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FISH AGGREGATION DEVICES IN THE PACIFIC ISLANDS REGION

(Paper presented by the Secretariat)

The attached paper, entitled "Fish Aggregation Devices in the Pacific Islands Region", was prepared by the Commission at the request of FAO and presented at the Indo-Pacific Fisheries Commission's Symposium on Fish Aggregation Devices and Artificial reefs in Colombo, Sri Lanka in May 1990. It is tabled here for the information of participants and to assist with discussions during the FAD workshop to be held as part of the present meeting.

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South Pacific Commission

FISH AGGREGATION DEVICES IN THE PACIFIC ISLANDS REGION

by

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Prepared for

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Summary

This paper summarises the historical development of Fish Aggregation Device (FAD) programmes and the major issues that concern FAD utilisation in the South Pacific Commission (SPC) region at present. The paper is intended to refer only to anchored FADs: there is no reference to artificial reefs, which are essentially unused in the region.

Because of its currency, as well as the paucity of documentation on Pacific Island FAD programmes, much of the information contained is necessarily anecdotal and/ or speculative. References are provided where written sources have been used.

SPC's historical and possible future involvement in FAD-related issues is also discussed.

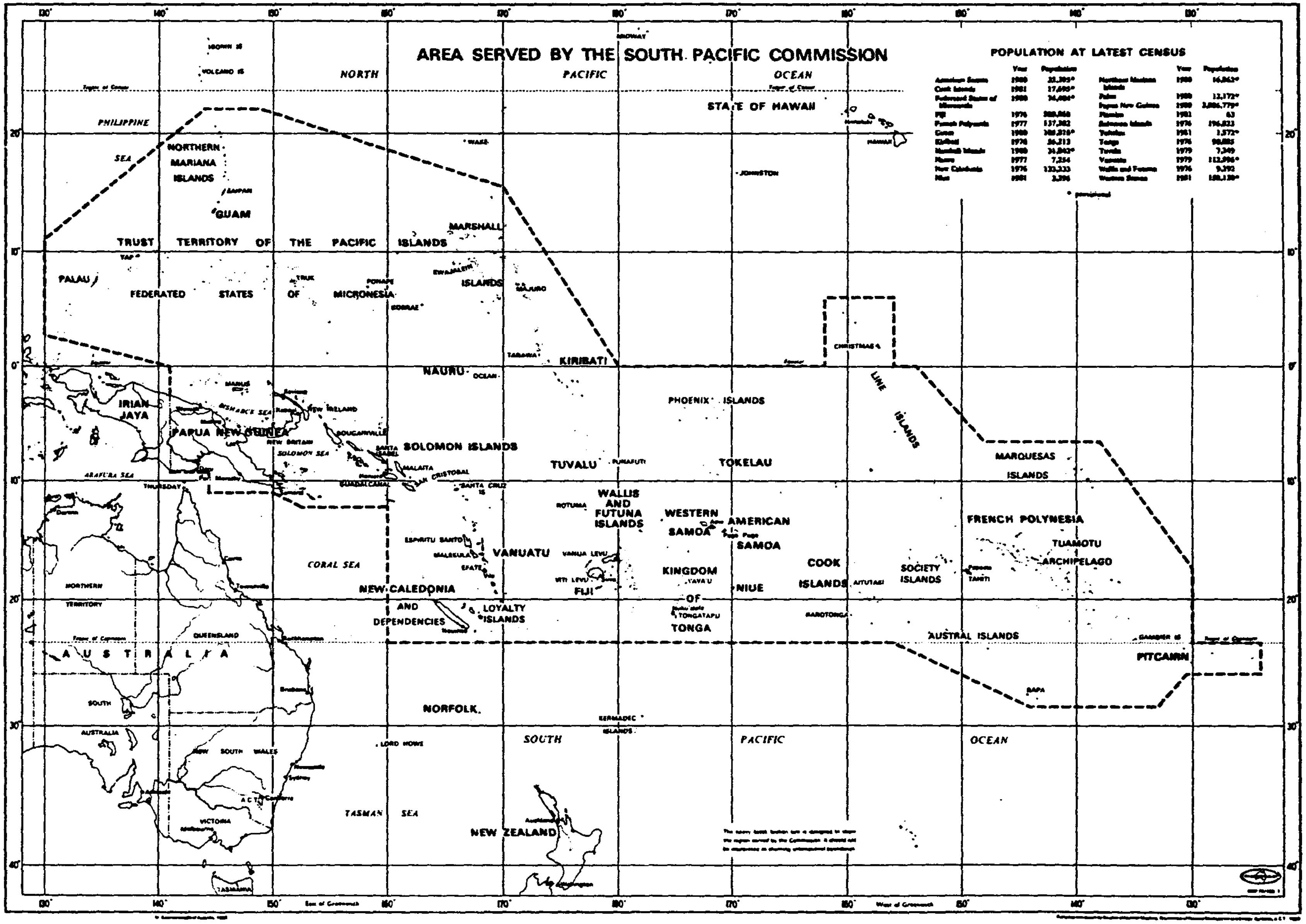

Figure 1: SPC area of operations

FADs in the South Pacific region

Background

The SPC operational area is shown in figure 1. It contains 22 Pacific Island countries and territories with a diverse range of cultures and physical environments, from the resource-rich continental islands of Melanesia to the tiny isolated islands and atolls of Micronesia and Polynesia. The SPC region has a combined total area of over 20,000,000 sq. km., of which only 2% is land, and a further 2% shallow enclosed or coastal seas. The remainder is deep ocean.

The level of fisheries development in Pacific Island countries is as varied as the countries themselves. Fishing activities range from very low-technology subsistence activities such as reef gleaning, diving for seafoods, and spear fishing; through small-scale artisanal fishing with nets, hooks and lines, or other gears, sometimes on a commercial or semi-commercial basis; to larger, more sophisticated vessels such as pole-and-liners, longliners and prawn trawlers operating in nearshore waters; and finally to high-technology fisheries, such as tuna purse-seining, usually offshore.

FAD programmes

FADs have been in use as fishery resource enhancement tools in the SPC region for over a decade. Boy and Smith (1984) reported that, as of March 1983, over 600 FADs had been deployed by 23 countries and territories in the region, with a further 300 deployments planned at the time. At an average unit cost of about US$3,000, an overall investment of some US$ 2.5 million had already been made, with an additional US$ 1.25 million planned. These figures are the most recent presently available for the region. However, an ongoing SPC study scheduled for completion in August 1990 should provide more up-to-date information on the degree of commitment to FAD programmes by Pacific Island countries since that time.

The rationale for using FADs in the region varies from country to country. In all Pacific Island countries except Pitcairn FADs have been deployed by governments wishing to foster subsistence or artisanal fishing activities for a variety of reasons, such as to improve the productivity, economics or safety of small-scale fishing operations, or to divert fishing effort to less heavily exploited resources. In three countries (Papua New Guinea, Solomon Islands and Fiji) they have also been deployed in large numbers by industrial fishing operators who benefit from improved catch rates or reduced scouting time and associated travelling costs.

All FADs deployed by government or public agencies and small private fishing groups are anchored to the seabed in coastal waters in positions intended to be accessible to small-boat owners. In almost all cases they consist of a surface raft or buoy moored to a heavy anchor in deep water (500 m plus). The floating part of the FAD usually (but not always) has appendages suspended from it to improve its aggregating ability. These are usually improvised from available materials such as palm fronds, netting, strings of tyres threaded on ropes, etc. Occasionally sub-surface FADs are used, in which the buoy is moored below the surface. These are not common, but appear to have potential that warrants further investigation, especially in shallow water areas.

In addition, free-floating (non-anchored) FADs are deployed by industrial fishing concerns. These are used in oceanic areas and their position is monitored by the use of radio marker beacons. Their use is exclusive to the industrial purse seine fishery and they are not considered in detail in this paper except where the information also applies to anchored FADs.

Problem areas

Irrespective of the reasons for FAD deployment or their specific design features, problems still remain in optimising their use. Despite the generally accepted benefits that FADs can bring to both industrial and smaller scale fishing activities, and the large sums of money that have been spent on FAD deployments, FAD loss rates in the region remain unacceptably high. Important questions that were being asked in the early 80's about the cost-effectiveness of FADs, the way in which they work, and their effects on fishery resources, are still being asked as we enter the 90's. Despite commitments to improved understanding of FADs by the governments and fishery agencies of the region, there remains a dearth of factual and quantitative information on all aspects of FADs and their associated fisheries.

A coordinated approach to research and development work is still needed in the areas of FAD engineering, methods of exploiting FAD-associated species, the biological effects of FADs on fishery resources, cultural and social issues relating to FAD programmes, and the economics and management of FAD-based fisheries. The following sections discuss these issues in more detail.

FAD Engineering

Design

In the late 1970's and early 80's, the reported success of experimental FAD deployments in Hawaii, together with mainly anecdotal information on the payao fisheries of the Philippines, created considerable interest in FADs in the region and paved the way for their rapid introduction into Pacific Island countries. Early FAD programmes were driven by enthusiasm and by the promise of improved fishery opportunities, but were generally not backed by engineering experience appropriate to the design and construction of deep-water moorings. During this period, most FADs were constructed and deployed according to principles more appropriate to shallow water moorings, and as a result FAD longevity was low and loss rates were high (see, for example, Preston, 1982). The difficulties of detecting the causes of FAD mooring failure, plus the absence of a coordinated means of studying the problem, caused this situation to persist for several years.

In 1984, country concerns about persistent FAD losses and the growing level of investment in FAD programmes led to a regional study by the SPC of FAD programmes and associated engineering practices. The study (Boy and Smith, 1984) determined that in March 1983 over 80% of all FADs set in the preceding three years had been lost, most within 12 months of deployment. Average FAD life expectancy region-wide was estimated at 9-12 months, and no FADs were reported to have survived for more than two years. The study attributed these factors to a number of specific mooring-line problem areas, including:

> the extensive use of counterweights on floating-rope moorings (or, conversely, floats on sinking-rope moorings), which led to underwater tangling, and subsequent weakening, of mooring lines. This was a particular problem where very long anchor line scope was allowed;
>
> the use of dissimilar metals in mooring components. This led to galvanic action between, and rapid corrosion of, metal mooring parts, especially where stainless steel was used for some components;
>
> the use of inappropriate rope terminations for mooring segments, and in particular the use of eye splice thimbles intended for wire rope, which led to failure of rope connections.

An important outcome of the study was a comprehensive series of practical recommendations on FAD design and construction methods. The most important of these was the use of a composite nylon/ polypropylene mooring line calculated to form a slack inverse catenary when correctly deployed. The new design provided adequate scope for depth measurement errors during deployment, and for variation in current strength after deployment, while avoiding the line tangling problems associated with the use of counterweights or counterfloats. Balanced lengths of sinking nylon rope in the upper part of the mooring and floating polypropylene rope in the lower part ensure that all the scope is contained within the catenary loop and prevent the mooring line from either sinking or floating during calm weather.

Other recommendations included the balancing of metal components to eliminate galvanic interaction, and the use of specially designed rope termination fittings. All the suggested improvements were backed up by detailed technical data to enable selection of the correct components for any given situation, as well as information on appropriate sources of hardware supply. Some working techniques not in common practice, such as the splicing of torque-free braided ropes, were also illustrated in detail.

The study had a major impact on FAD programmes in the region and the recommended SPC design has been adopted in principle by almost all countries and agencies presently involved in deploying FADs. As a result, earlier causes of failure have largely been eliminated in FADs where the recommended guidelines have been rigidly adhered to. FADs built according to the SPC design regularly achieve their planned life expectancy of two years, and some have exceeded four years (e.g., Chapman, 1988).

The main exception to the adoption of the SPC design is in the large-scale deployment of FADs by purse-seine or other industrial fishing companies. Here the desirability of long-lived FADs is offset by their extra cost and the extra care and time needed in their construction, as well as the need to set large numbers of FADs quickly. In addition, industrial concerns tend to visit their FADs regularly in order to monitor fish concentrations on them. In doing so they are also able to check the condition of the FADs and, other circumstances permitting, haul them aboard for maintenance or repair when necessary. As a result, the regions industrial fishing operations continue to deploy low-cost, low durability moorings and to tolerate relatively high loss rates.

Following the widespread adoption of the SPC mooring design, FADs in the region showed a gradual increase in average life span. However, difficulties arose when the design was applied to FADs deployed in shallow water. The inverse catenary requires a certain minimum depth, which varies depending on the rope sizes used, the scope allowed, and the amount of terminal hardware on the mooring. If a FAD is to be set in less than the minimum depth, it may not be possible to build into the mooring line enough floating rope to suspend an adequate length of anchor chain off the bottom, without exceeding the floating-rope:sinking-rope ratio necessary for the catenary curve to form. In marginal cases, it may be possible to form the catenary curve but at the cost of having it approach the surface too closely and risk fouling from fishing gear or vessel activities.

In these cases, alternative design considerations apply. In response to requests from its member countries for advice on installing FADs in shallow water, SPC undertook further study of this issue, resulting in the publication (Boy and Smith, 1986) of detailed information on this topic. Alternative designs recommended for shallow water focussed on semi-taut moorings in which the slack-absorbing action of the inverse catenary curve was substituted by a system of chain and floats incorporated into the line.

Despite the advances made so far, there remain substantial FAD engineering problems to be solved. Boy and Smith's inverse catenary and shallow water designs, together with the widening use of improved or more appropriate construction materials, have eliminated many of the early causes of mooring line failure, but, predictably, this has led to new problems arising. Now that mooring line life expectancies are longer, there are also increased opportunities for some other component of the FAD to fail first.

There is a growing body of information to suggest that raft or buoy design is the next major issue to be addressed. Breakup or sinkage of FAD rafts was not usually an issue when mooring lines typically lasted less than a year, but, at least in some areas, is a problem on FADs that have been in place for long periods. In general, the raft has been the target of most experimentation and improvisation because it is the most visible and accessible part of the FAD. Raft designs vary widely from country to country, usually to allow the use of locally available materials or fabrication facilities as a cost-cutting measure. As a result, rafts often have undesirable characteristics: in fact, rafts continue to suffer from the empirical approach that characterised entire FAD systems in the early 80's. Typical faults include: weak construction; the use of materials which are not strong enough or which will waterlog, delaminate, corrode, or otherwise deteriorate with time; incorrect flotation characteristics; and excessive wave or current resistance. This latter feature is especially important: rafts may function adequately under normal, or even quite rough, weather conditions, yet still cause failure of the FAD during storms when wind and current strengths increase exponentially.

Many unexplained mooring line breakages during early FAD deployment programmes were attributed to bites from sharks or other fish. While it is now accepted that many of these cases of assumed fishbite were probably due to other causes, there is also a growing body of documentation on cases of fishbite that have been confirmed by laboratory analysis of recovered mooring line fragments. Analysis involves microscopically examining the rope end and comparing the statistics on numbers of fibres cut, stretched, fractured, sheared or necked with those from known standards. From this evidence, plus occasional finds of teeth embedded in mooring lines, it is clear that some types of fish do indeed bite FAD moorings and sometimes cause their breakage. Several possible reasons have been advanced for fishbite, including attacks on prey species sheltering close to the mooring rope, and attacks on the rope itself stimulated by its appearance or by current-induced movement or vibration ("strumming"). However, there is little evidence either to support or to refute these speculations.

The true importance of fishbite remains unknown, but it is expected to be significant in some areas, including Vanuatu and New Caledonia, both of which have confirmed cases of fishbite leading to FAD loss despite only small numbers of FADs being deployed. The problem will probably become more important as engineering improvements continue to reduce the chances of FAD failure for mechanical reasons. Research into means of avoiding fishbite is under way and has included the experimental threading of anti-strumming streamers through the main mooring line, or the use of protective plastic casings around it. However, no system has been satisfactorily field-tested so far, and each appears to have its drawbacks - tangling potential and increased current drag in the first case, cost and rope handling and jointing difficulties in the second. Further research on possible anti-fishbite measures is therefore needed as a matter of priority.

A final design-related danger to FAD systems which acts through the raft is the potential for damage by boats tying up to the FAD in order to fish,or for other reasons. The frequency with which this occurs will vary from country to country. As a general principle tying up is undesirable since there is increased strain on both the raft and the mooring, and in some countries is prohibited by local regulations. However, the social realities may be that fishermen will tie up to the raft regardless of regulations and that enforcement may be beyond the capacity of the raft-deploying agency. In this situation, the most realistic counter-measure is to account for this possibility by providing strong points for vessel attachment and by increasing the size and strength of FAD components, particularly the mooring, to allow for the extra weight of attached vessels.

Construction

Apart from engineering considerations, other factors continue to be important in FAD loss, not least the maintenance of adequately high construction standards. Numerous FAD losses can be attributed to carelessness during assembly, especially of the mooring system. Minor construction faults, such as loose splices, shackles not adequately tightened or moused, or incomplete application of protective coatings to metal parts, can ultimately lead to loss of the whole system. Meticulous attention to detail is therefore paramount in FAD construction. Lack of this degree of care has undoubtedly been responsible for many of the FAD losses in the region.

Deployment

FAD deployment in the region occurs from a range of vessel types and sizes. Industrial fishing concerns typically set FADs from medium- to large-sized offshore fishing vessels (pole and line boats or purse seiners). Government Fisheries Departments and agencies servicing the development of smaller scale fisheries may not have access to vessels of this size and frequently set FADs from small fishing boats, sometimes working in pairs. Deployment is normally by one of two more or less standard methods: "anchor-first" or "anchor-last".

The anchor-first method is rapid, crude, and, especially on small vessels, potentially dangerous. A very long mooring line is typically prepared in advance and laid in loose coils in a well or pound on the deck. The anchor, usually a mass of concrete, is attached via a chain termination to the bottom end of the mooring line, and released in the selected site. The weight and rapid sinking of the anchor, followed by the mooring rope, makes control of descent difficult or impossible. If loops or bights have formed in the well, there is a good chance that they will form a tangle as they go over the side, weakening the mooring line as they tighten up into knots. There is also potential danger to the crew, the vessel's equipment, and the mooring line itself if the rapidly-moving rope becomes caught on an obstruction on the boat.

Once the anchor has touched bottom, the length of the mooring line is adjusted by making or undoing joints at the top end. The raft is attached and jettisoned and the vessel is then ready for another deployment. The advantage of this method is speed. Its disadvantager are the danger to personnel and equipment, and the fact that final adjustments need to be made on the spot, making it difficult to correctly adapt a composite mooring to the water depth unless this is known in advance. Vessels using the anchor-first deployment method are normally setting numerous low-cost, non-composite FADs, typically for use in purse-seine fishing.

The anchor-last method is more often used in the deployment of FADs that are intended to remain in place over the long-term. Normally the site is investigated thoroughly, using an echo-sounder to run transects along and across the prospective deployment spot, in advance of the deployment date. The mooring is then constructed to fit the known water depth, and loaded as a complete unit onto the vessel. On deployment, the site is relocated and the FAD raft jettisoned first, while the anchor remains secured on board. The vessel steams away from the FAD paying out rope, typically in a circle, so that the vessel is re-approaching the raft when the bottom end of the mooring line is reached. Wind or current need to be allowed for so that the unit will not drift off the deployment site during this procedure. Once the mooring line is over the side, the anchor is released, normally at a calculated distance past the actual deployment spot, to allow for the fact that it and the raft will swing together as the anchor sinks. The FAD is observed until it settles.

The advantages of this method are safety, the fact that the whole mooring can be carefully assembled on shore prior to deployment, and adaptability to use from a small boat. The main disadvantage is the potential for drifting off-station and into a depth for which the mooring is not designed. If the FAD lands in water too shallow, there is a danger of the mooring line fouling on the bottom, and an attempt may have to be made on the spot to shorten it. If the FAD drifts too deep and, as is usual, the weight of the anchor and hardware exceeds the buoyancy of the raft, this means immediate loss of the whole unit by sinking. Although this may not in fact diminish the aggregation potential of the FAD, the mooring will be less likely to remain firmly anchored, (because of the extra buoyancy of the submerged raft), and may "walk" off station in strong currents. In any case, an unplanned subsurface FAD is unlikely to confer the same benefits to fishermen as one that is intended to be located by visual methods.

In general, similar considerations apply to questions of deployment as to construction. Care and time need to be invested in pre-surveying sites and in ensuring that the FAD is in the expected depth, and not in danger of drifting over a drop-off, before releasing it. In the early days of Pacific Island FAD programmes FAD loss during deployment was commonplace, especially where depth estimation was manual (using sounding lines or extrapolating from charts) rather than by use of an echo-sounder. Experience, and the acquisition of echo-sounding equipment (in one case by a regional agency, the FAO Regional Fishery Support Programme, which loans the sounder to its member countries for use during FAD deployments) have alleviated these problems to some extent. While many countries still lack staff with the expertise necessary to gain the full benefits of sophisticated echo-sounding equipment now available, and while the accuracy of charting of survey sites could often be improved, FAD losses during deployment are nevertheless now the exception rather than the rule.

The major deployment-related problem still remaining is the potential for shipping to collide with FADs. Many FADs are deployed with inadequate markings and with no consideration given to local shipping activities. In most small Pacific Island countries there is no suitable formal mechanism for ensuring that local navigational materials (charts, pilots, etc) are kept up to date with FAD placements. The only solution to this problem is for the deploying agency to ensure that appropriate local shipping or marine authorities are consulted before FADs are set, and that where necessary they be marked with dayshapes, night lights and radar reflectors. These markings are normally necessary anyway if fishermen are to be able to locate the FAD in the dark or low-visibility weather conditions. In the numerous cases where this factor is neglected, then as well as the increased threat of damage collision to both the FADs and local shipping, the potential economic benefits to be derived from FADs are diminished.

Maintenance

Irrespective of the efforts that are directed towards design improvements and careful construction and deployment, an upper limit to FAD life expectancy will ultimately be achieved. There will always be one link in the system which is the weakest and there will come a point when further improvements can only be achieved by post-deployment maintenance and the replacement of deteriorating components before they fail.

Planned maintenance and repair schedules are absent from most Pacific Island FAD programmes. In many cases this is because the deploying agency does not have a vessel capable of recovering a FAD already in the water. Where such vessels are available, there are invariably difficulties in meeting maintenance schedules, because of conflicting vessel commitments, weather conditions, or for other reasons. The result is that most FADs receive little or no inspection or maintenance after deployment.

Under ideal circumstances, any FAD programme should include provision for regular (say monthly) visits to all deployed FADs to allow the visual checking and, if necessary, repair of the upper components of each. The removal of deployed FADs after a given period, say one year, in the water, and their replacement with another similar unit held in reserve according to a system of rotation should also be scheduled. If, as in most Pacific Island countries, vessels of an adequate size to pull the entire mooring are not available, then the principle could at least be applied to the raft and upper hardware down to the beginning of the main mooring line.

Careful examination of the freshly-pulled unit, and documentation of any deterioration that is observed, should be followed by repair or replacement of suspect components, following which the unit can be re-deployed in place of the next FAD to be hauled. Over the longer term, this would reduce FAD losses and increase the service life of each component, as well as permitting the accumulation of information on the degradation of each component, and consequent design improvements. Under these circumstances, maximising the life expectancy of FADs would become less critical since few would approach their design life span anyway.

FAD Fabrication and maintenance practices were identified as key problem areas in Boy an Smith (1984), and the value of accurate record keeping as a part of this procedure was emphasised. The only likely real 'rawback to mid-life FAD removal and replacement would be the possible interruption in aggregating effect that might occur. However, it has not yet been demonstrated that such a hiatus would occur, and in any case this disadvantage is outweighed by the potential benefits of this type of FAD maintenance.

Nevertheless, such maintenance schedules have not in general been adopted in most Pacific Island countries. The mistaken notion that once a FAD is set, no further action is needed is still too widespread and this is a major area requiring attention and rectification in future FAD programmes.

FAD resources

By far the most important FAD-associated fish species presently exploited commercially in the Pacific Islands region are skipjack (*Katsuwonus pelamis*) and yellowfin (*Thunnus albacares*) tunas. Other less important species include bigeye tuna (*Thunnus obesus*), mahimahi (*Coryphaena hippurus*), wahoo (*Acanthocybium solandri*), rainbow runner (*Elegatis bipinnulata*) and albacore tuna (*Thunnus alalunga*), bigeye scad (*Selar crumenophthalmus*), and round scad (*Decapterus spp*). Numerous other types of fish, at present not commercialised, are also present, including other small pelagic species, oceanic triggerfishes, and sharks.

Depending on their habitat requirements and behavioural characteristics, different species of fish tend to remain in association with the FAD for shorter or longer periods, and to range more or less widely from it. Some species, particularly those whose individuals are small, are more or less permanently resident on the FAD and stay close to it for most of the time. Others are only temporarily resident, and may range many miles from the FAD during their period of association with it, returning from timeto time according to patterns that are only partially understood at present.

There is conflicting information on the movements of fish once they have become associated with FADs. Tracking by acoustic tagging in Hawaii suggests that yellowfin move away from the FAD at night, returning the following day, while skipjack remain in the proximity of the FAD day and night (Anon, 1987b). However, observations by fishermen operating in the Pacific Islands are not always consistent with these results. Studies using echo-detection equipment have demonstrated large aggregations of yellowfin beneath FADs at night, and commercial purse-seining experience supports these observations, since almost all purse-seine sets on FADs (for which yellowfin are the target species) are made immediately before dawn. Anon (1987a) indicates that skipjack appeared to move away from the FAD during daytime, while yellowfin remain catchable by trolling.

The reasons for the attractiveness of FADs to fish have yet to be elucidated. Possible attractive effects that have been suggested include shade, shelter from predators, a forage base, an orientation clue, or a combination of these or other factors. Neither is it known what factors cause some FADs to become effective very quickly, while others may take months to "mature" (attract good quantities of commercially important fish) or may never do so at all. There have been numerous attempts to explain the attractive successes or failures of particular FADs in terms of site-specific physical characteristics (bottom topography, current patterns, proximity to reefs and islands, etc) or traditional local knowledge of good and bad tuna fishing locations. However, no consistent pattern has yet emerged from these observations and this is an area that warrants further research.

On occasion, the aggregating effect of a FAD can be rapid and spectacular. One FAD deployed in Fiji in 1981 yielded 130 tuna to a single small boat trolling with 4 lines the morning after its deployment, and pole-and-line fishing vessels subsequently harvested 45 tonnes of tuna from it in the next 10 days. A review of the colonisation process of a more typical newly-deployed FAD

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FAD exploitation

Purse-seining

Industrial purse-seining for tunas is presently practised in oceanic areas throughout the western and central Pacific. Purse-seining is used in coastal areas only in Solomon Islands, although it has in the past taken place in Fiji and, intermittently, elsewhere. Except for a small local fleet in Solomon Islands, all purse-seining in the region is presently carried out by foreign vessels, mainly from the USA, Japan, Korea and Taiwan. Purse-seine fishing effort increased explosively in the early part of this decade due to a movement of US vessels into the region. The fishery is expected to undergo a new phase of expansion in the next year, with an anticipated growth in existing fleets and the appearance of new ones.

Purse-seining in the SPC region tends to rely on sets made on natural floating objects or, by extension, man-made free-floating or anchored FADs. Contrary to the situation in the eastern Pacific, tuna schools in the SPC region are not found in association with dolphins or porpoises, and this is a strong attraction to US purse seiners who are faced with strong and increasing pressure to avoid the incidental capture of marine mammals.
Although some purse-seine operators in the Pacific Islands region have set successfully on wild schools or schools held in position by baiting, most acknowledge the potential benefits of FADs by arranging for their deployment in large numbers. In areas of deep ocean these may be free-floating, in which case their positions are monitored by the use of radio buoys. These are essentially man-made versions of the floating logs and other debris on which purse-seiners depend for most of their fishing operations.

In coastal areas, and sometimes on the high seas, purse-seiners deploy FADs that are anchored. In the Solomon Islands, for example, one network of over 30 FADs has been deployed within an area of about 600 square miles, and is maintained by a purse-seine company to service one net-boat. In Fiji in the early 1980's a foreign company carrying out purse-seining trials deployed over 70 FADs to service two net-boats.

The main reasons that purse-seiners use FADs is to cut down on fish searching time, and to improve the likelihood of making a successful set. However, there may be other, less direct reasons. For instance, in Fiji again, in the late 1980's, during more fishing trials carried out by a (different) foreign purse seine company, a line of over 35 FADs was set in an east-west direction north of the group in an attempt to extend the fishing season by retarding the annual northward movement of tuna out of Fiji's coastal waters.

Although attempts to establish permanent small-scale purse seine fisheries in the region have only been successful in one country (Solomon Islands) so far, there remains considerable interest in doing so, particularly because Pacific Island states perceive greater opportunities for participation in such fisheries than in larger-scale offshore purse-seining activities. It seems likely that continuing small-scale purse-seining trials will ultimately lead to the development of more permanent locally-based purse-seine tuna fisheries in the region.

The growth of purse-seine effort in the region, together with the dependency of purse seiners on flotsam and FADs, raise concerns about the potential for overfishing, since the effect of fishing on FADs is to reduce search time, and hence costs, to the extent that the economic structure of the fishery is altered. FADs allow harvesting at lower economic margins, thus making it economically possible for fishermen to continue fishing when stock levels are lower and the fishery may in fact be over exploited.

Pole-and-line fishing

On a smaller scale, industrial pole-and-line fishing operations also make use of FADs, particularly in Fiji, and less extensively in Solomon Islands, Kiribati and Tuvalu. In all cases, pole-and-line vessels make opportunistic use of FADs set by government fisheries agencies and mainly intended to benefit small-scale fishermen. Only in Fiji does the industrial pole-and-line fleet also finance FAD deployment itself, both directly (by deploying FADs) and indirectly, through a small levy (F$5.00 per tonne) on catches which is used to finance the government FAD programme.

There is only a limited amount of information on the levels of catches on FADs by pole-and-line vessels. During a period of about 2-3 months, five Japanese pole-and-line boats fishing under charter to Fiji's national fishing company, Ika Corporation, provided the government Fisheries Department with catch information on their FAD-fishing activity. From this small information base it was estimated that 50% of fish caught by these vessels was being taken on FADs at that time. It is not known to what extent this reflects the overall importance of FADs to pole-and-line fisheries, in Fiji or elsewhere.

Pole-and-line fishing is also carried out on a smaller scale by artisanal fishermen in French Polynesia, Kiribati, and to a lesser extent Tuvalu. FADs have received mixed responses from these potential users. In French Polynesia, only 20% of pole-and-line boat owners make regular use of FADs, and both total catches and fuel consumption remain essentially unchanged since their introduction (Farman and Dashwood, 1989). Fishermen are said to prefer fishing on non-FAD schools whenever possible, since these produce a better CPUE when the fish are biting. A similar attitude prevails in Kiribati, where fishermen frequently fish away from the FADs in the hope of a better biting response.

Trolling

The most widely practised artisanal FAD-fishing method in the region is trolling, which is widespread. Like most small-scale fishing activities, it is practised for commercial, semi-commercial, recreational and subsistence purposes. FAD trolling is undoubtedly more productive than trolling in any other location, except occasionally on well-biting free schools. Anon (1983) presents fishing results from a total of 737.5 line-hours of trolling in Vanuatu. Catch rates during undirected trolling while travelling to and from bottom-fishing grounds or FADs averaged between 0.15 and 0.6 kg per line-hour: these catch rates may be considered typical for coastal trolling activities away from reefs. By contrast, catch rates around FADs averaged 7.8 kg per line-hour. Similar results have been reported from Fiji, Western Samoa, Papua New Guinea and elsewhere. There is little doubt that FADs are widely effective in improving the profitability of trolling operations by reducing the time and fuel spent searching for fish, improving average catch rates, and reducing the number of trips on which the catch is zero.

Part of the key to success in FAD trolling is in being able to locate the FAD at night and be in place and fishing when the fish begin to bite actively for a short period before and after dawn. In locations where FADs are not marked by night-lights, fishermen are largely unable to exploit the FAD during this important, very productive period. In this case the economics of FAD-based fisheries are affected substantially, to the point that FAD programmes may be deemed economic failures. Night-lights should thus be considered as an integral part of a FAD design, not only for the safety reasons mentioned previously, but because of the potential benefits to troll fishermen, who are the most extensive small-scale users of FADs in most countries of the region.

Down-lining

The other established fishing method that has come to be practised around FADs is down-lining, or deep-water handlining, for larger deep-swimming tunas. Variations of this fishing method, in which leaves, stones or clam shells, and chewed up fish are used to sink and chum the hook, are practised traditionally in the Pacific, especially in atoll countries. Fishing is often carried out from very small boats, including one-man paddling or sailing canoes. Landing large tuna from a small boat of this type requires considerable judgement and skill.

Where information exists, it suggests that this type of fishing is considerably more productive around FADs than elsewhere. In French Polynesia, flying-fish boat operators, who in the past carried out down-line fishing part-time, now derive 50% of their income from this fishing method (Farman and Dashwood, 1989). Similar improvements in catch have been reported anecdotally from Tokelau, the Cook Islands, and elsewhere.

Vertical longlining

Numerous attempts have been made to develop new or improved fishing methods to take advantage of the opportunities offered by FADs. One of the most successful has been a long-term SPC programme to establish the technique of vertical longlining around FADs in Pacific Island countries. Vertical longlining is a modification of the commonly used down-line fishing method, which exposes a vertical series of up to 20 hooks to the fish, rather than just one, and which takes advantage of simple low-technology fishing reels to increase the speed at which lines can be set and hauled. SPC Master Fishermen have now adapted the technique and demonstrated it to local fishermen in American Samoa, Cook Islands, Fiji, French Polynesia, Kiribati, Niue, Tokelau and Tuvalu, and more extension work of the same kind is planned. In five of these locations, this work has led to the establishment of permanent small-scale tuna fisheries based on this techniques.

Other fishing methods

Other fishing methods that have been trialled by SPC and other agencies in a less extensive manner, but which nevertheless show promise around FADs or merit further investigation, include:

hanging bait traps below the FAD. This has been trialled by SPC in Niue and yielded small but consistent catches of small pelagic species used for bait on vertical longlines. Although bait catches were not large in themselves, they were essential to the success of the vertical longline trials;

jigging for small pelagic species. Good bait catches can be taken by jigging using small feather or plastic lures. In SPC gear development trials carried out in Tonga, catches typically exceeded 300 fish per night. While not large in quantity, fresh bait can be crucial to the success of other fishing methods, especially down-lining and vertical longlining;

deep-trolling for tunas and other large FAD-associated species. This has been under development by SPC and most technical obstacles have now been overcome, although good catch rates have yet to be achieved;

pelagic gill netting for tunas. Experiments with this method, in which attempts were made to lure fish into the net using farmed live bait fish, have been carried out by the Western Samoa Fisheries Department, with only mixed results. SPC has also tested this method in Vanuatu, but trials were discontinued because of strong currents in the vicinity of the FAD, plus a heavy infestation of sharks.

There remains considerable scope for the evaluation and development of new and improved FAD fishing methods, especially for the larger deep-swimming tunas associated with FADs. The Pacific Islands region could probably learn from South-east Asian experience in this field.

FADs and people

The deployment of FADs by public agencies is frequently an attempt to create a new, alternative fishery, for varied reasons that may include improving financial returns on fishing activities, taking advantage of market opportunities, diverting fishing pressure from over-exploited resources, etc. Extension work carried out in association with such programmes may involve persuading fishermen to change their habits to make more use of FADs, to the point of abandoning previous fishing methods and gears. In such cases, there is clearly a responsibility on the part of the agency concerned to ensure that the FAD deployment and maintenance programme is maintained. If this is not done, then the fishermen concerned will lose the time and money they invest in gearing up for FAD fishing, and may have difficulty in re-entering their previous fishery. This situation has occurred in Fiji, where political developments interrupted a FAD replacement programme for several years.

Social factors are almost as important as mechanical ones in FAD loss, and will probably increase in importance as the average life span of FADs grows and as FAD programmes continue to expand. In some locations, competition for space around FADs - especially when trolling - is intense, and disputes have arisen between individual boat owners or rival fishing fleets that the participants ultimately try to resolve by violence or cutting off the FAD. FADs have been cut off as a result of arguments in Fiji, Cook Islands, Western Samoa and probably elsewhere. In the latter location, disputes at sea around the FAD became so frequent and serious that fishermen began carrying shotguns on board their small vessels and at least one was holed below the waterline in a shooting incident.

FAD lights have also been shot out by Western Samoan fishermen to prevent competitors finding the raft in the dark and profiting from the pre-dawn bite. Bullet holes have been found in FAD buoys in Hawaii, where local fishermen have also complained about FAD deployments in traditional tuna fishing areas based on information that the fishermen themselves provided. They reason that this constitutes a divulgence of valuable traditional information to their less knowledgeable competitors, as well as the general public, and that this is likely to influence their fishing success. In New Caledonia, FADs have been cut away by professional fishermen for similar reasons: they see the potentially increased catches in the large recreational fishery, and the consequent likely increase in amateur-caught fish on the local market, as a threat to their trade.

Not all deliberate FAD sabotages arise from competitiveness or malice. In some cases, FADs have been lost due to theft of the rope, chain, buoys or other fittings by passing boat owners. In the islands of Nui and Nukufetau in Tuvalu, at least two FADs were cut away from their moorings by canoe fishermen who were afraid that the rafts would attract whale sharks to their vicinities. Tuvaluan fishermen down-lining from fragile, non-motorised one-man canoes know from traditional experience that whale sharks are attracted to floating objects, and have a justifiable fear of being approached by them, since these animals are believed to have overturned canoe fishermen in the past.

If people are determined to sabotage FADs, for whatever reasons, then no amount of engineering or fabrication ingenuity will prevent them in the long run. Better policing may go some way towards alleviating these problem, but they will only be fully resolved by alterations in fishermen's attitudes to FADs and to each other. In the short term this will require a commitment by deploying agencies to extension work that will help encourage fishermen to understand and effectively use FADs. In the longer term, there is a need for improved education and public information programmes designed to raise awareness of fishery resource exploitation and management issues, including those associated with FADs.

Future work on FADs

Overall requirements

From the foregoing discussion, several aspects of FAD programmes requiring further work by both national and international bodies can be identified. These include, but are not limited to:

trials to establish the aggregating effects of sub-surface FADs, and to assess their potential in reducing the effects of wave action and associated motion-related wear on mooring systems;

further engineering and hydrodynamic studies on FAD rafts and buoys, with the aim of improving longevity and minimising strain caused by current and wave action;

development of materials to reduce the incidence of, and damage caused by, fishbites on mooring lines;

upgrading FAD construction standards;

upgrading deployment practices, especially by improving the application of echo-sounding, navigation and position plotting skills;

improved understanding of the behaviour of commercially important fish species around FADs, and of the relationship between FAD-associated fish populations and the parent stock;

continuing evaluation of factors which affect the attractiveness of FADs, including appendage form and type, FAD density and interaction, and local environmental features;

continuing development of new and improved fishing techniques with application to FADs, from small- to industrial-scale;

data collection to permit monitoring and evaluation of performance of specific FAD programmes in economic, social and biological terms;

extension work to reinforce positive attitudes to FADs on the part of fishermen and the general public;

education and information programmes to improve public understanding of natural resource exploitation and management issues, including those pertaining to FADs.

Much of this work, especially that which relates to country-specific development issues, needs to be undertaken at the national level, and in a manner which conforms with specific local conditions and requirements. In addition, there is a more general need for in-country work to focus on the overall development issues associated with FAD programmes. The basic planning process, which should involve developing a clear set of social and economic objectives for a FAD programme, followed by a realistic assessment of whether the programme is in fact likely to achieve those objectives, is generally overlooked. Instead, the approach has generally been to deploy FADs as a quick-and-easy solution to fisheries development problems of all kinds. Identification of the specific social groups that are intended to benefit from the FAD deployments, and consultation with these groups early in the planning process, will be valuable steps towards tailoring the programme to their needs and anticipating any user conflicts or social discontent that may occur once the FADs are in the water. In addition, design characteristics, deployment sites, etc, could and should be adapted to the requirements of the user groups. Not enough attention has been paid in the past to ensuring that the goals of FAD deployment programmes are fully consistent with the aspirations of their supposed beneficiaries.

In many cases, the support of international bodies may assist the countries to achieve their development objectives. Other aspects of FAD research and development work, especially those which are investigatory, are relevant to the needs of several or many countries and could benefit greatly from the active involvement of international bodies in carrying out work at a regional level, or in coordinating national-level activities to ensure the dissemination of useful information.

SPC activities

Several ongoing or planned SPC projects are intended to respond to the needs identified above, as follows:

the SPC Deep Sea Fisheries Development Project, within which roving Master Fishermen provide technical assistance, training and other forms of support to national-level fisheries activities. SPC Master Fishermen continue to assist Pacific Island states on request in all aspects of practical FAD fishery development including design, deployment, training, and the development of fishing methods for small-scale use;

a detailed technical review, just commenced, of regional FAD programmes and progress with remaining problem areas. The review, which will be completed before the end of 1990, will document recent country experience with FADs and has specific objectives which include development of raft design improvements

production of a revised and updated version of the 1984 SPC FAD handbook, highly illustrated and containing detailed technical information on the materials and procedures involved in FAD construction, deployment, maintenance and use;

convention of a 1-day workshop on FADs for Pacific Island Fisheries Officers, to be held in conjunction with the 21st SPC regional Technical Meeting on Fisheries in August 1990;

evaluation of aspects of FAD-associated fish behaviour, including movement between FADs, by analysis of tag returns from the ongoing SPC Regional Tuna Tagging Project. Tagging, which will take place for a total of 24 months, is currently under way from a pole-and-line vessel and special efforts are being made to tag around FADs;

establishment of a Special Interest Group on FADs within the activities of the SPC Fisheries Information Project. The group, which will be added to those that already exist, will act as a source of information and contact among FAD workers in the SPC region and beyond;

an SPC proposal to commission a small purse seine vessel to undertake experimental fishing trials for resource assessment and feasibility study purposes in selected regional locations. This has been strongly endorsed by regional fisheries officers, approved at policy-making level by SPC member countries, and submitted to a funding agency where it is presently being considered. As well as assessing the development potential of small-scale purse-seining in four sub-regions within the SPC zone, a detailed study of FAD performance is planned which will involve the deployment and monitoring of large numbers of FADs in selected sites over a 3-year period. Studies will be made of the effects of spacing between FADs on aggregation performance, longevity effects of FAD design modifications, and the long-term performance of individual FADs.

Several other SPC activities are also relevant to FAD research and development work in a smaller or more general way, and additional programmes or activities may be developed in response to regional- and national-level needs and requests. The Commission is committed to supporting the efforts of Pacific Island countries to establish and rationally manage FAD-based fisheries at all levels.

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