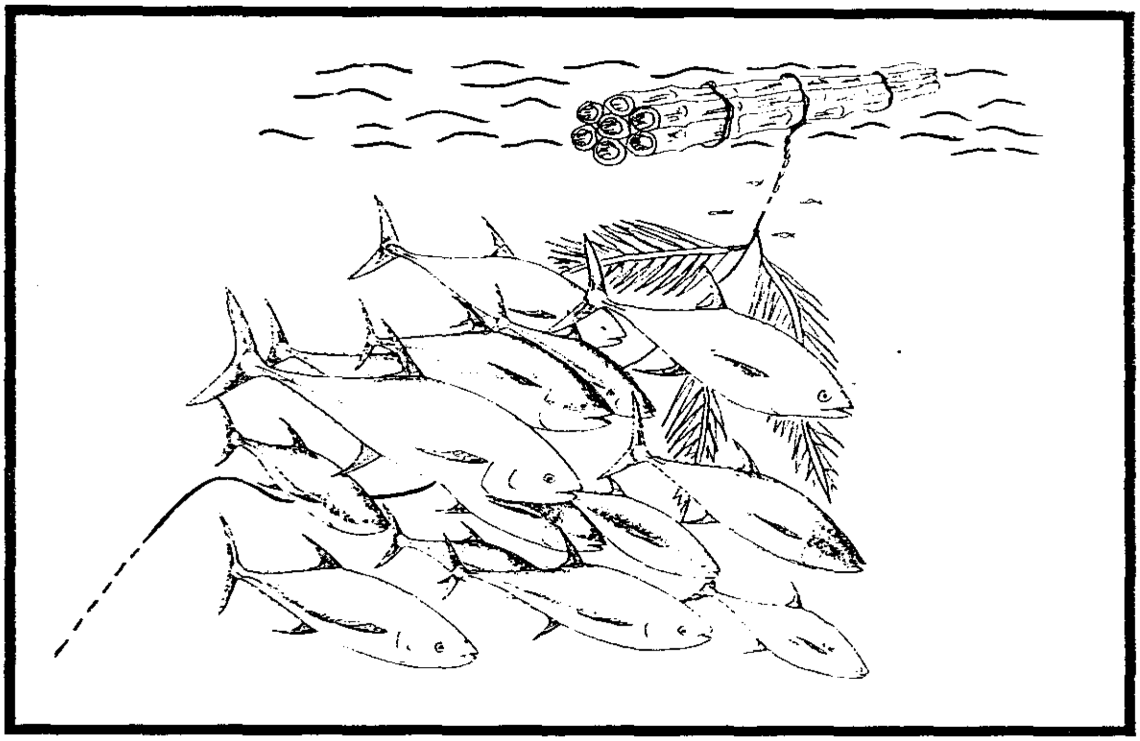
THE ASSESSMENT OF THE INTERACTION BETWEEN FISH AGGREGATING DEVICES AND ARTISANAL FISHERIES

Document 1: Synthesis of Research and Recommendations



FISHERIES MANAGEMENT SCIENCE PROGRAMME

OVERSEAS DEVELOPMENT ADMINISTRATION

Project R. 4777

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DRAFT FINAL REPORT

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Executive Summary

The proposition that Fish Aggregating Devices (FADs) can provide a means to improve fisheries undertaken by artisanal fishermen in tropical marine environments has a relatively long history. Practical programmes for FAD deployment have been undertaken in numerous places with varying degrees of success. If further use of FADs is to be considered it is clearly desirable to synthesise the reasons for their success or failure and to offer guidelines that will ensure that FAD deployments - whether by government departments or fishermen - function for the purposes intended; to enhance catchability of fish and improve production and economic performance of fishermen (a development issue) and/or to divert fishing effort away from fish stocks that are in need of conservation (a management issue).

This research project was designed to address biological, social and economic characteristics of FAD projects for artisanal fishermen. Because of the limited budget, and therefore scope, for detailed experimental work involving FAD placements and monitoring this research project was undertaken in collaboration with FAD deployment programmes of the South Pacific Commission (SPC). At the start of the project a series of FADs were deployed in Vanuatu and a monitoring programme was established by MRAG to measure the biological, social and economic consequences. It became clear relatively quickly that a number of factors thought to be critical for successful FAD programmes had not been accounted for in site selection and that the FADs did not successfully aggregate fish or fishermen. Nevertheless, confirmation of the importance of such factors was vital to the production of guidelines, an output for which the research project was primarily designed.

A similar SPC FAD programme followed in Fiji to which MRAG supplied the monitoring and assessment component. Although results were mixed there were sufficient comparative successes, particularly on information collection, to offer some scope for an analytical approach.

This research report on the assessment of the Interaction between Fish Aggregation Devices and Artisanal Fisheries consists of a document series as follows:

Document 1 - Synthesis of Research and Recommendations.

Document 2 - Vanuatu Country Report.

Document 3 - Fiji Country Report.

Document 4 - A Handbook for FAD Programmes.

Document 5 - A Review of Bioeconomic and Sociological FAD Modelling.

This document (Document 1) provides a synthesis of all research undertaken, both background and field, the results obtained and the conclusions and recommendations revealed. Part I offers a general introduction to FADs, the techniques and costs of their placement, and their importance to both industrial and artisanal fisheries of the South Pacific. Part II describes the objectives of the research to identify biological, economic and social attributes of artisanal FADs and the ways these can be used to plan for the future. Part III provides some conclusions on the aggregating effect, the placement of FADs and their contribution to sector performance and goes on to offer general recommendations for further research work.

The case studies (Documents 2 and 3) for Vanuatu and Fiji provide detailed descriptions of the work undertaken and the site specific results achieved. A comparison of these reveals clearly that social, cultural and to some extent economic characteristics of fishing communities are likely to be more important to FAD success or failure than the extent of the biological effect.

As a result of background research and these field case studies the nature of the direct practical output could be identified. This feature of the project was always meant to be output of a practical nature to assist in meeting the wider objectives, as stated in the project document: *to improve the socioeconomic conditions of marine artisanal fishermen.*

Since MRAG and SPC had collaborated on information and the research programme it was believed appropriate to take the practical output - the Handbook for FAD Programmes - to the stage of publication and dissemination through both the ODA and the SPC. Document 4 is the result of that collaboration and provides a complete guide to the assessment of the potential success a FAD programme might enjoy in any area, including economic and financial appraisal. It is hoped that the Handbook (and spreadsheets that are available to undertake the calculations) will provide a useful tool for governments, fishing companies and fishermen in their assessment of the value of FADs to their particular needs.

Lastly, Document 5 takes a broad look at bioeconomic and sociological modelling of FADs. It reviews all the available scientific literature and suggests avenues for further research, both theoretical and experimental.

Acknowledgements :

The research programme was undertaken by Jim Anderson with additional support from the South Pacific Commission, particularly Garry Preston, Peter Cusack and Paxton Wellington. Project Direction was by David Evans; Document 5 was prepared by Julie Rossouw; proof reading and publication was carried out by Graham Pilling.

The Governments of Vanuatu and Fiji collaborated to a major extent, offering advice, information, enthusiasm and material and organisational support.

PART 1 : INTRODUCTION TO FISH AGGREGATION DEVICES

1. *Fishery Enhancement Methods*

1.1 General Techniques

The basic theory of fishery enhancement methods or 'accessory fishing gear' (Aprieto, 1990) is that fish will be attracted (aggregated) to a structure facilitating the targeting of that particular resource by fishermen (Fish Aggregation Devices ,**FADs**). Alternatively, structures are placed that create additional niches for fishes to exploit therefore increasing the local stock biomass (Artificial Reefs ,**ARs**). In many nations the use of ARs in particular, is seen as a positive fishery management step in the face of declining coastal fishery yields.

- **Artificial Reefs**

Artificial reefs may comprise old boats, concrete blocks, old passenger buses, tricycles or car-tyres strung together and are placed in areas currently yielding little, if any, fishery resource.

Deployment of ARs would generally take place in shallow waters (5-40m) with a flat, sandy sea-bed. The aim of such structures is to mimic the spatial complexity of natural reef areas and this is enhanced by deployment in areas with good water clarity to facilitate the growth of encrusting organisms such as corals and algae. Artificial reef programmes may also include seeding of fish larvae where natural recruitment rates may be locally poor. Sustained larval seeding may however be necessary to maintain population levels because self-recruitment is considered by some researchers to be unimportant in determining reef community structure and biomass (Doherty *et al* 1985 etc).

Artificial reefs may also be employed by fishery managers to positively discriminate in favour of artisanal fishermen. In Thailand for example, ARs have been deployed for artisanal fishermen, using handline and gill-nets, to exploit resources that were previously monopolised by trawl fishermen (eg Thailand, see Sinanuwong, 1991). The reef structure itself prevents the use of trawl nets.

In the Philippines, fishermen have traditionally utilised structures such as artificial reefs ("Rama") and fish aggregations devices ("Payaw") to increase yields. There are an estimated 5,000 FADs currently in use in The Philippines (Stequert, 1989 in Venkatasami, 1990). Artificial reefs have been utilised in Malaysia since the turn of the century (Fai Hung, 1991), with fishermen sinking derelict vessels, tree branches and other such objects to increase the number of niches available to demersal species. In many local fisheries projects in Malaysia there have been joint deployments of ARs with FADs to mark the location of the reef. In the central Visayan Islands some 16,000 small AR modules have been set along 40 km of coastline; an important aspect of the project is that the ARs are planned, deployed and maintained by the village fishermen (Miclat, 1988 in Polovina, 1990).

In the southern Indian state of Kerala, yields for artisanal fishermen were found to be higher near a sunken wartime vessel. This led ultimately to the development of artificial reefs by a co-operative of fishermen in the area.

Japan, probably the nation with the most extensive development of artificial reefs, was known to have artificial reefs as early as 1650. In 1974, the Coastal Fishing Ground Development (ENSEI) Programme was initiated in Japan. The extent of the development of ARs in Japan subsequently has been a response to the declaration of the 200-mile exclusion zone by the USA and USSR which caused a decline in landings from deep-sea fishing. Following the declaration there was obviously increased pressure on Japan's own fishery resources. ENSEI has been a well planned and funded programme which has established artificial reefs in over 7,000 locations since its conception.

Artificial reefs may simply act to aggregate formally more dispersed biomass, but because ARs often exhibit higher biomass concentrations than natural reef habitats and may also display a higher species diversity, then it is likely that some increase in local biomass would occur simply through the provision of additional habitat (Hagino, 1990). Bohnsack (1989) argues however that there is no proof of ARs actually increasing the stock size. Polovina and Sakai (1989) studied the impact of ARs off Hokkaido, Japan and did record an increase in overall biomass of the octopus (*Octopus dolfleini*) which was explained by the increase in area of habitat provided by the AR. Much of course would depend on the status of adjacent reefs if the AR was to be left to naturally develop its own population structure. If local reefs are denuded through over-fishing or pollution then the same restrictions on population development that impinge on the natural reef will affect the artificial reef.

Correctly located, ARs can provide significant benefits to local fishing communities, if only through the aggregation of perviously dispersed resources. Sinanuwong (1991) reported a quadrupling of numbers of species recorded after AR deployment for handline and fish-trap fishing gears, with an estimated increase in overall fish abundance of 20 fold for artisanal fishermen, notably of Lethrinids and Lutjanids. In Thailand the effects of placing ARs has been quantified clearly; in 1985 two fishing villages in the project area landed 1.92mt of fish (primarily Threadfin, *Polynemis* spp) for an effort level of 408 trips by gill-net fishermen. In 1986, following installation, there was an increase of 364% in landings per vessel. Unfortunately, in 1987, the AR modules sank into the muddy sand and were lost, however the declared aim of increasing income to small-scale fishermen had clearly, if only temporarily, been achieved.

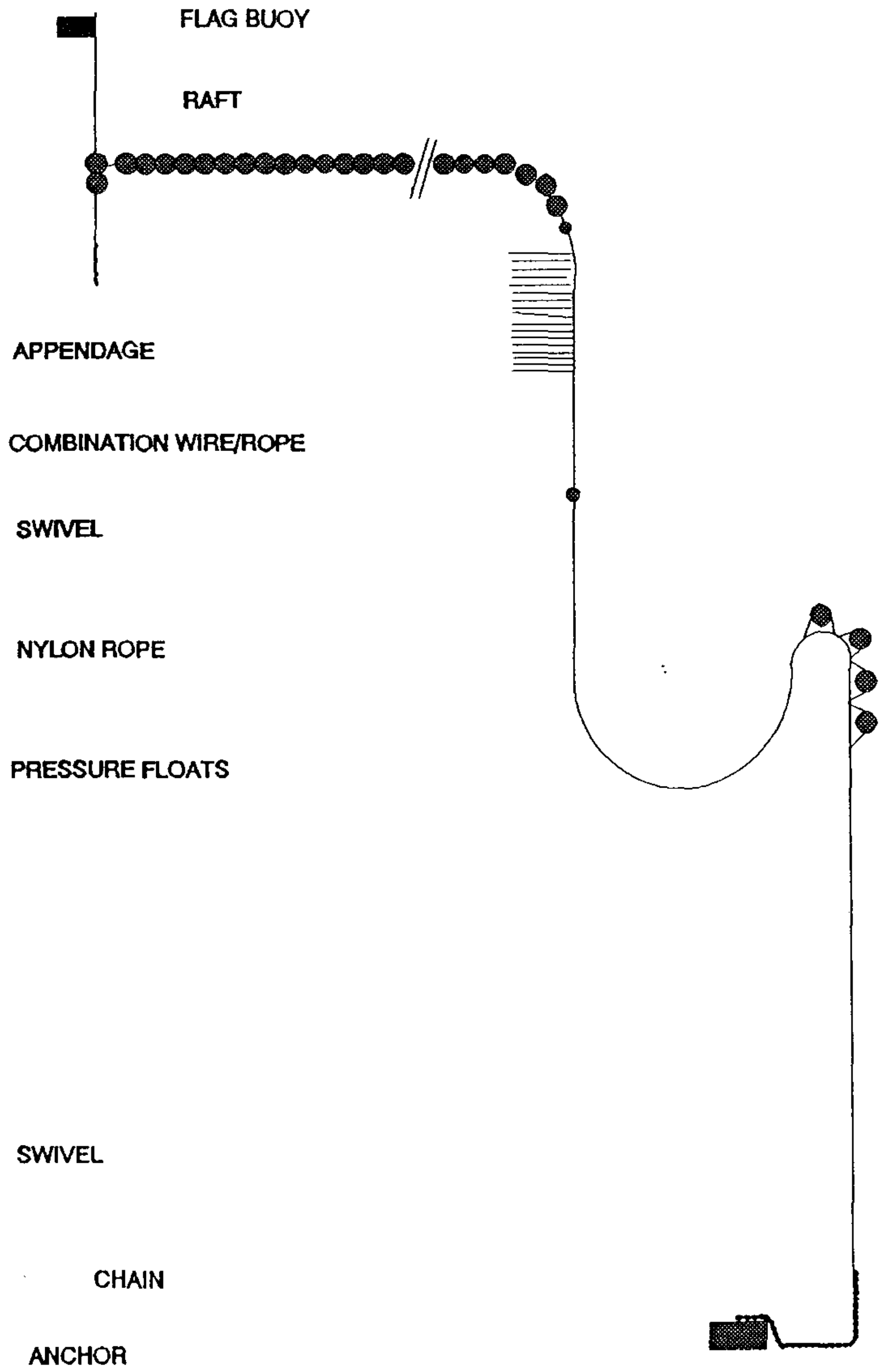
- **Fish Aggregation Devices (FADs)**

"A Fish Aggregation Device is any method, object or construction used for the purpose of facilitating the harvesting of fish by attracting and thus aggregating them" (Bergstrom, 1983). In this section the term FAD will only refer to those structures with a floating component anchored to the sea-bed with the precise aim of aggregating pelagic species. A typical FAD consists of three basic components; the anchor, mooring line and surface raft. In addition some form of sub-surface 'aggregator' is affixed to the top 5-30 metres of the mooring line. This may take the form of coconut palm fronds, old nets or lengths of rope. A typical modern FAD design is shown below in Figure 1.

The basic concept behind FAD deployment is that highly migratory pelagic species such as skipjack (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*) are attracted to a FAD and take up residence (for greater or lesser periods of time) in the vicinity of the FAD. This clearly affords fishermen the opportunity to target their fishing activities around the FAD as opposed to searching large areas of open-ocean for schools of tuna. The South Pacific Commission (SPC) Regional Tuna Fisheries Database records that the largest catch from a purse-seine set on an anchored FAD is 165 mt (mixed school) compared with 300 mt on a drifting FAD, 354 mt on a free-swimming school and 354 mt on a log (Hampton and Bailey, 1993).

Tagging experiments on FADs, through the use of Bailey's Binomial model (Seber, 1973), have estimated the numbers of tuna at between 3,452 (sd = 370) for an anchored FAD in the Philippines and 24,888 (sd = 7,125) for an anchored FAD in Indonesia (Hampton and Bailey, 1993).

Figure 1: Generic FAD Design



The species composition of FAD-caught fish varies with the nature of the FAD. Large yellowfin (> 80 cm) and skipjack (> 60 cm) are less commonly caught around logs than in free-swimming schools while small yellowfin, skipjack and bigeye (< 40 cm) are more frequently caught around logs and FADs (Hampton and Bailey, 1993).

FADs are generally deployed for two reasons; firstly where inshore fisheries production may be declining or showing signs of over-exploitation. The deployment of FADs may be used to attract fishing effort away from the inshore area, to offer fisherman an alternative to currently exploited species (and to increase income). Examples of programmes designed for such a purpose can be found in Vanuatu and Fiji.

FADs may also be deployed with the aim of enhancing overall fisheries production perhaps for fisheries that are not highly developed such as in small, high islands groups where fringing reef areas are not extensive. In the absence of FADs, exploitation of these pelagic species may have been simply too costly and landings too variable. Examples of such deployments can be found in the Comoros Islands.

In the Philippines, artisanal fishermen are in an almost unique situation in that commercial fishing operations deploy FADs and encourage the use of the FADs by small-scale fishermen as a symbiotic relationship. The artisanal fishermen benefit from the use of the FAD to catch deep-swimming tunas, while the FAD owners benefit because the fishermen can give early warning to owners that a FAD needs maintenance or has been lost or that suitably large aggregations of surface tunas have developed around a FAD.

1.2 Tuna Aggregation Theories

Exactly what prompts the aggregation of fish around FADs is not understood with certainty. In general terms the reasons for aggregation would seem to depend on the type of FAD in question.

Shallow-water FADs tend to attract smaller species of fish, such as scads (*Decapturus* spp and *Selar* spp) and appear to provide some increased security from predators. The basis of this protection being that resident schools become habitualised to the presence of the mooring-line and aggregator. In the event of a predator (eg *Acanthocybrium solandri, Sphyraena* spp) attacking the school, refuge is sought close to the mooring-line. The predator is not habitualised to the mooring line and thus takes avoiding action, facilitating the escape of the smaller fish.

For FADs deployed in depths of up to 1200 meters and located anywhere from 3 to 20 nautical miles off the coast there are currently a number of theories:

- that aggregation is driven by the need for a forage base :

  This theory is often argued from an (anthropocentric?) viewpoint that the ocean is a feature-less, homogeneous environment, which is certainly not the case. Tunas (and many other species) migrate through a complex environment of varying solenoids, magnetic fields, currents and temperatures; many species migrate thousands of kilometres annually across entire oceans. It is unlikely, therefore, that these animals do not have an equally complex and sophisticated navigation system that allows them to 'know' exactly where they are at all times. The need to utilise a fixed navigation point would therefore be unnecessary.

  However, the daylight dispersion and subsequent re-aggregation at night clearly lends credence to the forage-base theory. FADs are generally accepted (in the Pacific region at least) to have a radius of attraction of 4.5 nautical miles; if the mechanism that allows tunas to sense the location of a FAD is physical (perhaps through the lateral line) then the FAD could provide a static base from which tuna could radiate out while foraging. There remains however the question whether the area in which the FAD is deployed has sufficient prey resources to hold the tuna in that area. FADs are usually deployed in areas that are known to have tuna and are therefore likely to be suitable feeding environments. However, diffusion theories (eg Mullen, 1989) suggest that the tuna hold themselves in an area of high productivity by adjustment of the direction in which they swim (determined perhaps by some minimum prey density). Tuna may therefore have to leave an area of high prey density to return to the forage-base (the FAD), the possible advantage of which remains unclear. An interesting adjunct to the forage-base theory is that FADs act as centres of communication, in the same way bees return to their hives to pass on information on the location of suitable sources of nectar and pollen (Evans, pers comm).

- That FADs assist in predator avoidance :

  Research suggests that several free-swimming schools aggregate around the FADs, probably forming a single large school at night which disperses into sub-schools during daylight when the fish feed (Preston, 1991). The size of individual fish and the size of schools typically aggregated make explanations based on the FADs themselves providing protection from predators, in the way suggested for shallow-water FADs, unlikely. Clearly a large school would give more protection to individuals then a smaller one but this begs the question of why such large schools appear to only form around FADs (both natural and artificial). Given the distance over which FAD-associated tunas range it is unlikely that this theory is valid, the tunas could not retreat sufficiently rapidly to the FAD to gain any protective advantage.

- That FADs aggregate prey items for the tunas :

  Perhaps a useful insight into the phenomenon can be gained by looking at aggregation under natural circumstances. The effect of oceanic gyres and currents tend to lead to the formation of aggregations of natural FADs (such as floating logs). Such areas are also likely to be more productive than adjacent areas because of the meeting of currents, and may therefore explain why flotsam and jetsam act to aggregate tunas. The size and age of logs appears to correlate with catches. However, artificial FADs are usually not placed with respect to considerations of local productivity, although they are often placed where tunas are found or on tuna migration paths. The FAD must therefore provide sufficiently attractive feeding opportunities to hold tuna schools.

  Industrial fisheries utilise both inanimate floating objects and live whales as indicators of possible concentrations of tunas. The purse-seine fishery operating north of Papua New Guinea target live whales in the first and fourth quarter of the year and the presence of tunas are possibly related to the presence of prey species common to both whales and tunas (such as the Ocean Anchovy). FADs therefore may enhance feeding by aggregating prey species; research does suggest that for example the pelagic larval stages of reef fish are aggregated by floating objects (eg Leis, 1993); stomach content analysis of smaller coastal yellowfin tuna (mean weight of 4.3 kg) have shown that post-larval and juvenile reef fish (Monocanthidae 12.9%; Chaetodonitdae 9.9%; Acanthuridae 4.3%) comprised 27% of the total food intake although these fish were not taken at FADs.

Alternatively, it may be that the innate aggregating behaviour that leads to aggregation around natural floating objects causes the tuna to school around FADs even though there may in fact be no energetic advantage. There is some evidence that large FAD-associated yellowfin change their target prey which may explain how such large biomass (up to 1500 mt) can sustain itself in a relatively small volume of water. Brock (1985) reported that yellowfin caught at some distance from FADs (>2km) deployed off Hawaii, had a significantly greater volume of food ($p < 0.0005$) in their stomachs than those caught around FADs and that dietary composition was dominated by fish (66% by volume). Those yellowfin caught around the FADs fed primarily on crustaceans (85% by volume) of which 78% (by volume) was the mid-water shrimp, *Olophorus gracilirostris*.

The situation is far from uniform however, with apparent significant regional variation; analysis of the stomach contents of yellowfin caught off FADs deployed in the North Celebes Sea indicated that 68% of the weight of food comprised juvenile tunas (prey and chum) (Yesaki, 1983). Sonar surveys do not suggest that the olophorid shrimps are aggregated by the FADs and do not appear in the stomach contents of other FAD associated predators. Brock suggested that although the large biomass found locally around FADs reduced overall prey availability, the switch of diet could imply that FADs actually enhance yellowfin production.

2. FAD Deployments and Programme Planning

2.1 Introduction

Although FADs are fairly simple structures, the ocean environment in which they are placed is generally one of high-energy with strong forces (of current, wind and wave action) affecting the FAD. Design efforts are concentrated on reducing the unit costs of FADs, while attempting to reduce the likelihood of loss from cyclones, shark bite, vandalism or simple attrition. These efforts are primarily aimed at modification of mooring materials but have also led to changes in the surface structure, in the form of reduced size of surface rafts and floats, although there does appear to be a definite regional preference for raft design.

2.2 Design Developments

In 1984, the South Pacific Commission undertook a study of FAD deployments in the region in order to address the problem of the high rate of loss of FADs (Smith and Boy, 1984). In the Pacific region early FAD deployments suffered a high loss rate, 80% of the FADs deployed prior to 1984 were reported lost after an average time on station of less than 12 months. The study included an in-depth examination of all engineering, construction and deployment aspects of FADs and produced recommendations for Pacific nations. Since the conclusion of this work and the dissemination of the recommendations the average life-span of FADs has increased to 2 years.

Some fishing companies, particularly for fishing on the high-seas, have deployed non-anchored FADs that are fitted with radio-beacons allowing tracking by purse-seine vessels. There has also been some interest expressed in the development of FADs with no surface component, so-called mid-water FADs. Such FADs probably do not aggregate fish any more successfully but rather the lack of a large buoy or raft reduces the stresses affecting the FAD, particularly the stresses of wind and current which often work in opposite directions to each other.

The modern FAD is designed with a shock absorbing inverse-catenary curve and heavy-duty swivels are used to allow for the rotation of the raft with the changing wind and tide conditions. Typically FADs have some aggregating materials which may be natural or synthetic, the former requiring more frequent replacement. Aggregator materials range from coconut palm fronds or strings of tyres through to high-technology fibreglass 'Kites' manufactured by Macintosh Marine.

The importance of the size of the aggregator (or the materials from which they are constructed) is not well understood, but it is likely to be a significant aspect of the overall attractive ability of the FAD. Intuitively, one might expect aggregators to increase the chance of the FADs actually being detected by tunas whether they utilise visual or electromagnetic sensors (the lateral line). Buckley (1987) reported that FADs with attractors had more fish and those with opaque attractors had a larger number of fish than FADs with translucent attractors. Results from Rountree (1989) on shallow-water FADs off South Carolina, USA found that the size of the vertical profile FADs presented was the most important factor accounting for the attractive ability of FADs. Overa (1980) reported that following the loss of the aggregator from a FAD placed off Apia, Western Samoa, no fish were observed with the echo-sounder of a purse-seine vessel, although schools had been reported one week previously. Two days later the appendage was replaced but catches returned to previous levels only after some weeks. Overa argued that the significance of the aggregator was well demonstrated in this situation, but noted that logs with no sub-surface aggregator also prove very effective at attracting pelagic species. Hampton and Bailey (1993) suggested that the size of schools associated with floating logs was dependent on the area submerged (as well as the distance from other logs). Highly buoyant logs (such as coconut palms) tend to have very low associated biomass and are rarely set on by purse-seiners. Naeem (1987) simply concludes that FAD attract fish whatever the design features.

Shark bite is thought to be responsible for the loss of some FADs, notably in Vanuatu and New Caledonia (Preston, 1991). This, and the stresses of twisting and stretching, necessitate the use of substantial mooring lines. The mooring components recommended by the SPC now include the use of 8 or 12-strand mooring lines. The stresses a mooring line is subjected to can create so-called 'hockles' in 3-strand rope whereby one strand affectively becomes redundant, reducing the strength of the mooring line by one-third. In addition the use of combination wire/rope for the surface 50 metres has been promoted in some areas to reduce loss from shark-bite and human interference.

Recent developments in mooring system are currently being trialled in New Caledonia where the mooring line comprises only mono-filament long-line. It remains to be seen the advantages of such a material over the use of multi-strand ropes.

2.3 FAD Deployment Techniques

Techniques have become standardised in the Pacific region, the 'raft first' method being the preferred option. This method entails deploying the surface component of the FAD followed by the mooring line (generally in a large circle around the exact spot intended for deployment). The anchor is sent overboard last. This method is preferable to the 'anchor first' technique primarily because of the enhanced safety of being able to gradually pay out the mooring line rather than have the weight of the anchor drag it off the deck.

One of the key issues regarding FAD deployments is the distance they should be placed apart, which would seem to depend on the abundance of the target species. For shallow-water FADs deployed to attract small pelagic species, a closer deployment can be afforded; deep-water FADs attracting large schools of tunas tend to have a wider spacing associated with the greater distances these species forage over and therefore the effective increase in the 'catchment area' of an individual FAD.

For example the 'Jukatjerut' fishery in Malaysia typically uses 10-20 shallow-water FADs placed approximately 200m apart, while the 'Kannizzati' fishery in Malta utilizes FADs placed 1 n.mile apart (Prado, 1991). There are various rules-of-thumb being used by fishermen or Fishery Departments deploying deep-water FADs. For example Filipino fishermen generally agree on 5 nautical miles between FADs but this is as much in an effort to reduce crowding and potential conflict than for any particular biological basis.

An alternative approach to deployment criteria is not to look at the problem from the perspective of biological factors *per ce* but rather from the perspective of utilisation of FADs by fishermen from nearby fishing ports. Potential sites are therefore ranked according to their expected effect on returns from fishing the FADs. Simplifying assumptions are made regarding the availability of sites and yields expected and the only explicit reference to distance between FADs is that a minimum distance is assumed and that if FADs are located closer than this distance then the deployment of 2 FADs has the same aggregate effect as the deployment of a single FAD (Samples and Hollyer, 1989). Further discussion of the merits of this approach can be found in the literature review in Section 3.

2.4 FAD Costs

The important consideration in FAD deployment costs is that the returns are likely, on average, to significantly outweigh the costs of deployment; Roullot *et al.* (1989) working on FADs in Mauritius found that the costs of FAD construction and deployment was only valued at 3.98% of the total value of fish landed from it in a year.

In many situations the actual costs of FAD may either be hidden in the form of aid-projects or may not be the only criteria for deployments. What may be of equal significance in planning is the affect on fisheries production. FADs are often seen by fisheries departments as a quick and easy method of opening up (or at least increasing) an artisanal fishery for pelagic species. The importance of this may increase if inshore fisheries production is either approaching sustainable yield levels or is in fact declining. The deployment costs that a Government may need to budget for must, therefore, be balanced against the costs (both social and economic) of further reductions in the yields from current fisheries and therefore the likelihood of unemployment (or at least reduced incomes) for the artisanal fishermen.

The decision of what level of costs to outlay will obviously depend on the intended use (artisanal or industrial), as well as expected recurrent expenditure for maintenance or replacement. In general, industrial fisheries would deploy their own FADs quickly and in relatively large numbers, cheap FADs that would not be expected to last more than a few months, reflecting the highly mobile nature of the pelagic fish stocks that long-liners and purse-seiners exploit. For example, 35 FADs were deployed in an East-West alignment by a Filipino purse-seine fishing company north of the Fiji group in an attempt to extend the length of the fishing season, the success of this venture is unknown (Preston, 1991). There are of course exceptions to this, for example FADs deployed by the IKA Corporation in Fiji for the pole and line fleet are of robust and relatively expensive design, clearly intended to remain on station for considerable lengths of time.

The development of FAD technology has gone hand-in-hand with the reduction of costs, particularly the cost of the surface raft component, which constitutes 40% of the total cost. The most expensive design of FAD tend to be those with variously shaped steel rafts with radar-reflectors. For example FADs set off Grenada in 1990 were estimated at US $ 3,000 of which US $1,000 was the cost of the steel catamaran buoy. The FADs used in the Indian Ocean which use floats strung on the top section of mooring line cost US $ 2,000 while the FADs (Payao) used in the Philippines cost between US $1,900 and US $ 2,300 for a modern industrial design but only US $ 200-250 for a bamboo raft.

The FADs most recently deployed in Fiji cost an estimated F $3,643 for those with a steel spar-buoy and F$ 2,800 for the Indian Ocean design utilising old purse-seine floats (US $ 2.00 each) for the surface raft.

2.5 Decision Making and Programme Planning

There are many factors that should, under ideal situations, be considered when developing a FAD programme. Many authors have attempted to give definitive descriptions of the criteria that should be met for a successful FAD programme, the prime example being the extensive collation given by Pooley and Boggs (USAID FAD Workshop, American Samoa). It is, however, true to say that historically FAD programmes have not been economically evaluated prior to development, except perhaps in the most general sense. In such circumstances the costs of deployment were often met by provision of FAD hardware from overseas development funds; advice, technical assistance and training was given by regional agencies such as the South Pacific Commission. Following initial deployments, further programmes often consisted of *ad hoc* deployments as and when materials and staff become available.

Despite this low level of planning, many FAD programmes have proven very valuable to artisanal, industrial and sports fishermen alike. This would suggest that FADs have a degree of 'robustness' that allow a minimum of planning for adequate returns.

However, as the supply of financial aid and equipment provided to developing nations declines, so funds will have to be found from within Fishery Department budgets. In fact this is already the case for a number of Pacific nations including Fiji. In such circumstances the requirement for economic justification will increase and so detailed planning of FAD programmes may actually become the norm. Given the lack of pre-deployment planning and cost-benefit analysis and the subsequent lack of the monitoring of the success of the FADs, it is likely that the full potential of FAD programmes have, in the majority of cases, not been realised. There is, therefore, a need to develop both broad and detailed guidelines for pre-deployment assessment of FAD programmes and undertaking post-deployment and monitoring.

One would hope that the amount of time and effort Fishery Departments are willing to expend on development of a FAD programme would be generally commensurate with the expected benefits to be gained in terms of overall fisheries production. However, many Fisheries Departments are generally small and under-staffed and have large areas of responsibilities including industrial fisheries, aquaculture and licensing. There is therefore a requirement that any tool to assist in decision making and programme planning be practical but simple and a tool that perhaps more junior members of fishery staff could use.

Perhaps the most useful and concise work to date has been that of Cayre, De Reviers and Venkatasami (1990) who developed a simple planning 'key'. The basis of this work is that it provides a chronological framework of questions that should be followed in order that a FAD programme will only proceed when it is entirely appropriate for the fishery/area in question.There is no evidence, however, that suggests that this advisory key has been utilised in programme planning.

The principle tasks and questions proposed by Cayre et al are listed below;

1 : Undertake a gross evaluation of the overall abundance of species that could potentially aggregate around FADs

2 : Are oceanographic conditions suitable to the deployment of FADs?

3 : Undertake a gross evaluation of dietary needs.

If the results from points 1-3 are not appropriate then the FAD programme should not be considered for that particular site.

4 : Estimate the relative importance of the exploitation of the different marine species in the current fishery.

5 : If tunas are not of significant value in the fishery then determine why this is the case (cost of exploitation, cultural taste etc); what is the potential for altering some aspect of marketing or fishing technology for example that would increase exploitation or consumption of tunas?

6: If tunas are popular within the fishery, can the market absorb increased landings without a fall in price and is there export potential for the product?

7: Undertake a census of the potential sites bearing in mind oceanographic, cultural and fisheries aspects.

8: Identify a user-group and attempt to assess how the group will react to the deployment of FADs and what the likely returns to the fishery will be.

The major problem with current programme assessment techniques is that many answers are highly subjective (eg questions 5, 6, 8), although local knowledge will essentially permit some local weighting of critical factors. Furthermore, this approach does not offer guidelines to assist in the interpretation of the data gathered during the assessment phase; in many smaller developing nations, data collection and assessment methodologies are not currently well developed. What is required at this stage is that these valuable points are brought together into a more user-friendly framework with examples of real problems and successes experienced in FAD programmes around the world. The apparent lack of use of this, or any other, framework is as much a feature of its presentation as it is of its content.

3. *The Importance of FADs in the Pacific*

3.1 FADs for Industrial Fisheries

In general the use of artificial FADs (whether anchored or drifting) by industrial fisheries in the Pacific compliments the use of natural FADs (logs, whales etc) and sets on free-swimming schools, although there is much variation both regionally and between the distant-water fishing nations (DWFNs) that dominate industrial fisheries in the region. Table 1 shows the percentage by association of total sets for a selection of DWFNs as recorded in the SPC Regional Tuna Fisheries Database (Hampton and Bailey, 1993).

Table 1: Data for Distant Water Fishing Nations

Nationality	School	Log	Drifting FAD	Anchored FAD	Animal
Japan	31.26	65.28	0.44	0.28	2.75
Korea	39.01	55.42	0.32	0.10	5.16
Taiwan	4.77	93.86	0.90	0.20	0.27
United States	75.32	24.39	0.17	0	0.12
Solomon Islands	0.84	2.32	0	96.83	0

It is clear from this table that anchored FADs are really only of significant importance in the Solomon Islands purse-seine fishery where a network of over 30 FADs were deployed in a 600 square mile area which are maintained by the purse-seine company.

In Fiji, FADs have been deployed by industrial fishing concerns since at least 1981 when 39 FADs were deployed, principally by purse-seiners owned by a New Zealand fishing company. Reports suggested that the majority of FADs were either lost soon after deployment or did not yield large quantities of fish, however the average yield of 6 mt and 10 mt per set for the two vessels fishing was a considerable improvement on the poor catch-rates the company achieved fishing free-swimming schools in 1980. This was very much a learning period for the fishery and during the latter half of the year advice was sought from a Filipino fishing company with UNDP development funds.

FADs continued to be deployed by purse-seiners (100 in 1982) and in 1989 a Filipino purse-seiner chartered by the Pacific Fishing Company deployed 70 FADs around the Fijian EEZ, partly in an attempt to delay the northward migration of tunas out of the zone for which the vessel was licensed. The majority of these FADs were deployed out of range of any artisanal fishing fleet.

FADs have also been extensively used by pole and line vessels, particularly in Fiji and to a lesser extent in Solomon Islands, Kiribati and Tuvalu, and in some cases have come into conflict with purse-seine vessels seeking to utilise the aggregated resource. In general the pole and line fleet fish on FADs that have been deployed principally for artisanal fishermen. In Fiji however, the Government fisheries company, IKA, have been deploying FADs for the pole and line fleet since at least 1981. However there was almost immediate conflict between the two fisheries each claiming that the other negatively affected catch-rates. This lead Fiji Fisheries Division to establish a pole and line zone for the main fishing season (January to June) and the phased removal of FADs previously set by purse-seiners in the exclusion zone.

3.2 FADs for Artisanal Fisheries

FADs have been far more extensively deployed for artisanal and small-scale commercial fishermen in the Pacific. Every one of the 22 nations and territories in the region (with the exception of Pitcairn) has had at least some experience with FADs, the majority of deployments having been assisted by the SPC's Deep Sea Fisheries Development Project which provided technical advice on construction and deployment and on-site training with the project's Masterfishermen. By 1983 there had been an estimated 600 FADs deployed in the region with a further 300 deployments planned for a total investment of US $ 3.75 million.

The various FAD programmes in the region have differed in the extent to which post-deployment training and research have been undertaken and the only notable (if only short-term) monitoring has been carried out in the Cook Islands, Vanuatu and French Polynesia. Given the limited budgets of the majority of Fishery Departments in the region this is not entirely surprising, but it has had significant effects on the development of FAD fisheries in the region. There has been a cycle of repeated requests for assistance to the SPC FAD team but the region has not really achieved any great degree of localisation of skills, although this is partly a result of the highly dynamic nature of appointments within Fisheries Departments in the region. In fact the failure to establish these FAD skills is a likely reason the cancellation, in 1994, of core-budget status for the SPC Master Fishermen programme.

3.3 FAD Research in the Region

The following sections will review two case studies of FAD deployment programmes, designed for small-scale commercial/artisanal fishermen, from the Pacific region. The two studies have been selected to illustrate the different situations experienced with FAD fisheries in the region and the relatively poor assessments of FAD performance in the area.

- **The Cook Islands**

The first FADs were deployed off Penrhyn and Rarotonga in 1980. An established pelagic troll fishery already existed and prior to the 1970's trolling was conducted from sailing cutters and paddling canoes. The current fleet numbers some 50 aluminium and marine-ply vessels powered by outboard motors with a large number of smaller canoes and run-abouts. The agriculture and fisheries sector employs an estimated 16.5% (1014) of the working population (FFA, 1993). The FAD deployments stimulated further development of the pelagic fishery. Regular deployments continued around Rarotonga, Penrhyn, Palmerston Atoll and Manihiki until, by 1986, 25 FADs had been deployed.

The Cook Island FADs, although deployed off both atolls and high-islands, were all located within 3 nautical miles of the coast, a relatively short distance. This proximity to the coast was possible because of the bathometry of the surrounding sea-bed; the FADs were deployed in between 1100 and 1500 metres of water.

In 1986 the Ministry for Marine Resources undertook a year-long creel census of the pelagic fishery in order to determine the real economic benefits from three FAD deployments scheduled for that year. The survey was undertaken at two sites on the north-coast (Avarua and Avatiu) and at one site on the east coast (Ngatangiia) for an overall coverage rate of 18.8%.

The prior existence of the troll fishery and the extensive history of FAD deployments meant that following the 1986 deployments, the fishing and boat skills required for the exploitation of FADs were already present in the fishery and the marketing structure for pelagic fish was well established. Market prices for fresh, whole skipjack tuna was NZ $5.00/kg on Rarotonga and NZ $3.00/kg on Palmerston; yellowfin sold for NZ $5.50/kg. By comparison, yellowfin fillets imported from Western Samoa were priced at NZ$ 7.50/kg (FFA, 1993).

Results of the survey indicated that the south-eastern reef zone maintained the highest catch-rates using trolling gear (2.6 kg/line-hr) compared with between 1.6 and the 1.9 kg/line-hr at the three FADs and 1.5 kg/line-hr for the remaining reef zones. Catch data indicated that although FADs produced larger numbers of fish, the fish caught off the reef zone were generally of a larger size. For example, yellowfin tuna recorded an average weight of 9.5 kg from reef zones as against 7.2 kg for FAD caught fish. Despite this and the larger contribution of (less-valuable) skipjack from FADs, the higher CPUE generated NZ$0.91/line-hr more than trolling in reef areas. The proximity of the FADs to shore has affected species composition with a higher proportion of reef-associated predators caught (especially Wahoo, *Acanthocybrium solandri*) than is typical of catches from FADs deployed 5-10 nautical miles off shore.

Although data was reported that indicated the breakdown of effort between FADs (43%) and reef-edge (57%) sites, there was no reference to the break down of this effort between the three ports surveyed. One of the major factors to consider when deploying FADs is the target fishing group; it would be interesting, from the view point of determining the relative economic benefits to each port of each FAD, to have a breakdown of net revenues for FAD sites and the reef-edge by each fishing port. Data is presented on catch-rates and total effort at each site and the number of trips per harbour but the length (and value) of these trips is not presented. Given the proximity of FAD #4 to Ngatangiia Harbour, net returns from this FAD will be higher (for a given catch-rate) for fishermen from this harbour than from the more distant Avarua and Avatiu ports on the north-coast.

One of the significant developments from the FAD deployments was the use of mid-water drop-stone fishing (Palu-ahi) and vertical long-lining fishing techniques which yielded 4.93 mt of yellowfin and 0.628 mt of other species for a total value of NZ $26,548. The majority of the catch from this fishery was sold to the local restaurants and hotels; this was a major aim of the deployment programme: to reduce the reliance on imported yellowfin and other species to satisfy local and tourist demand.

An additional aim of the deployments was to increase safety at sea for the pelagic fishery, the Cook Islands spends an estimated NZ $3.0 million per annum on search and rescue. There has been at least one instance of a life-being saved as a result of the presence of a FAD, which of course not only aggregates fish but also fishermen, a potential rescue service (Dashwood, pers comm).

The assessment of this fishery clearly demonstrates the estimated net value of the mid-water fishery catches from FADs and the net value of catches from trolling afforded by the deployment of FADs. However, there is no information that allows comparison with the fishery prior to these deployments off Rarotonga; have the FADs increased overall production (and to what extent) or have they (though the opportunities to mid-water fish) partially re-distributed effort away from reefs?

- **Efate Island, Vanuatu**

A preliminary assessment of the efficiency of FADs set off Port Vila, the capital of Vanuatu was conducted by ORSTOM scientists in 1990. The costs of the FADs, deployed some 10 miles off Port Vila itself, were met by funds (and through the provision of hardware) from aid-donor nations and were therefore not included in the overall economic analysis.

This analysis reported that starting a fishing enterprise based on utilising FADs is not a viable proposition for small-scale commercial fishermen in Port Vila, Efate Island. It is argued however that the lack of comparative data (pre-FAD and non-FAD), in particular the lack of data for lease vessels and the economic performance of other sectors of the fisheries of Efate, makes judgements based on the data presented invalid.

The costs involved in the initial outlay of capital to equip a fishermen with a suitable vessel (Hartley monohull of LOA 5-7 metres), engines and reels is calculated at US $5,760. Capital loans are granted with an amortization period of 8 years and therefore the capital equipment replacement cost over this period is US $4,360. The annual repayment of the loan was calculated at US $1,398 (Lindley, 1990) (this figure was not reached by calculation of compound interest, the true figure would be US $1,905).

The research points out that the optimum profit generated by trolling around the FADs, which are located 2 hours from Port Vila (4 hours round-trip) is attained after 4.5 hours of trolling at a mean catch-rate of 10.3 kg per line-hour (assuming 2 lines per vessel). The profit received is US $11.91, approximately 11.8% of the total revenue generated from the fishing trip. Cillauren points out that for vessels leased from the Fisheries Department the percentage the leasee is guaranteed from fishing is 20% of Gross Revenue and that fishing the FADs is an unattractive option for fishermen. While this is clearly true for the data presented by Cillauren, there is no reference made to the actual mean revenue received by fishermen in the lease scheme. A fisherman operating under the lease scheme would have to obtain a Gross Revenue of US$59.55 per trip to equal the mean profits from the FAD fishery. Without this comparative figure observations on the percentage returns on total revenue are useless. If the FAD fishermen leased a vessel from the Fisheries Department and fished the FADs (obviously assuming that the optimum fishing effort was applied at the stated catch-rate) he would receive US $ 20.21. Of course the advantage (from the point of view of the Government) of the situation described is that the fishery is developed (and the risk borne) by private individuals rather than the Fisheries Department.

In terms of economic analysis how does the fisherman's investment perform in relation to the minimum required by the Vanuatu Development Bank's criteria? Using the concept of Internal Rate of Return (IRR) and assuming that the initial investment in the vessel and additional equipment (engines etc) is all paid in the first year (of the 8), then the (financial) IRR generated in this scenario is 45.2%. This figure is well above the 6% that is generally regarded as a minimum return on investment for agricultural projects in Vanuatu (Blust, pers comm). In addition, although profit levels are negative in Year 1, subsequent years show a profit (profit as a percentage of total revenue) level of 47% (the catch-rates, costs etc are all assumed constant over this period).

Cillauren concludes that 'Trolling, as carried out in South-West Efate around FADs,....is not really a viable proposition' and suggests that there are two options for the Fisheries Department to consider. Firstly, that access to FADs is facilitated either by improving direct access on the coast closer to the FADs or by deploying FADs closer to Port Vila. Obviously a reduction in the variable costs through a reduction in travel time will improve the profit margin of fishermen, assuming that aggregation is not affected by proximity to the coast. The second recommendation is the development of mid-water fishing techniques by the fishermen, permitting the targeting of large, high value yellowfin tunas (and other species) suitable for the sashimi market. The international airport of Port Vila would permit export of such fish to the lucrative markets of Japan. In reality the profitability of the fishing operation around the FADs off Efate is likely to exceed that calculated by Cillauren; inclusion of the cost of a backup 8 hp engine is rarely considered by most fishermen (despite its obvious merits) and moreover, the opportunities to purchase a second-hand vessel would clearly be an attractive option for fishermen.

The assessment of this FAD fishery, while suggesting that it is a theoretically favourable investment for fishermen, clearly depends on the availability of data on alternative fishing opportunities, the performance of the troll-fishery sector prior to the deployments of FADs as well as data on the actual performance of the FAD fishery (relative CPUEs, total landings and values of fish etc).

PART II - RESEARCH PROGRAMME

1. *Objectives of this Research*

1.1 Assessment of the Aggregating Effect

There are two aspects that need to be considered in the context of aggregation; the biological process of aggregation and fisheries aspect (the effect of an aggregation of fishermen).

- **Biological Aspects of Aggregation**

Two basic designs of FADs were studied during this research; shallow-water FADs in Vanuatu designed to aggregate small coastal pelagics (eg *Selar* spp) and deep-water FADs in Fiji (although three shallow-water FADs were also deployed on the West coast) designed to aggregate tunas. The basic approach to attempting to assess the aggregating effect was through a combination of experimental fishing and analysis of artisanal catch and effort data.

That the majority of FADs aggregate fish is not in question, but there remains no generally accepted description of the mechanism or mechanisms of this process. This lack of understanding implies that the relationship between overall stock biomass and aggregated biomass is unknown and given the lack of suitable indices of abundance for schooling stocks there is a very real risk of over-fishing where industrial fleets exploit FADs (Floyd and Pauly, 1985). The need for a better understanding of aggregation is particularly important therefore for industrial FAD fisheries, which in turn will affect co-existent artisanal FAD fisheries.

Information is therefore required on the behaviour and quantity of biomass to be aggregated, artisanal fishery managers need to be able to estimate what level of production (both the total production and its temporal distribution) that can be expected from one or more FADs. Estimates of the potential of the fishery can then be utilised in forecasting economic performance and developing budgetary submissions.

The aggregation process is of course dynamic in the sense that once aggregated, tunas do not remain immobile but migrate through the sphere of influence of a FAD. An important aspect of the aggregation effect is therefore the behaviour of tuna schools over a diurnal temporal scale; tunas disaggregate, or become otherwise unavailable to the fishery, during some periods of the day (although the literature is contradictory on this matter which may suggest that it is very site dependant). However it is generally accepted that the best catch-rates are obtained at the so-called dawn-bite. Understanding of any temporal variation in tuna behaviour would then permit better assessment of the optimum time that fishermen should fish (perhaps related to weather conditions or seasons). This may also have implications for the design of FADs (for example, are lights on FADs, assuming that they are not required for navigation purposes, really necessary?) and would be a useful addition to any economic forecast. In addition, advice to fishermen could improve the profitability of individual fishing operations.

- **The Relationship Between Catch and Effort**

A key issue is the relationship between catch and aggregate effort; if the level of effort directed at a FAD does not reduce catch-rates then site choice is significantly facilitated. FADs can be deployed as close to ports as possible (subject to spacing and depth constraints) and potential problems of conflict arising when fishermen from other ports relocate their operations to the FAD port should not materialise; a constant catch-rate model permits limitless effort with no reduction in returns for the fishermen.

If an inverse relationship exists between catch and effort exists this not only impacts on site choice (the easier the access the larger the number of vessels likely to fish the FAD and therefore the greater the reduction in returns) but may also signify that the biomass is being affected by fishing mortality (it may also mean however, that there is some effect resulting from interference between vessels).

Understanding of aggregation dynamics can then be utilised with analysis of the dynamics of the aggregation of fishermen (possible non-linear interactions between catch and effort) to determine the overall potential performance of the fishery.

1.2 Socio-Economic Benefit Analysis

Given the level of investment required to initiate and maintain a FAD programme, it is clearly important to be able to identify what social and economic factors critically impinge on the success of FAD programmes. It is unlikely, given the diversity of social conditions and levels of economic motivation between fisheries, that a single set of required conditions could be identified. However, there are likely to be 'keystone' requirements that will lead to the success of the FAD programme. This research intended to gather not only basic economics data (eg revenues from the FADs) but also to assess the social/fisheries framework in which the FAD fishery operated and, through contact with other individuals/organisations working in the field, to build up a better understanding of this aspect of FADs. Programme failures have usually resulted from fishermens' indifference (because of poor marketing opportunities, or simply lack of motivation) or because of social conflicts which may evolve from village rivalry, user-conflicts or marketing problems. All these aspects can at least be recognised and addressed prior to FAD deployment and steps taken to minimise the risk of conflict developing; an attempt to take the guess work out of FAD programmes.

1.3 Development of Planning Aids for FAD Programmes

Given the points raised in Sections 1.1 and 1.2, the logical next-step is to develop a planning aid that brings together all these aspects. With this a fishery manager is therefore in a position to go through a relatively straightforward process of site assessment with a comprehensive set of questions and guidelines. Given the current level of knowledge (of aggregation and market response) and experience (of the social effects) of FAD deployment programmes there is insufficient justification for the development of overly complicated assessment procedures and planning aids.

Furthermore, bearing in mind the variation, at least amongst developing nations, in the availability of fishery and other statistics, the planning tool has to be relatively simple in its data requirements. The key aspect of this area of research therefore concentrated on identifying the keystone factors that appear to define use-rates, potential conflicts, marketing success etc. As a first cut keystone factors can at least identify deployment sites (including the physical aspects such as bathometry and social aspects such as the local demand for fresh fish) that are *not* suitable for FADs.

1.4 Further Modelling of FAD Programme Development

Given that the identification of keystone factors has been achieved and these have been developed into a systematic, if rather qualitative, assessment procedure, the next logical step would be the development of more complex modelling approaches. This would permit the interpretation, by computer model, of certain fishery, social and economic statistics; the output would then rank each potential site according to various criteria defined by the individual fishery manager, whether it be purely economic or with a stronger social perspective (provision of employment opportunities in an area of low investment for example). This model would have to incorporate such features as the probability of conflict arising due to different fishing gears or as a result of poor marketing opportunities. The practical utility of the increasing complexity required in this area, for example through the modelling of human behaviour, is at present difficult to judge. The development of a handbook of advice is particularly attractive because it requires only simple data and site choice is based more on the knowledge of the local situation that the fishery manager already possesses than on a rigid application of (mathematical) methodology. The additional complexity not only requires more data but also more interpretational skills; experience in the Pacific region indicates that use-rate of computer software is, *inter alia*, inversely proportional to its complexity (Preston, pers comm), development of complex 'FAD assessment' models, while certainly attractive must therefore be carefully considered.

2. *Conduct of this Research*

2.1 Linkage to SPC programmes

The Regional Technical Meeting for Fisheries (RTMF) at the South Pacific Commission (SPC) in Noumea, New Caledonia, proposed that extensive work be carried out to assess the potential value, both to fisheries and the community as a whole, of inshore, shallow-water FAD deployment. The early emphasis of the SPC FAD programme had been placed on deep-water FAD design and longevity. The 22nd RTMF delegates emphasised the need to address other aspects of FAD deployment. The principal aim was to 'develop effective technology on design and deployment of shallow-water FADs dedicated to aggregating small pelagic species (especially for bait supply) and effective harvesting techniques' (SPC, 22nd RTMF, 1990). The SPC FAD deployment programmes have not explicitly included a monitoring or assessment phase, although data from trial fishing by masterfishermen is regularly published. This project therefore provided an opportunity to assess the impact of the FAD deployments on a case by case basis to the benefit of the SPC.

The commencement of the project's first case-study (in Vanuatu) coincided with the arrival of SPC masterfisherman Paxton Wellington. As described in the separate case study reports that accompany this document, the Vanuatu field-work failed to generate data of the type and quantity required to fulfil the projects aims and objectives. Following the completion of the SPC's project work in Vanuatu the Masterfishermen had relocated to deploy deep-water FADs off the coast of Viti Levu in Fiji. The Vanuatu field-work was therefore terminated in April, 1993 and the field officer returned to London where a case-study report was produced and a project proposal developed for continuation of the work in Fiji. The Fiji component of the study began in July, 1993 and was completed in March, 1994.

After completion of the Fiji case-study, the association with SPC continued with the production of the FAD Handbook. The SPC have, over the last 2 years, been developing a FAD construction, deployment and monitoring manual and although the technical aspects of FADs had been well produced there were reservations as to the quality of the monitoring and assessment phase of the project. A joint publication was therefore planned between SPC and the ODA's Fish Management Science Programme covering FAD programme development, monitoring and economic assessment. The extensive experience of SPC staff and the work already produced provided a very useful basis for the development of the Handbook and a draft version of the Handbook was completed during a six-week period spent by the project officer in Noumea. The Handbook has now been edited by MRAG staff and publication is currently planned for late July 1994. Prior to this work the project officer presented a report on the findings from the Fiji case-study at the bi-annual Regional Technical Meeting on Fisheries held at SPC during March.

2.2 Case Study Summaries

- **Vanuatu**

In April, 1990, the Vanuatu Department of Fisheries requested the assistance of the SPC to prepare a FAD programme proposal and assist in FAD deployments. The Vanuatu Government defined the aims of the FAD programme as :

1) To increase fish landings from FADs to alleviate shortages of fish in the main fish markets of the capital Port Vila and at Luganville on Espiritu Santo.

2) To increase catchability of baitfish resources.

3) To stimulate development of rural fisheries throughout the country.

In response to this request, an SPC Masterfisherman was assigned to the Vanuatu Fisheries Department in Luganville, on Espiritu Santo island. The aims of the SPC programme in Vanuatu was to deploy deep and shallow-water FADs and to develop suitable fishing techniques, especially for the capture of baitfish species such as *Decapturus* spp and *Selar* spp.

While the SPC mandate was originally to concentrate on technical aspects of FAD deployments and fish capture, there was no planned assessment of the effect of the FADs on fishermen. This project commenced in September, 1991 with the aim of assessing the nature of the interaction between shallow-water FADs and artisanal fishermen. Three deployments around South Santo were carried out but pre-deployment surveys were not carried out; subsequent monitoring of the FADs concentrated on both aggregation of small pelagic species (in the absence of any significant contribution by the SPC programme) and on the reaction to the FADs of the artisanal fishermen. Problems were experienced both in data-collection and trial fishing with the former abandoned completely in September, 1992; schools of scads (*Decapturus* spp and *Selar* spp) were observed in the vicinity of the two deeper FADs (Urelaber and Elia) but fishing activity was rare and appropriate fishing techniques not developed. Observations using SCUBA appeared to confirm the role of shallow-water FADs providing some shelter from predators through their habituation to the presence of the mooring line and aggregating material. The FADs also proved successful in providing suitable settlement habitats for reef fish juveniles (Kyphosidae, Carangidae, and Pomacentridae), although the extent to which the FADs actually aggregated these larvae and juveniles was not examined.

Overall the FADs failed to aggregated fishermen; observations and discussions with local people suggested that the fishing gears available to the artisanal fishermen was inappropriate (particularly the reliance on 3-4metre dug-out canoes); fishing was not of high priority in the village for which the FADs were targeted and the adjacent reef environments offered easier fishing opportunities. The extent of the probable decline in the importance of fisheries in this area can be seen through the termination of the SantoFish collection/delivery service.

In attempt to improve the options of the project, second-phase deployments were undertaken in the Segond Channel and to the north at Port Olry (on Espiritu Santo). The sites in the Segond Channel too were unsuccessful in aggregating fishermen and also appeared to aggregate small pelagics only ephemerally; it was hypothesised that the strong current in the Channel did not encourage aggregation around these FADs.

Fishing activity at the site at Port Olry was monitored prior to the deployment of a single FAD in 40metres. This village is fronted by a shallow lagoon and is the largest producer of small pelagic fish on the island, there is a (seasonally) active fleet of 50 canoes and the village is serviced by the SantoFish collection truck. Fishing was monitored and the views of fishermen sought to assist in the choice of site. A FAD was deployed in October, 1992 some 500 metres from the shore in an area through which small pelagics were known to migrate; villagers were encouraged to fish the FAD and advice offered on trolling (with simple feathers) and the use of simple fish-traps (2 of which were provided). Although fishing continued in the village after FAD deployment there was no record of any fish being caught off the FAD, a few fishermen reported that they had visited and fished but had lost their lines to barracuda. During observations by the project staff, no aggregation was noted with the exception of the reef species noticed around the FADs in South Santo.

Following the failures of the FAD programme to aggregate fish or generate information on aggregation itself the project was relocated to Fiji where the SPC had been requested to assist in a deep-water FAD deployment programme off Viti Levu.

- Fiji

This phase of the project commenced in July, 1993. Two deep-water FADs (Nasese and Mau) had been previously deployed off Suva Point in April, 1993 by the Fiji Fisheries Department in collaboration with the SPC deep-sea fisheries programme; both these FADs were of the Spar-Buoy design. The FADs were planned to provide opportunities for fishermen operating out of the Suva area, as stated by the Fisheries Division to '..ease commercial pressure on coastal reefs and lagoons...especially those around urban centres' (Anon, 1982). Although FADs have been deployed in Fiji since at least 1981 there had been little data collected on their real social or economic value; with the FAD budget for 1994 in some doubt there was clearly a need to undertake a thorough assessment of the FAD programme.

Three field sites were chosen; Nubukalau Creek Market in Suva, and the west coast towns of Lautoka and Ba, the latter two sites did not have FADs at the time of project commencement but deployments were planned. FADs deployed subsequently were not successful and no evidence of targeted fishing was available; the Fiji country report therefore concentrates solely on the Suva site, it is intended to compile a report on the substantial quantity of fisheries data from the west coast fisheries in the near future.

Total sales from the reef fishery of the Central Division (incorporating Suva) have declined from an estimated 3200 mt in 1985 to approximately 1800mt in 1993; analysis of historical data reveal that virtually all the major families (Lutjanidae, Scaridae, Acanthuridae, Serranidae and Lethrinidae) have declined. Nubukalau Creek market on the other hand has shown an growth in sales since 1985, reflecting the strength of the urban market and the increasing demands of the hospitality industry.

A total of 42 fishermen were known to have used the FADs of whom 8 contributed 60% of total landings; the majority of fishermen were either recreational but when full-time had not generally been reef fishermen, although a number had been involved with the spear fishery. Approximately 90% of the marketing was undertaken by the FAD fishermen themselves or by their wives or relatives.

A total 366 fishing trips were monitored during the survey period with estimated landings of 29.3 mt of skipjack tuna (*Katsuwonus pelamis*) and 5.7 mt of yellowfin tuna (*Thunnus albacares*) were sold at Nubukalau Creek market valued at F$63,933; this yields an approximate benefit/cost ratio of 4. One of the most significant developments during the project was the sales of sashimi quality tunas (primarily yellowfin) to a local export company, FijiFish Ltd, worth an estimated F$ 15,780.

Analysis of data did not reveal any relationship between aggregate effort and catch, but with the possibility of constant recruitment and relatively low effort levels this was expected. There was however a strong negative correlation between the length of fishing trip and catch per line hour ($R^2 = 0.86$) confirming the role of time of day in determining catch-rates. There was no significant difference between catch-rates between the two FADs.

Following the presentation of an information paper at the SPC's Regional Technical Meeting on Fisheries in New Caledonia in March, 1994, the Fiji Fisheries Division confirmed that funding for future FAD deployments would be guaranteed and that they would in fact look to increase the annual budget.

2.3 Output : Production of a Planning Tool

The initial results from the research undertaken in Vanuatu appeared to suggest that assessment of the potential response of fishermen to the deployment of FADs was difficult. It appeared that decision-making and project planning programmes intended for artisanal fisheries can not be undertaken following rigid, quantifiable parameters (such as the status of alternative fishery stocks).

However, the second phase of fieldwork, in Fiji, has lead to the development of ideas that suggest that the potential success of FAD programmes to aggregate fishermen, assuming a minimum level of fishery development, may be possible. Although currently only developed as a handbook of ideas and questions, there are no reasons to believe that, following the collection of more data-sets of economic and sociological data, a more complex, bio-socioeconomic model could not be developed with the aim of producing a tool that further facilitates development of FAD programmes. Through the research activities of this project it has become clear that despite the large quantity of anecdotal evidence of the success of FADs in general there is little data; the continuation of funding for FAD deployment programmes (previously in some doubt in Fiji for example) clearly requires that fishery managers develop a more systematic approach to deployment and subsequent monitoring, permitting the presentation of rational and justifiable budget proposals to Government as well as a realistic expectation of the benefits to flow from the deployment of FADs.

The Handbook, prepared in collaboration with the SPC, is designed to take the fishery manager stepwise through the entire process from site choice to estimates of economic return, recognising that conflicts between user groups is as likely to derail the success of the FADs as is the failure of the FADs to aggregate fish.

Chapter 1 is a basic introduction to fish aggregation devices and includes information on potential fishing gears and an explanation of the notion of FAD programmes (as opposed to *ad hoc* FAD deployments) which is believed to be the key to maximising the returns (both to the fishermen and the Government) from the FADs. Chapter 1 also covers ideas on the potential benefits of FADs; these benefits are not limited only to improvements in the efficiency of a fishing operation but also include observations on the benefits that can arise from the use of FADs as foci for small-scale economic development, improvements in safety at sea and the opportunities to improve food supply.

Chapter 2 of the Handbook introduces the importance of planning programmes; FADs do not always work as they were hoped to and this chapter is intended to stimulate objective assessment of the real need for FADs. Of critical importance is the need for a wide-ranging pre-deployment assessment encompassing physical aspects of site choice as well as post-deployment requirements such as marketing potential and the risk of conflict between (or within) user-groups. Many FAD deployments, for example in the Pacific region, have not considered the impact of increased supplies of fish on market price (and hence the profitability of the fishing operation). Poorly conceived FAD deployments can not only have effects on those individuals concerned directly with the fishery, but also for relations between Fishery Departments in general.

Chapter 3 discusses the importance and some simple techniques for the monitoring of FAD programmes. The importance of this aspect of FADs has become clear during the course of this research; the majority of FAD programmes have not undertaken monitoring of their performance and subsequently budgets remain contested. Monitoring also provides real-time data on the potential for conflicts which can jeopardise an entire programme at great cost to both Government and the Fisheries Departments.

Finally, Chapter 4 begins to develop approaches for the development of indicators of the economic performance of a potential FAD programme (or programmes). This has been identified as an essential aspect of the future development of FAD fisheries with budget restraints and the demand of donor-agencies that projects to receive assistance be well structured and have clear goals and indicators of performance; this is encapsulated in the current popularity of Logical Frameworks in project definition.

It should be emphasised that this handbook has been developed not to provide black-box advice rather it is intended to stimulate the questions for which answers fishery managers generally have the answers. However, it is intended that further research be undertaken on a number of aspects of FAD fisheries both in terms of a better understanding of the aggregating effect and in terms of assessing the socio-economic framework required for effective use.

PART III : CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

1.1 On the Aggregating Effect

No real evidence was unearthed as to the mechanisms behind the aggregation of tunas around FADs, primarily due to constraints on the project, the failure of the shallow-water FADs in Santo to aggregate suitable quantities of fish and partly because of the difficulty in organising regular trial fishing trips to the FADs off Suva in Fiji. In hindsight the decision to monitor both west and east coast sites in Fiji was a mistake but despite this with the facilities available determination of aggregating mechanisms was always going to be difficult. However a number of interesting observations were made.

- **Shallow-Water FADs**

The shallow-water FADs off Espiritu Santo were observed to aggregate only sporadically and it is thought that the presence of numerous natural features in the area around the FADs (small islands and reef patches) 'diluted' the aggregating potential of these FADs. Observations of FADs deployed at shallow, open water sites off Panama City indicate that FADs can aggregate large schools (1000,s of fish) regularly in areas where natural aggregators are largely absent. Shallow-water FADS did provide a settling place for pelagic larvae of reef-associated species (eg *Gnathodon speciosus*; *Abudefduf* spp). Aggregation of pelagic larvae and other planktonic organisms may also be an important factor in determining the attraction, at least for shallow-water FADs. Observations using SCUBA during this research seemed to confirm that schools of small-pelagics do behave in the manner postulated by workers who believe predator avoidance is a factor in aggregation. Aggregated species become conditioned to the presence of the mooring line and aggregator but predators, who are not conditioned, are 'spooked' by the line and break off the attack.

- **Deep-Water FADs**

In Fiji, the re-deployment of the deep-water Mau FAD and the subsequent concentration of fishing effort on this single FAD suggests that FADs can either cause tunas to aggregate in areas of sub-optimal habitat (defined by relative prey-abundance), or that the level of aggregation by a particular FAD is determined by the seasonal availability of food resources within its sphere of influence. This has important implications for determining the potential returns from a FAD programme as well as determining the location of FADs within a identified 'tuna habitat'.

The Mau FAD is located within an area believed to be of higher productivity resulting from the upwelling of water over the shallows of the Beqa Channel; the sea-bed bathometry is also characterised by a number of steep submarine valleys thought to be favoured by tunas. The Mau area is generally considered by local fishermen to be the best area for tunas. However, prior to the re-deployment of Mau FAD the majority of fishing effort was centred on Nasese FAD to the east not open-water sites around the Mau Passage area where one might expect fish to congregate. Following its re-deployment all successful fishing effort for a period of 8 weeks was concentrated at Mau FAD, it appeared that the tuna aggregated at Nasese had simply relocated to the Mau FAD.

A possible explanation for this is that the distribution of prey items is in seasonal flux in the water-body to the south of Suva, aggregation around the nearest FAD (or not when they remain in free-swimming schools) is therefore determined by local prey abundance. But, given that the deployment timing of Mau FAD was basically random, it is unlikely that it coincided with a sudden increase in prey abundance around the Mau area.

Assuming therefore that the tuna aggregated around Mau FAD because it is gives some advantage, the previous aggregation around Nasese must have been a sub-optimal location. If the tuna were aggregated in an area of sub-optimal prey abundance there are likely to be additional explanations for the aggregation effect, some other advantage that might outweigh the fact that food resources may not be optimal; alternatively this behaviour is innate, there is a genetic/behavioral imperative to aggregate.

The final alternative is of course that the fishermen specifically targeted Nasese FAD because they assumed that it would be the most productive site but in the area in which Mau FAD was subsequently re-deployed tunas were constantly present but simply not exploited by the fishermen. Given that fishermen always seem to know where the fish are and probably undertake short searches around the area when catch-rates drop on the FAD, it is maintained that the peak aggregations were at Nasese only during this period prior to deployment of Mau FAD.

The issue is further complicated by the observation that from late-December fishing became more evenly spread between open-water sites and the two FADs, possibly reflecting an increased abundance of prey items or more even distribution.

1.2 On Depth and Spacing of Deployments

Deployment of FADs off Suva followed the generally accepted requirements of spacing (4-5 miles) and depth (> 1000 metres) and therefore no comparison with FADs deployed within the accepted 'minimum distance' were possible. However fishing effort was not evenly distributed between sites during the period of research. During the wet-season fishing was concentrated first on Nasese FAD and then, following its redeployment, on Mau FAD to the exclusion (for 8 weeks) of Nasese. The question is whether Mau FAD attracted fish away from Nasese during this period or whether, as discussed in 1.1, the migration away from Nasese was in response to changes in the distribution of prey. It was unfortunate that the Mau FAD was lost; it is impossible to know whether the tunas would have aggregated around Mau FAD year-round (further confirmation will be sought from Fiji Fisheries Division). However, the dispersal of effort over both FADs and open-water sites since late-December would seem to suggest that the optimal spacing of FADs within a 'tuna habitat' of a particular size is determined by abundance and distribution of prey in relation to the position of the FADs and that deployments *within* the minimum distance would be viable during certain times of the year.

1.3 On the Sector Performance

There are a number of conclusions that can be drawn from this work, particularly from the results obtained in Fiji. It has often been quoted that the increased landings of tunas resulting from FAD deployments can de-stabilise fish markets leading to a spiral of conflict and ultimately even shootings at sea (Preston, 1991). The diversity of outlets, the development of the highly valuable market with FijiFish and the large amount of recreational/subsistence fishing on the FADs have meant that prices in Nubukalau Creek market have remained steady too date. The group of 8 FAD fishermen often commented that their fishing effort was to some extent limited by what they thought they could sell for a given price, there is therefore some degree of self-regulation in the marketing of tunas. However, these observations and those made of the fisheries in Vanuatu suggest that where natural resources are abundant and the standard of living relatively high, there are strong cultural breaks on entrepreneurial spirit rather than higher and higher levels of exploitation. This cultural imperative implies that the reaction of artisanal fishermen to FADs will be strongly context sensitive.

2. *Recommendations for Future Work*

2.1 Biological Research

The basis for all biological research should be aimed at understanding the exact nature and driving forces of the aggregation effect itself. It has been argued in Part I : Section 1.3 - FAD Aggregation Theories, that the most reasonable explanation for the aggregation of the bulk of FAD-associated biomass is that FADs either aggregate prey items or mimic natural aggregators where prey items (or general productivity) are higher. In association with this there is also likely to be some 'forage-base' component, given the horizontal scale over which FAD associated fish have been observed to feed, particularly for the skipjack and juvenile yellowfin tunas.

It is therefore recommended that research funds be directed at researching the productivity of natural aggregators (logs, whales, etc) in terms both of primary productivity (especially where such natural floating objects aggregate along, for example, current lines) and in terms of the diet and energetics of associated tunas. Are there significant differences between schools found at such locations and schools elsewhere? Secondly, more detailed analysis should be carried out on the productivity of waters around FADs and on the dietary composition of FAD associated tuna species (of different size-classes). It has already been shown by a number of researchers that the larger, deep-swimming tunas have significantly different diets when associated with FADs, whether it be olophorid shrimps off Hawaiian FADs (Brock, 1985) or juvenile tunas around FADs in the Philippines (Yekasi, 1983). Does this behaviour occur with FAD populations throughout the world ?

Determination of indicator characteristics of FAD-associated diet, possibly in association with seasonality, currents or other oceanographic conditions, may lead to site choices based on such characteristics. Therefore are 'pre-deployment' surveys a useful tool for assessing or ranking potential FAD sites?

From a practical perspective such research could be expensive but a possible approach would be to station a research officer on commercial purse-seine vessels which would fish at precisely the locations from which data are sought. For the SPC region at least, detailed knowledge of each DWFN's preferred target sites (natural FADs, anchored FADs, free-swimming schools) are known and data could therefore be collected at a number of different sites of aggregation. Such work could be coordinated with the SPC's current observer programme.

Although the larger purse-seine (and possibly pole and line) vessels can take significant proportions of a single aggregated biomass, artisanal fleets have such low aggregate effort levels, compared to industrial catches, that it is unlikely there is a significant depletion of biomass caused by artisanal fisheries alone.

However, care must be taken regarding the use of traditional indicators of biomass abundance, namely CPUE. If recruitment to FADs is a continual process, the rate of which is determined by a density-dependent relationship, then clearly any declines in overall population could be masked if FADs were the principle target for the effort of the fishery (there would be no comparative data to identify declines in open-water catch-rates/total catches).

If the rate that tunas aggregate at FADs plus non-FAD mortality exceeds the growth rate of the population in general, then high fishing mortality at the FAD can severely affect the total exploitable biomass. There is therefore a need at least for research to quantify the dynamics of recruitment to FADs (fishing mortality and population growth rates are relatively simple to quantify). Is the rate of recruitment density dependent at the FAD or dependent on the background population size (or density). The most useful tool in this area is likely to be tagging studies over a small spatial and temporal scale, a technology which already exists.

Elucidation of the aggregation process should go some way to explain the variability and seasonality of catch-rates. This is an important aspect to understand because, as reported for Fiji, catch-rates and total catches at FADs can be very seasonal; if an established pelagic fishery exists then fishermen have increased options and reduced expectations of the FADs. If the FAD fishery dominated all the landings of tuna seasonal variations in catch-rates (especially when tunas migrate out of the area) could create problems for fishermen who have either to accept lower profit margins or target alternative resources (eg reef fisheries). A number of other FAD fisheries have been shown to display seasonal catch-rates (eg Mauritius) and understanding seasonal catch-rates not only prepares fishermen for reduced catch-rates but also makes the expected economic performance of the fishery (and therefore the chane of the Fishery Department achieving the intended goals of the project.

2.2 Economic Research

This research project has indicated that the behaviour of artisanal fishermen is a complex interaction between biology, economics, and sociology and to assume that fishermen will be attracted to the fishery for profit maximisation alone is probably an over-simplification of the situation. The use of simple economic indicators (eg Internal Rate of Return or Benefit/Cost Ratio) remains a valid tool for preliminary assessment of the possible returns from FADs (Fisheries Departments would clearly like to make the most efficient use of their limited funds); it would be useful therefore to compare the performance of various FAD programmes around the world and assess the success of these in terms of their stated objectives. Where FAD programmes have under-achieved in terms of production increases, employment enhancement or profitability what is the economic context of this failure and can aspects of this context be parameterised.

Where possible data-sets should be obtained (for example from the Comoros Islands, the Maldives and the Philippines) that describe not only current FAD fishery economics but also, for example, local economic opportunities, alternative fisheries resources and the relative contribution of FADs to the overall fishery. Can a set of parameters be identified that can enhance any assessment of the potential success of a FAD programme? Can fishery managers, using appropriate weighting for these parameters, place confidence in a model that would predict (estimate) the economic behaviour of a FAD fishery.

2.3 Sociological Research

This is the third aspect to consider in terms of developing a FAD model. This aspect of interaction is one of the most important, the number of FAD programmes that have failed, not because of lack of fish, but as a result of conflicts between and within user groups is significant (eg Western Samoa, Vanuatu, Kiribati, New Caledonia, Cape Verde Islands, Dominican Republic).

Unfortunately, because of the complexities of cultural differences and social interaction in general, it is also one of the most complex areas for research and modelling. Fishery managers clearly need to be able to anticipate problems of social interaction between fishermen that are precursors to conflict and possible failure of the FAD programme. These interactions are likely to be highly context sensitive, therefore inclusion of human behaviour in any model needs to be carefully considered. For a given 'behavioural' parameter (eg. the demand for employment or the level of community rivalry) site specific weighting could be applied. This concept has been used, in a simplified form, in Chapter 3 of the FAD Handbook that accompanies this document; during the site selection process the risk of conflicts for example is considered and sites discarded when appropriate. Research therefore needs to identify various parameters of human behaviour and assess the effects they will have on the overall success of a FAD deployment programme.

There is a second area that impinges on the question of relations between fishermen in general, that of FAD ownership. Industrial fishing companies that deploy FADs (particularly those in the Philippines) have adapted to problems of poaching and vandalism by enlisting the cooperation of artisanal fishermen who, in a symbiotic relationship, guard the FAD (and notify the company when large aggregations have developed) in exchange for rights to fish the deep-swimming tunas that are not targeted by the fishing companies.

For FAD deployments undertaken and paid for by Fisheries Departments the majority of problems derive from the open-access nature of the fishery and the inevitability that some individuals take it upon themselves to become custodians of the FADs, to the exclusion of other individuals with equal rights of access. There has been much talk in the literature on the need for private fisheries enterprises to become involved in FAD deployments, which are essentially just another fishing gear. In a number of communities of fishermen in the Maldive Islands (northern Indian Ocean), fishermen's cooperatives or fishing villages have been encouraged to contribute funds to the deployment of FADs, the balance contributed by the Government (which maintained a share of the investment so that the very poor fishermen would have access to the FADs).

One should however consider the nature of the fishing operation itself; in the Maldives, fishing involves vessels with a number of crew (and is generally more cooperatively carried out), but the majority of the current FAD fisheries, in the Pacific for example, are undertaken by smaller vessels with perhaps one or two crew, there is therefore a greater degree of individualism as opposed to cooperation in the fishery. The strength of culture in some of these areas however (as described in the Vanuatu case-study, in general mitigates against private fishermen investing in their own FADs. Furthermore, while 'urban' fisheries may not be entirely suitable for this type of cooperation, village level cooperation is much more likely and the example quoted from the Maldives indicates that this is an avenue that warrants further research.

2.4 Final Conclusions

All the aspects involved in the success of a FAD fishery are clearly inter-related; for example high production can lead to reduction in price leading to conflicts between user groups; alternatively production may increase in response to increased demand (resulting from the lower price) and the lower price is offset by reduced costs of production.

The two case-studies carried out during this research have highlighted the fact that successful FAD programmes usually involve more than just the deployment of FADs; a host of conditions need to be fulfilled. The completion of the FAD Handbook is a first cut at developing an holistic approach to FAD programmes and is particularly suited to less-developed fisheries. The use of simple indicators of performance (eg IRR, NPV, B/C Ratio) remains valid but there is clearly a need to include feed-back loops, at least to allow for the effects of supply and demand on price and how this may affect production.

Many FAD programmes have been undertaken in more developed economies and fisheries but have often failed for the very same reasons that are quoted for artisanal fisheries (socio-economics). There is a need therefore to develop a bio-socioeconomic model that can be utilised for a more accurate assessment of the potential of a FAD programme, where expectations of these interactions and feedbacks can be explicitly included in the assessment of the programme.

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