead lights illuminated as well.

After the lights had been working for sufficient time to attract baitfish, the pole-and-line vessel would haul its bouke-ami net. When this was completed, the pole-and-line vessel moved toward the generator boat, dropped anchor ahead of it and then went astern until both vessels came into contact. The stern underwater light on the pole-and-line vessel was then lowered and turned on. When this light was in position and operating, the generator boat's light was turned off and the bait moved and aggregated around the new light source. The pole-and-line vessel was then able to use its own light and net as for normal operations. Once the net had been hauled, both boats were repositioned and the operation repeated. In this way four hauls a night were made compared with the usual maximum of two.

Results

The results of the three trials are given in Table 24. They show that the use of a generator boat can be used to double baitfish effort with a corresponding increase in catches. Where baitfish were abundant during the trials (in Butaritari), the generator boat attracted similar amounts of bait to the main light on the pole-and-line vessel and the species composition attracted to both lights was similar.

The increase in effort is especially important in Kiribati during the nights of the month the catcher vessel is limited to making only one haul a night. A typical fishing pattern for pole-and-line boats in Kiribati is that after the full moon they are able to undertake two or maybe three hauls of the bait net because of the long dark nights. However, as the month progresses the number of moonlight hours increases and the haul of the bait net has to be delayed until later each morning. This comes to the stage where, around its first quarter, the moon does not set until 05.00 hours. If there is any moonlight there is little evidence of baitfish schooling around the light. It is not until after the moon sets that baitfish aggregate around the light in any numbers. Due to the limited hours of darkness bait hauls are restricted to an hour or two before dawn, during this period of the month,which only leaves tim for one operation. A generator boat would allow a second haul to be made during this phase of the moon prior to it becoming full, instead of the one which often barely produces enough baitfish to allow for tuna fishing that day.

Another advantage of using generator boats is that baitfishing effort can be spread over a larger area of the lagoon. On occasions, large catches of baitfish were taken on one night but the following night from the same position were caught in low numbers. This indicates that the schools of baitfish have moved to another area in the lagoon. A similar situation was witnessed during the course of the project when large samples of sardines were caught in gill nets set at the eastern end of Tarawa Lagoon whereas pole-and-line catches at the western end of the lagoon on the same night were negligible. Schools of baitfish are found in different parts of the lagoon at different times, and with the use of a generator boat two separate positions would be tested at the same time, increasing the chances of locating baitfish schools. This situation is only useful if the pole-and-line boat is able to navigate to the generator boat during darkness.

Table 24. The catch rate per set and species composition of baitfish caught during three trials of a generator boat in Kiribati during July and August 1990 (*catches from Butaritari; rest of hauls from Abaiang).

Trial	Haul	Catch from main boat (buckets)	Catch from generator boat (buckets)
1	1*	>100 mainly *S. delicatulus*	>100 mainly *S. delicatulus*
2	1	11 *A. sirm*	22 *A. sirm*
	2	15 *A. sirm/S. delicatulus*	9 *A. sirm/S. delicatulus*
	3	35 *A. sirm*	40 *A. sirm*
3	1	~25 *A. sirm*	1 *A. sirm*
	2*	>100 *S.delicatulus/H. quadrimaculatus*	>100 *S.delicatulus/H. quadrimaculatus*

Other points to note from the trials include the following.

(1) Transfer of bait from around the generator boat's light to the main light was not a smooth operation due to difficulties in manoeuvring the pole-and-line vessel alongside the generator boat. If the generator boat attached two large floats along the anchor line the crew could use a grapple from the front of the pole-and-line vessel to pull the two boats together. This would ensure that all baitfish aggregated around the generator boat's light are close to the pole-and-line vessel before the lights are changed.

(2) The generator boat should be fitted with a transformer to regulate the brightness of its underwater light so that there would be no need for the pole-and-line vessel to turn on its light. The generator boat could raise and dim its light and move inside the bouke-ami net and the baitfish would follow the light. The net could then be hauled around the generator boat. This would speed up the operation and ensure no baitfish were lost during the turning off and on of the two lights.

(3) A small two-way radio should be installed in the generator boat to enable the crew to talk with the fishing master on the pole-and-line vessel. On one occasion during the trials (trial 3, haul 1, Table 24), large quantities of bait were around the light of the generator boat for 4–5 hours but had dispersed by the time the pole-and-line vessel arrived.

(4) The generator boat used 10–12 litres of petrol to power the one kilowatt light for the whole night, making it a cost-efficient way to increase catches.

Use of echo-sounders

A technique used on the SPC research vessel *Te Tautai* reduced the time needed to haul the baitnet and allowed the movement of the bait to be monitored. This method could be used on Te Mautari vessels. It involved the use of two echo-sounders to monitor the movement of baitfish into the net. The echo-sounder connected to the transducer on the hull was used to monitor the build-up of baitfish during the lighting operation. Once it was considered that there was sufficient bait aggregated around the light, the bouke-ami net was set.

A long bamboo boom was extended out over the starboard side of the vessel with its end stretching above the middle of the baitnet. A baitlight was suspended from this boom. This light could be manoeuvred by a person standing next to the flying bridge using a series of pulleys and ropes. A similar arrangement was set up for a transducer to hang from the boom with the echo-sounder located in the wheel-house. After the light had been lowered to the desired depth in the middle of the net, it was turned on and all other baitlights extinguished. The transducer was set at the surface and the echo-sounder turned on. The movement of fish towards the light could be monitored by the disappearance of marks from around the vessel's main echo-sounder and the appearance of marks on the sounder above the light. The light could be raised and dimmed in order to maximise the amount of bait close to the light. When the fishing-master was sure that all bait had moved to the light, the command to haul the net was made.

This method worked well and the transfer of bait from the light under the vessel to that in the middle of the net could be closely monitored. The use of a skiff to manoeuvre the light was not required, which speeded up the operation. It also had the advantage that the baitfish deep underwater could be monitored coming to the light and only when all the bait had risen was the net hauled. This cannot be seen with the naked eye, especially if underwater viewfinders are not being used, as was the situation on Te Mautari vessels.

Conditions during the hauling of the baitnet are often very rough, making the movement of the light difficult using a skiff. The operation described above would be of great assistance during rough conditions. The time saved during the hauling operation would be especially important during those periods of the month when a generator boat is used and an increase in the number of hauls is required.

Baitfish handling

Bait mortality in the bait wells is one of the major problems of the pole-and-line tuna fishery in Kiribati (McInnes 1990). Part of this problem is due to the weak bait species such as *S. delicatulus*. This species has been documented in Kiribati as dying quickly after capture. However, a significant proportion of the bait mortality is due to fish losing scales during capture and transfer to the bait wells. The number of fish dying due to this cause could be reduced by several methods.

(1) Regularly mending all holes in the baitnet. Baitnets on Te Mautari vessels were observed to have many small holes which were large enough for fish to gill themselves causing terminal damage or at least increasing their stress. Basic net maintenance would ensure fewer fish died or were damaged by this method.

(2) At present, crowding of the fish prior to transfer to the bait wells is done in a haphazard manner. Crew members often retrieve too much net, causing it to dry, leaving baitfish struggling against the net. This increases scale-loss and decreases their chance of survival. A more coordinated approach is required to the drying of the net to ensure baitfish remain in water and are gently herded to the centre of the net prior to bucketing into bait wells.

(3) The overhead light positioned over the middle of the baitnet is the same one-kilowatt light used to attract bait. It illuminates an area much larger than the dried-up baitnet, which causes the bait to struggle wildly against the sides of the net. A smaller, dimmer light positioned over the centre of the net would get the baitfish to swim quietly around the centre of the net reducing abrasion and scale-loss.

(4) Te Mautari vessels use only small metal buckets for transfer of bait from the net to the baitwell. This not only slows down the procedure but the small buckets mean that the volume of water per fish is small, increasing scale-loss and further reducing chances of survival. A larger number of bigger-sized plastic buckets should be used, so that these difficulties are overcome.

Conclusions

All these technical modifications to the bouke-ami technique routinely used in Kiribati have the potential to increase the baitfish catch and the survival of the bait when caught. But as all are new concepts in Kiribati, the fishing masters will need to be encouraged to modify their practices so that the use of these methods becomes part of the regular baitfishing pattern.

The use of generator boats has the greatest potential to increase nightly catch rates. However, discussion with the fishing master following the trials showed that, while he agreed that there was great potential for increased catches, he would not start using a generator boat himself. His reluctance may stem from several reservations. As a new idea, it would take time to become familiar with the use of these boats to maximise the catches. The generator boat also had to be towed around during the trials and so was an extra burden for the captain above his normal duties. If the generator boat could be lifted on board, transferring the generator boat to new sites would be safer. Another reason for the reluctance to use the generator boat was the lack of shelter and place for a crew member to sleep. Future versions should try to include accommodation in their design so that the crew is adequately protected from the weather and can sleep, while watch is kept on the generator. The increased number of hauls will also reduce the amount of sleep crew may get and may meet some resistance.

The use of echo-sounders and improved baitfish handling will both improve the efficiency of the existing baitfishing operation and lead to improved catches per haul and better survival of the baitfish, once caught. These improvements will enable the pole-and-line vessels to range further looking for tuna schools, and to remain on the schools longer, once they have been located, as the amount of time spent catching bait will be reduced. Additionally, the number of days lost due to insufficient bait could be significantly reduced if generator boats are introduced.

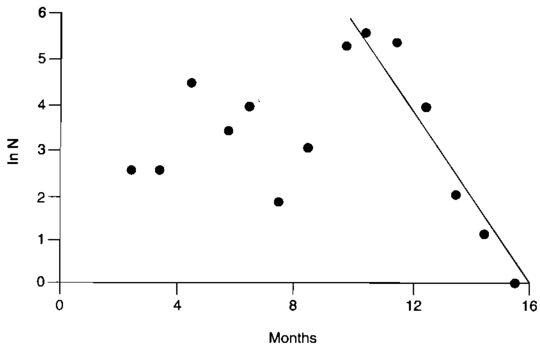

Fig. 1. The catch-at-age curve for *Amblygaster sirm* sampled from commercial baitfish catches during 1989 and 1990 (all sites combined).

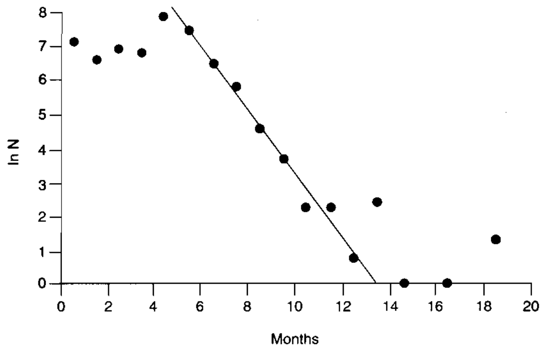

Fig. 2. The catch-at-age curve for *Herklosichthys quadrimaculatus* sampled from commercial baitfish catches during 1989 and 1990 (all sites combined).

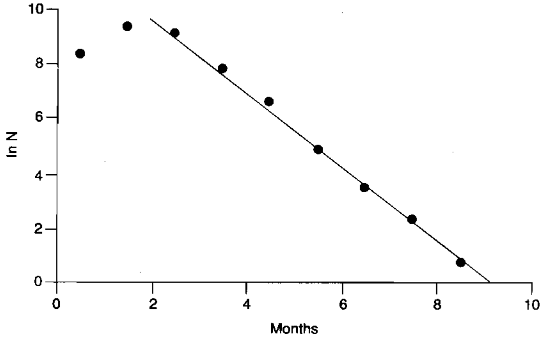

Fig. 3. The catch-at-age for *Spratelloides delicatulus* sampled from commercial baitfish catches during 1989 and 1990 (all sites combined).

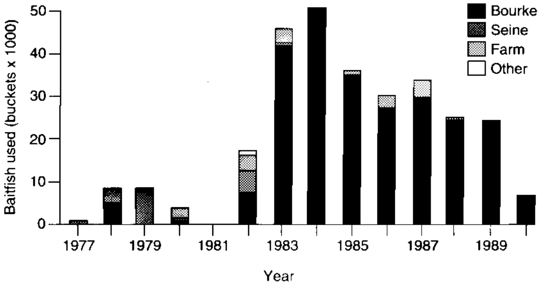

Fig. 4. Kiribati baitfishery 1977–1990, baitfish used per year by source.

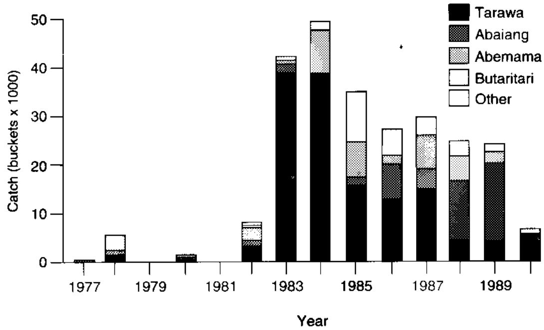

Fig. 5. Kiribati baitfishery 1977–1990, Bourke-ami catch by year by baitground.

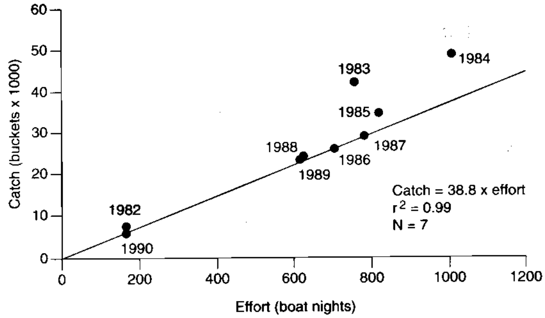

Fig. 6. Kiribati baitfishery, catch (buckets) vs effort (boat nights).

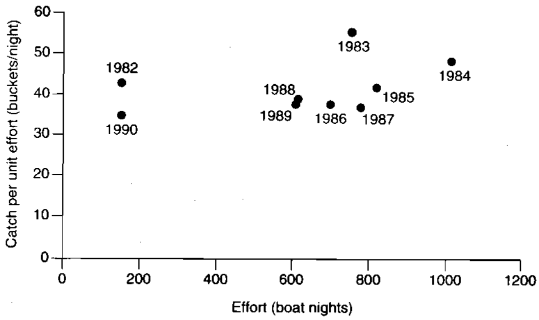

Fig. 7. Kiribati baitfishery, CPUE (buckets/night) vs effort (nights).

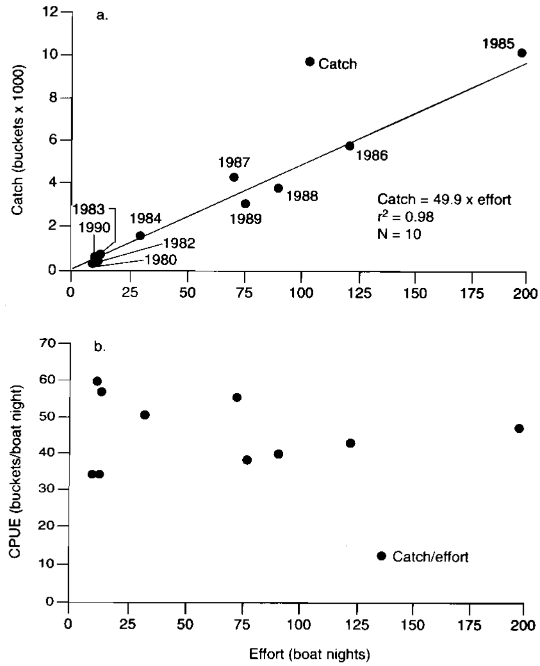

Fig. 8. Butaritari baitfish catch and effort (a) catch vs effort (b) catch per unit effort vs effort.

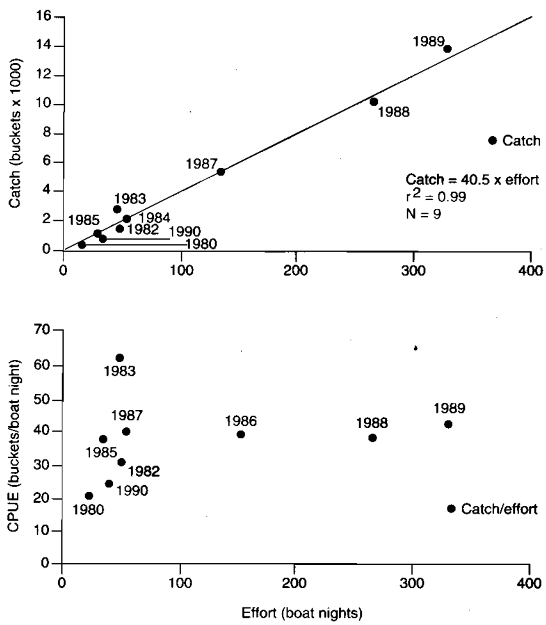

Fig. 9. Abaiang baitfish catch and effort, catch vs effort.

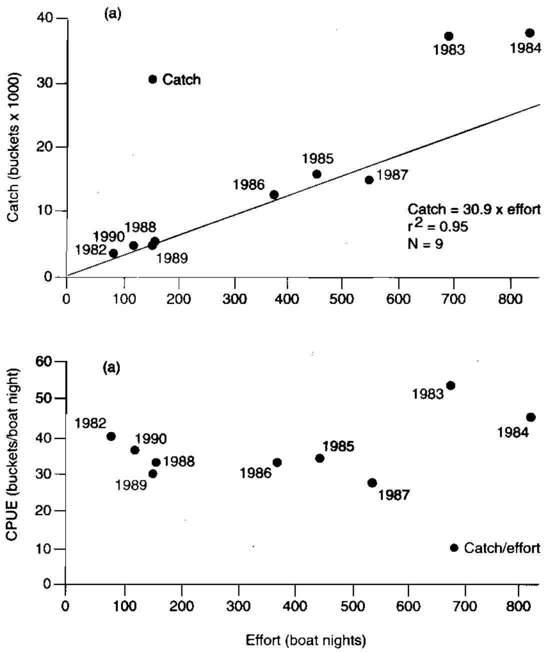

Fig. 10. Tarawa baitfish catch and effort (a) catch vs effort (b) catch per unit effort vs effort.

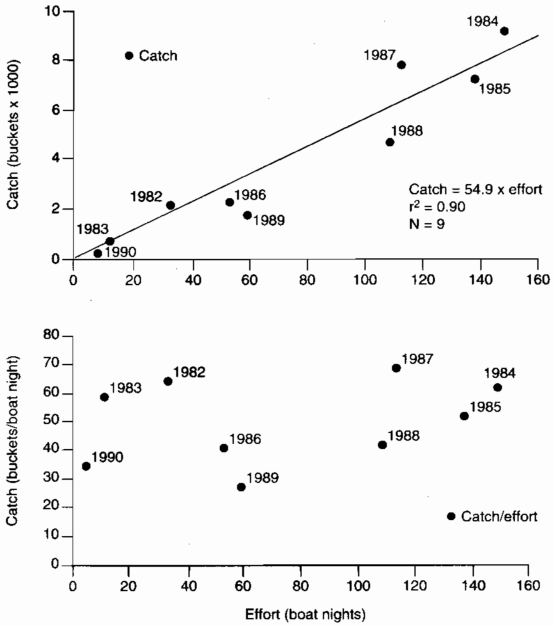

Fig. 11. Abemama baitfish catch and effort (a) catch vs effort (b) catch per unit effort vs effort.

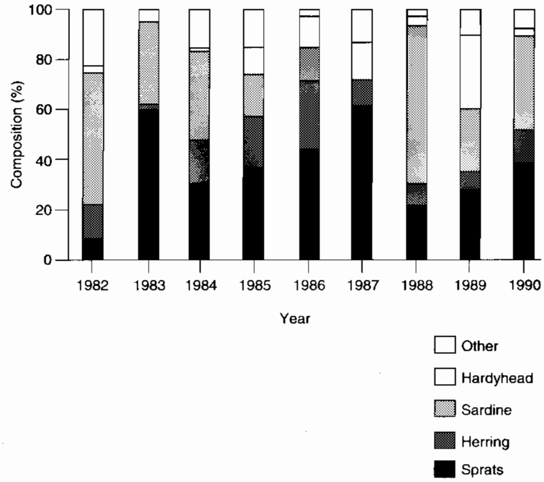

Fig. 12. Republic of Kiribati 1982–1990, baitfish species composition.

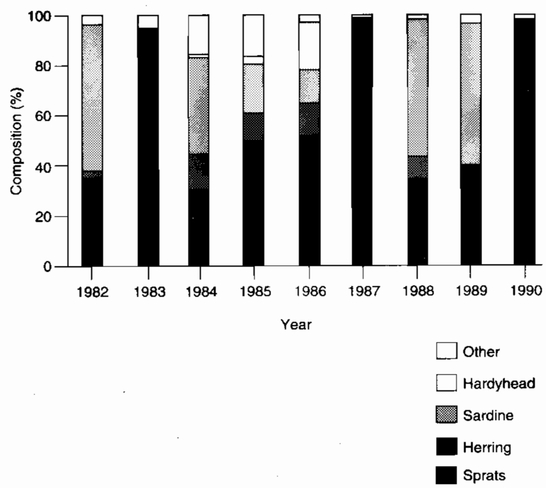

Fig. 13. Butaritari Lagoon 1982–1990, baitfish species composition.

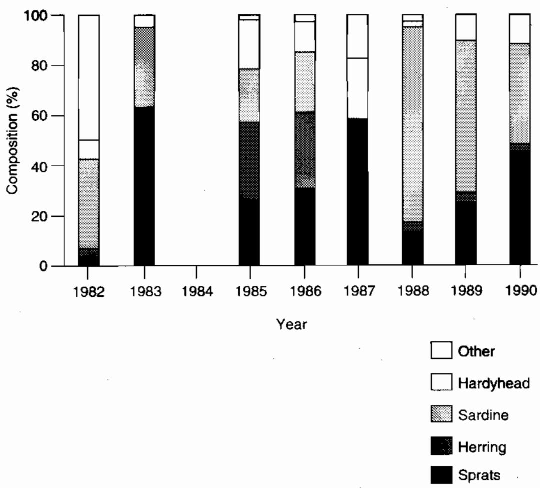

Fig. 14. Abaiang Lagoon 1982–1990, baitfish species composition.

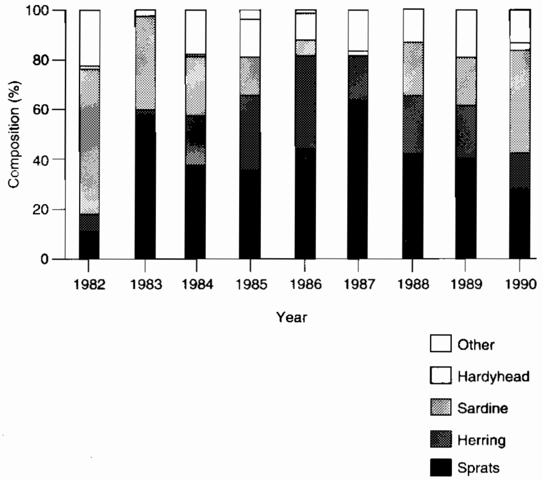

Fig. 15. Tarawa Lagoon 1982–1990, baitfish species composition.

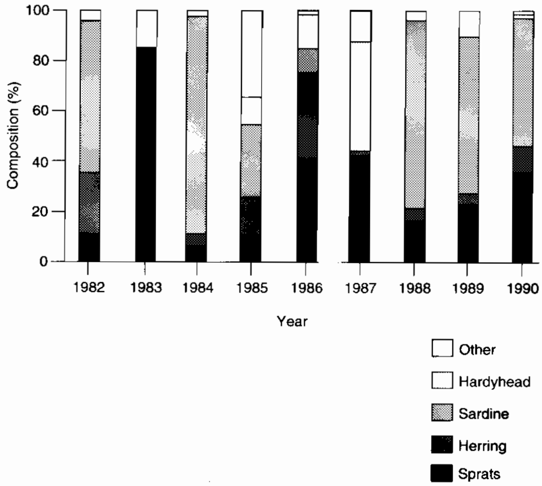

Fig. 16. Abemama Lagoon 1982–1990, baitfish species composition.

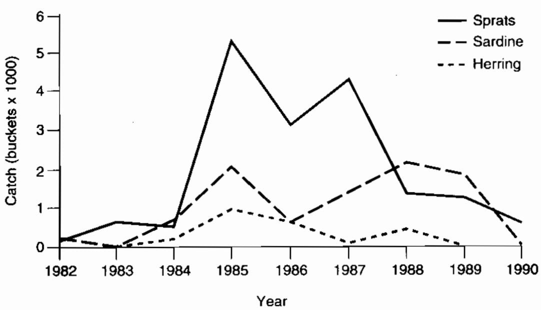

Fig. 17. Butaritari baitfish catch and effort, species catch by year.

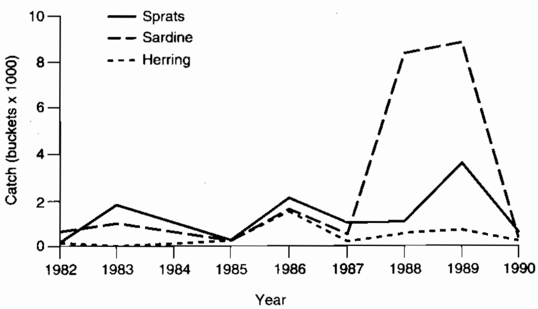

Fig. 18. Abaiang baitfish catch and effort, species catch by year.

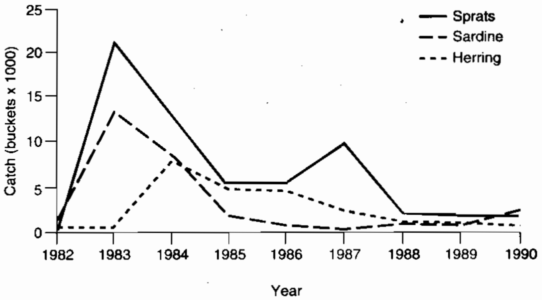

Fig. 19. Tarawa baitfish catch and effort, species catch by year.

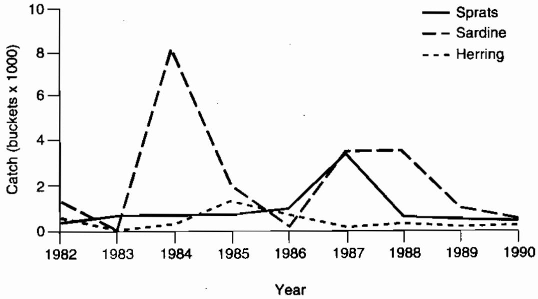

Fig. 20. Abemama baitfish catch and effort, species catch by year.

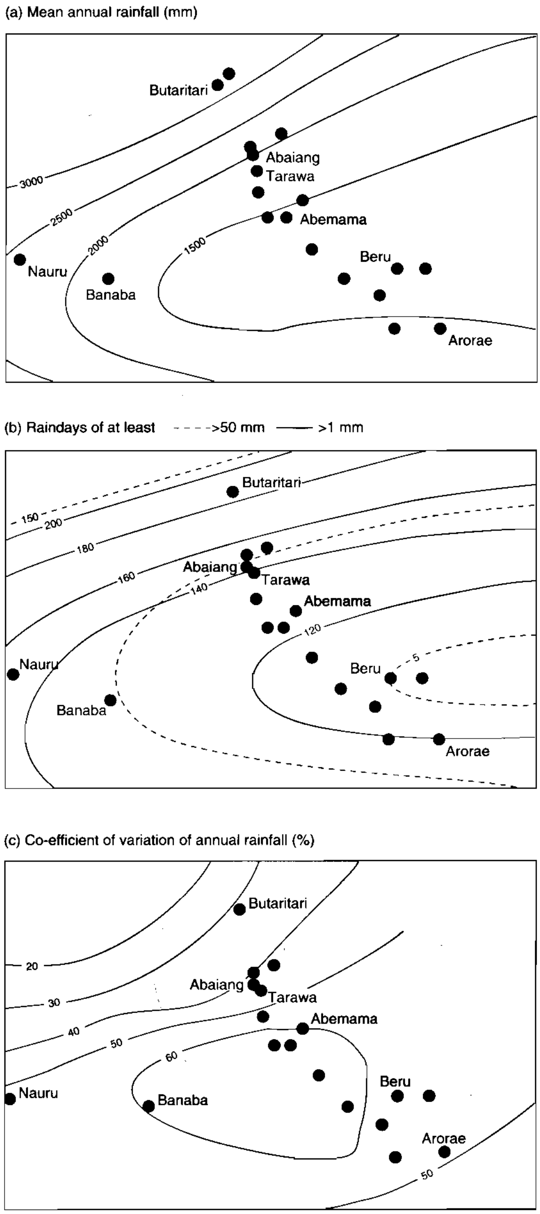

Fig. 21. Selected features of annual rainfall over Western Kiribati (1951–1980).

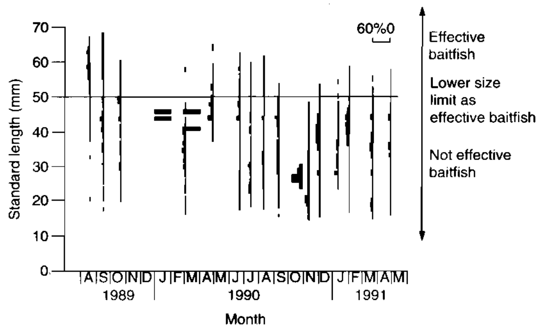

Fig. 22. The length-frequency distributions of *Spratelloides delicatulus* sampled from commercial baitfish catches at all sites in Kiribati between 1989 and 1991.

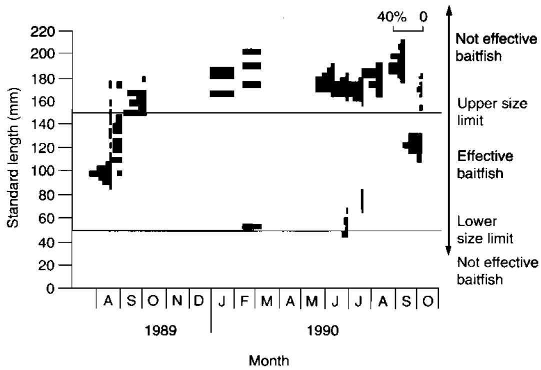

Fig. 23. The length-frequency distributions of ***Amblygaster sirm*** **sampled from commercial baitfish catches at all sites in Kiribati during 1989 and 1990.**

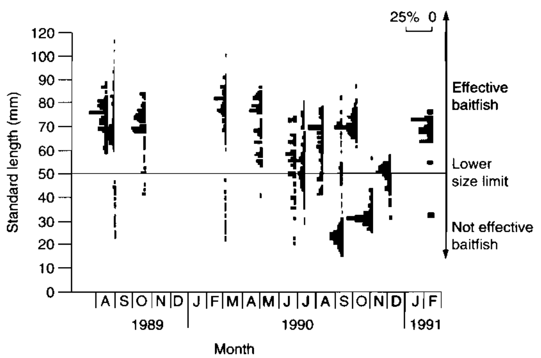

Fig. 24. The length-frequency distributions of *Herklotsichthys quadrimaculatus* sampled from commercial baitfish catches at all sites in Kiribati during 1989 and 1990.

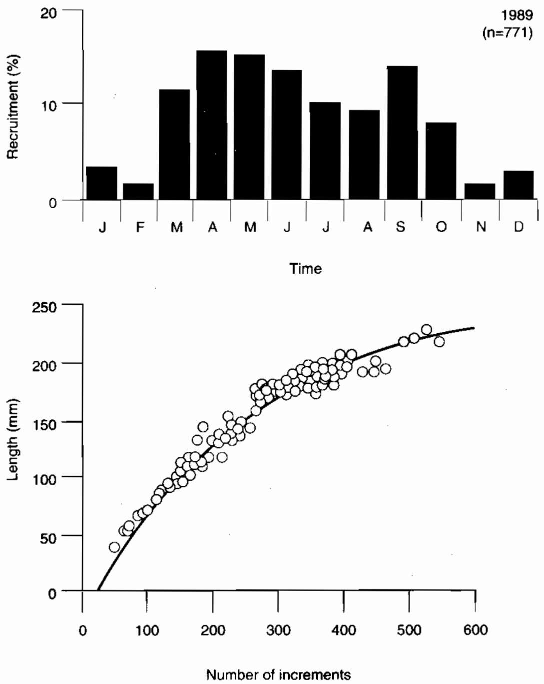

Fig. 25. The proportion of *A. sirm* born each month during 1989 (a) back-calculated from length-frequency samples, (b) assuming growth according to the relationship of Milton *et al.* (1992a).

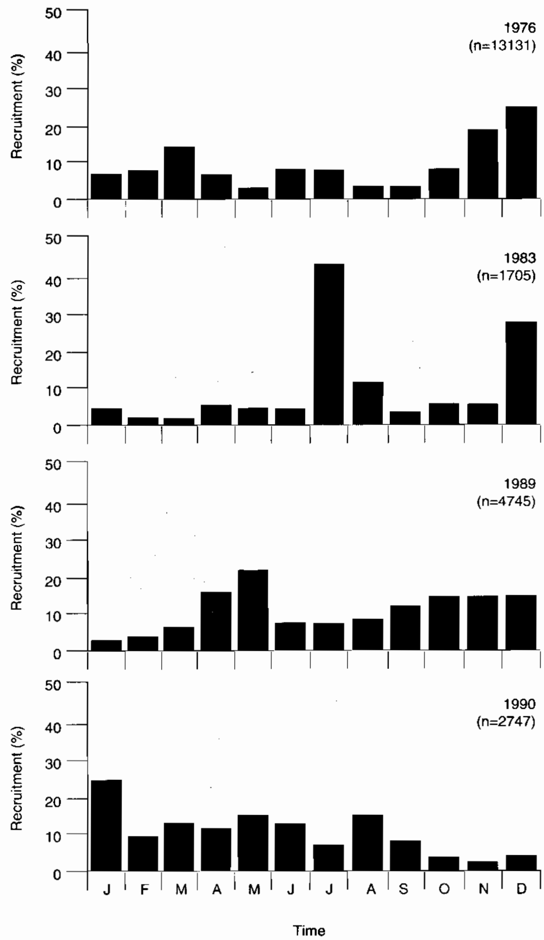

Fig. 26. The proportion of *H. quadrimaculatus* born each month in 1976, 1983, 1989 and 1990 (1976–Cross (1978); 1983 McCarthy (1985); 1989, 1990–present study).

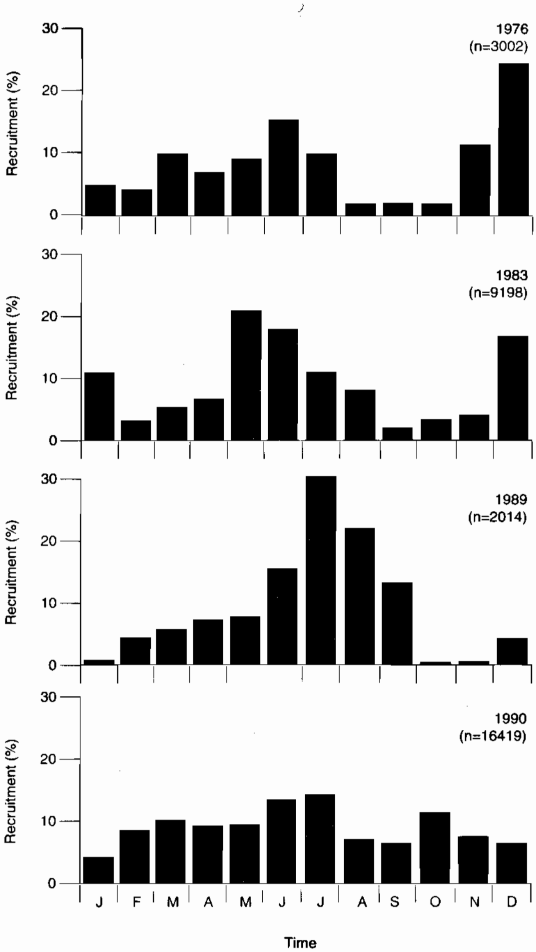

Fig. 27. The proportion of *S. delicatulus* born each month in 1976, 1983, 1989 and 1990 back-calculated from length-frequency samples (1976–Cross (1978); 1983 McCarthy (1985); 1989, 1990–present study).

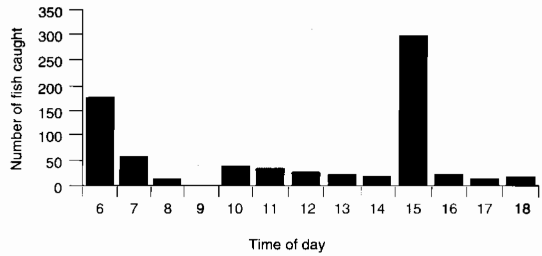

Fig. 28. The number of tuna caught throughout the day during the South Pacific Commission research cruise in early October 1990.

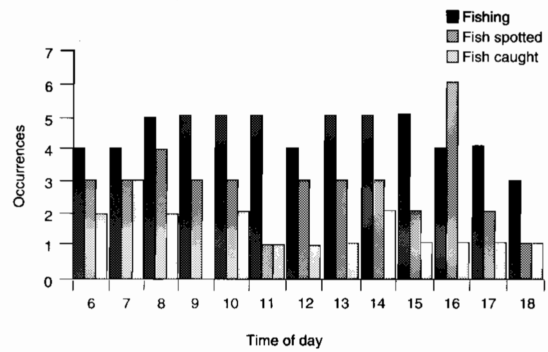

Fig. 29. The number of times that tuna schools were sighted, the vessel was fishing and tuna were caught at a particular time during the South Pacific Commission research cruise in early October 1990.

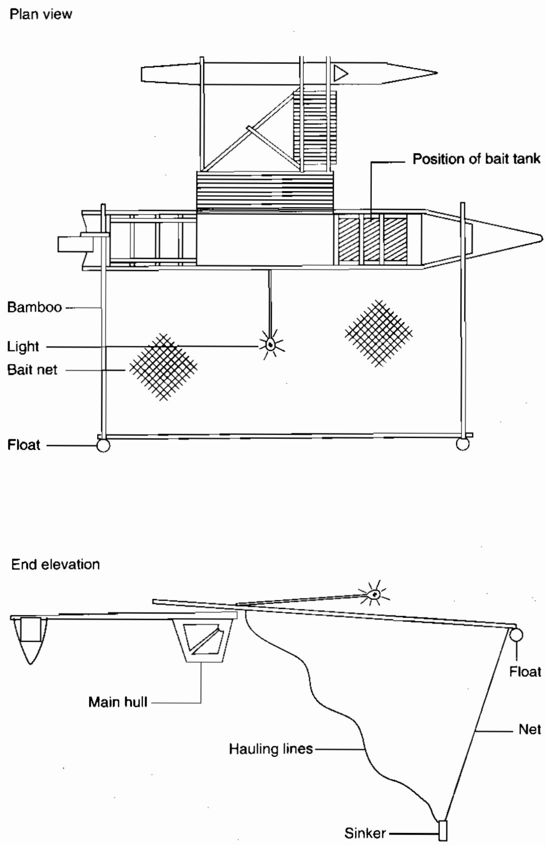

Fig. 30. The experimental baitfishing set-up of the 'PNG 11' outrigger canoe trialled in Butaritari.

An Alternative Tuna and Baitfishing Strategy

Artisanal fishing

The history of commercial pole-and-line fishing in Kiribati since its development in 1981 has been chequered (MacInnes 1990) and the continuing problems of quantity and survival of baitfish have limited its economic returns. In order to supplement catches of tuna made by the pole-and-line vessels, the Outer Island Project was initiated in 1987. The aim of this project was to encourage artisanal fishermen to catch tuna and supply them to Te Mautari Limited. Boats were built and supplied to fishermen at a reduced price and collection centres with blast freezers and cold storage were set up on the two outer islands of Abemama and Butaritari. Although tuna have been caught and preserved and supplied to Te Mautari, the operation has never been economic. A major problem is that the trolling technique used by the artisanal fishermen requires a large amount of fuel. The rising costs of fuel, decreasing prices of fish and generally poor catches of tuna, due primarily to the unpredictable nature of the occurrence of schools around the islands, have all played a part in the difficulties this project has faced.

Kearney (1975) considered that much smaller pole-and-line vessels (e.g. 8–10 metres) with smaller crews (e.g. 4–8) could operate economically with smaller bait quantities. If smaller vessels using greatly reduced quantities of bait can make economic catches of skipjack then the prospects of increasing local tuna production from a limited natural live-bait resource or some other supply of bait are greatly improved.

The use of small boats and live baitfish has been well established in the pole-and-line skipjack fishery in the Maldives in the Indian Ocean. The fishery relies on each boat collecting bait during the early daylight hours prior to the day's fishing operations. Each boat catches about 320 kg of tuna a day and the total annual catch for the country by boats using this method is over 52 000 t, which is well in excess of the largest industrial pole-and-line fishery in the Pacific (Maniku et al. 1990). The pole-and-line fishery in the Maldives relies on using about 5000 t of schooling reef fish species, especially cardinal fish (Apogonidae), fusiliers (Caesionidae) and sprats (*Spratelloides*) for baitfish.

As artisanal fishermen in Kiribati are traditionally used to using a pole-and-line technique which relies on pearl-shell lures, but no baitfish, and they are faced with economic problems carrying out their present fishing practices, the introduction of live baitfish into their operations might well improve their situation. However, for such an idea to be feasible it is necessary to develop a technique for catching the baitfish from a small boat. During extensive underwater surveys for the giant clam census during 1990 in Kiribati, only a few of any of the species used in the Maldives, except for *Spratelloides delicatulus*, were seen. Prevailing winds usually make conditions over the reefs of the margins of the lagoons, the areas in the Maldives where most of the baitfishing takes place, too rough to consider undertaking any form of fishing operation in Kiribati. Artisanal fishermen would therefore need to use a night-lighting method similar to the industrial fishery.

Several methods were developed to catch baitfish at night from small boats as a part of the regular sampling of the Baitfish Research Programme. Taking these ideas further, an attempt was made to catch baitfish from one of the boats used by the outer island project. The design of boat was an 9.5 m outrigger canoe which can be powered by both outboard engine and sail. The dimensions and general arrangements of the boat are described in RFSP (1990).

After different styles of operation were tried, the most suitable net design was a scaled-down version of that used in bouke-ami operations. A net 10 m^2 constructed of disused baitfishing net was attached to a rigid wooden cross-frame. This cross-frame was pushed out from the boat, on the opposite side to the outrigger, with the use of bamboo poles locally available from the island of Butaritari where the trials were undertaken. The net then hung down from the cross-frame which had plastic floats attached to ensure that it did not go underwater. Four hauling lines were attached to the bottom of the net which was weighted with cement-filled beer cans in order to sink it adequately. The hauling lines were attached to four points at equal distances along the length of the boat (Fig. 30). The bamboo poles were tied tightly to the boat in order to ensure the whole structure remained rigid. The operation of shooting and hauling the net could be comfortably carried out by four people, and on occasions was operated by only three people. After baiting operations were completed, the net, bamboos and remainder of the gear could be neatly stowed and did not interfere with other fishing activities on the boat.

This method was effective at catching bait that had aggregated around an underwater light driven by a portable generator. As there were large quantities of sprats available during the course of the trial, catch rates were generally high. Catches in excess of 40 kg were made on one night.

However, it is not feasible for each artisanal boat to possess an underwater light and a portable generator. Therefore, on a number of occasions a kerosene lamp as the light source was tested. The use of such lamps for fishing in Kiribati is common practice for the capture of flying-fish at night. Although not as effective as the one-kilowatt underwater light, the kerosene lamp did succeed in attracting reasonable quantities of baitfish, which were easily caught using the arrangement described above.

The baitfish species taken during these trials were mainly *Spratelloides delicatulus* with some *Herklotsichthys quadrimaculatus* and atherinids. Schools of *Amblygaster sirm* were not observed attracted to the lights during the course of the trials so it is not known whether they could be caught using such gear. Because of their habit of swimming fast and erratically around lights in normal situations they would probably be difficult to capture using such a method.

The trials were taken a step further by trying to keep the baitfish alive on the boat. A marine plywood bait box was constructed. Its dimensions were 50 cm square at its base, 95 cm high, and 70 cm by 92 cm at the top. An outlet pipe was fitted near the top of the tank on the starboard side so it could hang just over the gunwale. This box fitted neatly in the bow section of the boat just ahead of the forward cross-beam of the outrigger (Fig. 30). The box had sections added to it in each corner to give some curvature to its inside. The inside of the box was painted a light blue colour.

During the first use of this bait tank the bait died after a couple of hours due to overcrowding and limited water exchange. Before its second use a hand-operated whaler gusher pump was fitted to the boat. The inlet pipe to the pump was long enough to reach over the side of the boat into the sea and the outlet into the bait tank. After bait had been loaded it was possible to exchange the water in the tank at regular intervals. During this trial a total of approximately 10 kg of sprats was loaded into the tank before going in search of tuna. Unfortunately no tuna schools were seen so it was not possible to try and get a positive feeding response to the baitfish. However, on the boat's return to base in the middle of the afternoon the bait was still alive and could have been used for fishing. During one other attempt at using the live baitfish for catching *Euthynnus affinis*, present in vast numbers in the lagoon, a positive feeding response was achieved, and the boat at one stage was surrounded by a school of fish, although it was not possible to catch any.

As time available for these trials was limited the development of this technique could not be taken further. However, there were enough positive points coming from this experimental fishing to warrant further development in this area. Alternative light sources for catching bait at night (e.g. solar-powered), the formation of a dedicated baitfishing unit to supply boats with baitfish; work with boat designers on how best to optimise bait-holding capacity on the boats available, the use of cultured bait to assess whether the use of baitfish can produce better daily catch rates of tuna than those methods currently employed, the addition of a simple sprinkler system when fishing for tuna and other developments to increase the efficiency of the artisanal fishing fleet are all areas worth investigating.

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