



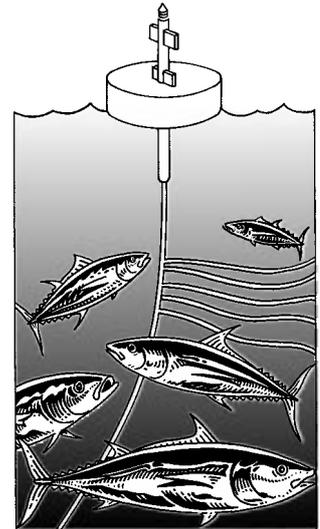
**FISHERIES PROGRAMME
INFORMATION SECTION**

FAD

Fish Aggregating Device

Number 2 — October 1996

I N F O R M A T I O N B U L L E T I N



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EDITORIAL

Thank you all for your positive comments following the publication of the inaugural issue of the SPC FAD Information Bulletin. We are happy to welcome new members, not only from around the Pacific region, but also from places like the Caribbean, India and Iran.

For this second issue, Dr Kim N. Holland, from Hawaii, gets the ball rolling with a very comprehensive review of the various studies undertaken on the behaviour of tuna associated with FADs. This paper proves that scientific research can sometimes become romantic, like when tuna are followed swimming in the direction of the rising moon. A lot of work has already been done in this field—one study being the famous ultrasonic tracking of tuna carried out by Dr Holland himself—and a lot more are currently underway in French Polynesia and the Indian Ocean. We will try to keep you informed on their progress in future issues.

The second article, by Shinichiro Kakuma, presents the well-developed FAD fishery of Okinawa. The situation there is comparable to many places in the world, where coastal fisheries have had to face a reduction of resources due to over-exploitation. In Okinawa, many fishermen targeting deep-bottom snappers are slowly shifting to FAD fishing. The FAD fishery is now so important that trials of a 'one million dollar FAD', expected to last at least ten years, are underway and show promising results.

The 'Hands-on FADs' section presents the latest techniques used to build FADs in French Polynesia, and two fishing techniques commonly used in La Réunion and in Okinawa. At the end of this issue you will also find an eight-page bibliography of FAD-related literature. We hope it will form the starting point of an exhaustive bibliography on the subject. If your work, or anyone's work you know of, is not in the list, please send us a copy—it will be cited in the 'Readings' section of the next issue.

Finally, please remember that this bulletin is intended to act as a relay between scientists, technicians, public and private fisheries managers, fishermen and other fisheries-related people. It is also a rare opportunity for you to be published both in English and in French. So, let us know about your work, the fishing techniques that are used in your region and the questions you would like to be answered.

Aymeric Desurmont

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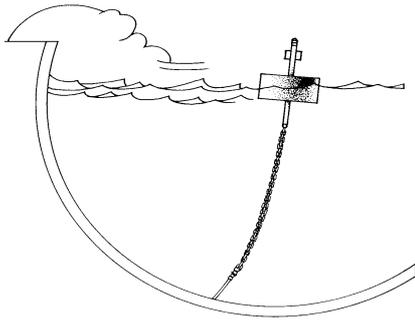
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News and Views

Biological aspects of the association of tunas with FADs

by Kim N. Holland ¹

INTRODUCTION

Although fish aggregating devices (FADs) have come to play an important worldwide role in all types of tropical and sub-tropical tuna fisheries (artisanal, commercial, sport fishing), we currently have a minimal understanding of the biological factors that underlie the association of tuna with FADs.

Nevertheless, it is encouraging to note the similarity in the results of different researchers working in different oceans and using a variety of techniques. Although the data are few, several studies are in agreement on the influence of FADs on tuna behaviour, and the behaviour appears to be consistent from one location to another.

While there is emerging general agreement among researchers about the behaviour of tuna around FADs, whether or not that behaviour actually imparts a biological benefit to tuna associated with anchored FADs remains unknown. The possibility exists that the aggregation of tunas around anchored, man-made FADs is actually a behaviour transferred from a different, natural phenomenon such as associating with seamounts. It is even possible that associating with a man-made FAD may have a deleterious effect on the short-term health of the fish (even if it doesn't get caught!)

This review addresses what is currently known about the behaviour of tuna when they are found in association with FADs and includes a discussion of what the current data indicate about why pelagic fishes, specifically tuna, aggregate around FADs.

This discussion considers only fixed FADs; that is anchored, as opposed to drifting, structures. It is not at all certain that the behaviour of tuna associated with anchored objects is the same as that of animals associating with drifting objects such as logs.

The final section covers the types of additional information that are needed for a better understanding of the influence of FADs on tuna behaviour and meso-scale distribution, and the methods that might be employed to acquire those types of data.

FAD RESEARCH

Research into the association of tunas with FADs falls into four categories:

- (a) ultrasonic tracking of fish caught and released at FADs;
- (b) tag-and-release and recapture of fish caught at FADs;

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- (c) acoustic surveys of fish schools associated with FADs; and
- (d) food-habit studies of FAD-associated tunas.

Ultrasonic tracking

Ultrasonic telemetry techniques have been used to track the fine-scale vertical and horizontal movements of FAD-associated yellowfin, skipjack and bigeye tuna. This method involves catching the fish at a FAD site, attaching a small ultrasonic transmitter to the fish (see Fig. 1 on next page) and then following its movements for periods of up to several days.

This type of research has been conducted in Tahiti (Cayré & Chabanne, 1986), Hawaii (Holland et al., 1990; 1992), and in the Indian Ocean on FADs located around the Comoros Islands (Cayré, 1990; 1991). Refereed publications concerning the tracks of FAD-associated tuna cover six skipjack, six bigeye and sixteen yellowfin tuna.

Excellent tracking work reported in various technical reports (Marsac et al., 1995; *inter alia*) provide data that are consistent with the findings reported in the refereed papers. The results of several other FAD-related tracks have yet to be reported (Holland, unpublished data).

Sonic tracking experiments have documented three types of behaviour in all three of these tuna species:

- (a) fish which leave the FAD and show no tendency to return to it over the duration of the track;
- (b) fish which spend the entire duration of the track (day and night) within a few hundred metres of the FAD; and
- (c) fish which spend the daytime at the FAD site, leave at night and return to the same or an adjacent FAD the next day.

Of the sixteen yellowfin for which tracks were reported in the literature, two (14%) stayed very close the FAD for the entire track, seven (44%) showed diel on-FAD/off-FAD behaviour and seven (44%) did not return to the FAD following their release. However, of these seven, four were tracked for less than 10 hours, which was insufficient time to show diel patterns of movement for these fish. That is, they might have been found returning to the FAD if they had been tracked longer.

These findings suggest that FADs exert a strong aggregating influence on yellowfin tuna once they have encountered the FAD. And, of the fish associated with a FAD over a given 24 hr period, only a minority display 'permanent' escapement from the FAD and become associated with other FADs or free-swimming schools.

However, it is important to remember that all tracks so far published for yellowfin and bigeye tuna, are from comparatively small 'sub-adults'. It is possible that FADs have a less strong influence on the movements of larger fish of these species; larger fish are usually much less prevalent (as measured by fishing success) at FADs than small animals. And, with mature fish, seasonal considerations, such as those associated with reproduction migrations, may modify the strength of the tuna-FAD association.

A consistent finding of tracks from Tahiti, Hawaii and the Indian Ocean is that the effective range of influence of FADs on sub-adult yellowfin and bigeye tuna is about five nautical miles. This is based on analysis of the maximum distances that FAD-associated tuna travel away from a FAD before returning to it.

This finding has practical ramifications for FAD deployment strategies. To minimise dilution of fish resources between adjacent FADs, the minimum separation between adjacent FADs should be about 11 nmi (Holland et al., 1990; Cayré, 1991), so that their fields of influence do not overlap.

Similarly, to avoid FADs competing with islands or seamounts, FADs should be placed at least 5 miles from these features (Holland et al., 1990). Of course, from a practical standpoint, the minimum distance of FADs from shore sometimes has to be shortened to accommodate the capabilities of the fishing fleet, or because the offshore ocean-floor topography will not permit more distant deployment locations.

Several tracking studies (Holland et al., 1990; Cayré, 1990, 1991; Marsac et al., 1995) have shown that tuna can learn the position of FADs and navigate between them, or make extended excursions away and then return to the same FAD.

The sensory systems that mediate this behaviour are unknown but the strongest possibility is that these movements are a sophisticated form of 'dead reckoning', assisted by the tuna's ability to detect magnetic fields (Walker, 1984) and possibly assisted by other cues such as sun and moon direc-

tion. For instance, on several occasions, tracked tuna have swum for prolonged periods in the direction of either the setting sun or rising moon (Holland, pers. obs.). Because the number of other tunas probably increases with proximity to a FAD, an arriving tuna may be able to follow a 'density gradient' of conspecifics once it is within a mile or two of its destination.

Another consistent finding of both tracking and sonar monitoring of anchored buoys is that, during daytime, the tuna spend most of their time on the up-current side of the buoy (Holland et al., 1990; Freitag et al., 1992; Plimpton et al., 1996). The biological significance of this phenomenon is not known.

In terms of vertical distribution, acoustic tracking shows that FADs cause yellowfin and bigeye tuna to swim closer to the surface than if they were in the open ocean away from the influence of a FAD.

This is especially true for bigeye tuna, which prefer quite cold, often deep, water (Holland et al., 1990). For example, in Hawaiian waters, bigeye tuna are usually found below 200 m and are only found near the surface when in association with a FAD or a natural floating object such as a log.

Tag-and-release studies

A modest (1,879 animals) tag-and-release project studying the movements of small yellowfin tuna associated with FADs in Hawaii (Okamoto & Nishimoto, 1989) produced two significant results.

First, within a few days after release, some members of a group of fish tagged at a particular FAD were recaptured at that same FAD, while others of the same group were being simultaneously recaptured at FADs a few miles away.

Second, the great majority of recaptured fish were caught at FADs—either the ones at which they were released, or at a different FAD. Very few fish (<1%) were recaptured in open schools away from FADs, although this may reflect the pattern of fishing effort.

Nevertheless, these data show that tuna shuttle between closely-spaced FADs and that FADs have a large influence on the distribution of small tuna, so that a network of FADs can act as discrete 'stepping stones' for the movements of tuna in any particular part of the ocean.

Similar implications for the movements of skipjack tuna are found in the analysis of the tag returns from a tag-and-release project conducted by the South Pacific Commission (SPC) around the Solomon Islands (Kleiber & Hampton, 1992; Kleiber, pers. comm.).

Modelling the pattern of recaptures shows that increasing the number of FADs in theoretical grid squares surrounding the archipelago (each square 30 miles on a side) increasingly restricts the movements of tuna up to a density of about five or six FADs per square, but adding more FADs beyond this number has little additional impact on the dispersal of tuna. Again, this suggests that the ef-

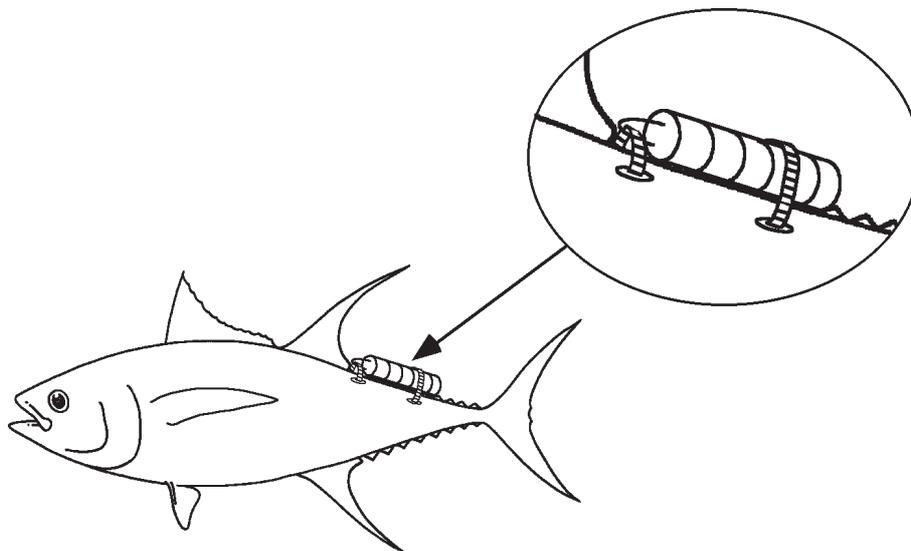


Figure 1: Transmitters used for the ultrasonic tracking, attached with 2 nylon straps inserted through the dorsal musculature and pterygiophores associated with the second dorsal fin

fective diameter of each FAD is in the order of about ten miles.

Thus, the results of tag-and-release studies and sonic tracking are in good agreement. Combined, they indicate that FADs exert a strong influence over the daily movement patterns of yellowfin and skipjack tuna, that the range of influence of FADs is of the order of a few miles, and that some fish remain at a FAD for prolonged periods while others 'escape' and are caught elsewhere. This last point indicates that the aggregations of tunas found at FADs are labile aggregations, the composition of which changes on a daily basis.

Acoustic surveys

A potentially productive source of data concerning the behaviour of fish around FADs comes from the use of acoustic (sonar) surveys. This technique is being actively pursued by researchers in French Polynesia (Josse, 1992; Bach, pers. comm.).

These methods would seem to be especially appropriate for describing the vertical stratification of fishes associated with FADs and for monitoring the temporal changes in the biomass associated with FADs. Acoustic surveys have demonstrated that there is a distinct vertical stratification of fish associated with FADs and that the aggregation phenomenon extends to over 200m below the surface (Josse, 1992).

In sub-tropical and tropical locations, the daytime strata typically may consist of skipjack, small yellowfin and bigeye tuna in the top 50 m, followed at greater depths by larger yellowfin and then bigeye, and possibly albacore in the deepest strata. The absolute position of these strata in the water column will be determined by the prevailing thermal structure of the ocean at the FAD site.

One consistent theme is that the large aggregations that can be detected during the day disperse at nightfall (Josse, 1992). This phenomenon has also been observed by doppler sonar systems mounted on oceanographic weather buoys, where the target strength of the assembled fish interferes with ocean-current measurements (Freitag et al., 1992; Plimpton et al., 1996). These sonar data corroborate the night-time departures of sonically-tracked animals.

There are, however, technical problems with acoustic methods that need to be resolved before

their full utility can be realised in assessing the dynamics of fish schools associated with FADS. Specifically, there is currently insufficient understanding of the various target strengths of different species to enable acoustic techniques to differentiate unequivocally between different species of tuna or between large specimens of one species (e.g. skipjack) and small specimens of another (e.g. yellowfin).

Also, there is the problem of using a moving platform (a boat) to try to assess a simultaneously-moving target (e.g. a tuna school orbiting around a FAD). Or, if the boat remains stationary, how can the surveyor know if successive targets are the same or different schools moving around the FAD?

Food-habit studies

To date, there are only two published accounts of food-habit studies of FAD-associated tuna, and the results are contradictory. This is due to the opportunistic feeding patterns of tunas and consequently, many such studies will be needed before general trends emerge.

Brock (1985) compared the stomach contents of yellowfin tuna caught by surface trolling at FAD and non-FAD sites in Hawaii. His results indicated that FAD-associated fish were less well-fed than their non-FAD counterparts and that they may display dietary shifts (towards deep-water shrimp) to compensate for reduced availability of normal prey species.

On the other hand, Lehodey (1990) found that in Tahiti, FAD-associated yellowfin had more food in their stomachs than open-ocean fish and that the FAD tuna had larger amounts of fish in their stomachs than non-FAD tuna. Interestingly, the fish species found in the FAD-associated tuna were not open-ocean species but rather reef fishes that were probably eaten when the tuna were away from the FADs.

Both these food-habit studies reinforce the concept that, although tuna may occasionally feed opportunistically at FADs, and schools of baitfish are sometimes located at FADs, FADs do not aggregate fish by virtue of the forage base associated with the moored object. Whether or not the tuna are confusing the moored FAD with a natural floating (and therefore, drifting) object which may impart some feeding advantage remains to be established, although the tracking and sonar data indicate that the temporal characteristics of FAD-associated schools are very different from those of the

schools associated with drifting logs that are frequently exploited in the purse seine fishery.

Obviously, many more food-habit and dietary-status studies are required. Dietary surveys that do not require hook-and-line methods of capture (e.g. purse seining) would be particularly instructive because capture by these methods does not depend on the feeding motivation of the fish.

SUMMARY

Although the data are still few, there is growing evidence that:

- (a) Tuna predominantly associate with FADs during the daytime and leave for various lengths of time at night;
- (b) The effective radius of a FAD is in the order of five to ten nautical miles;
- (c) There is vertical stratification of species at FADs which is dependent on the species present, the size of individuals of those species, and the thermal structure of the ocean. The absolute depths and size (biomass) of these biological strata change with time of day;
- (d) The aggregating effect of FADs extends well below the surface, down to several hundred metres;
- (e) Anchored FADs probably do not aggregate tuna by virtue of food available at the FAD;
- (f) The temporal characteristics of FAD aggregations are different from those of drifting log aggregations.

The apparent unimportance of FAD-associated food, the diel on-FAD/off-FAD movements of most tuna, and the increasing number of sonar targets during daytime suggests that anchored FADs serve primarily as an orientation point for school formation. Tunas, especially the smaller species and size classes, form daytime schools (either to facilitate hunting or, in the smaller sizes, to avoid predation). These disperse at night when tuna forage for night-time prey such as vertically-migrating crustaceans and squid.

Tuna behaviour may have evolved to take advantage of any environmental cue that serves to facilitate the reformation of the school after day-break. To this end, tuna may seek out obvious discontinuities in the pelagic environment such

as FADs, logs and even dolphin schools and whale sharks which, although mobile, move quite slowly and are obvious from below. Most of the available information indicates that opportunistic feeding occasionally occurs at deep-water, moored FADs. The relatively low mobility of FAD-associated tuna compared with open schools may allow them to compensate for the reduced food intake they may experience by associating with FADs (Holland et al., 1990).

FUTURE RESEARCH

Future research should focus on a better understanding of the feeding history of FAD-associated tunas, their condition (e.g., how heavy they are for their length) and temporal aspects of the association of tuna with FADs. Food-habit studies should pay particular attention to the timing of feeding as determined by the time of catch of the tuna and the degree of digestion of the stomach contents (Olson & Boggs, 1986). Previous feeding studies have suffered because the temporal aspects of feeding have been underemphasised.

Studying FAD biomass fluctuations on a daily and long-term basis in correlation with oceanographic factors would add significantly to our understanding of the FAD phenomenon. Acoustic surveys could be used (scanning units mounted on the FAD mooring line might be one method), but much more empirical data are needed regarding what type of target strength can be expected from which species and size. One possible solution to the target identification problem would be the use of LIDAR devices which use laser beams instead of sound to resolve targets. However, the practicality of these systems has yet to be established.

Comparison of the movements of tuna associated with FADs and the movements of tuna associated with natural drifting objects such as logs would clarify whether the two associations are based on the same or different behaviours. The best way to do this would be to conduct ultrasonic tracking experiments around logs in the same way that they have been conducted around FADs. One previous study yielded inconclusive data concerning horizontal movements of yellowfin caught at a drifting log (Yonemori, 1982) because only one of the tracks lasted over 24 hours.

Ultrasonic tracking technology has greatly improved and become less expensive. Certain areas where logs are plentiful, such as the Eastern Tropical Pacific and Western Pacific, would be the best locations for these experiments.

An improved understanding of the long-term influence of FADs on tuna movements would be gained by additional tag-and-release studies, especially those that incorporate FADs in their experimental design (Lewis, 1989).

Residence times and school mixing might be approached by the development of tags which reflect a distinctive sonar echo. These would facilitate census of resident tagged animals from a surface or FAD-mounted sonar device.

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FAD fisheries of Okinawa, Japan

by Shinichiro Kakuma ¹

THE OKINAWA PREFECTURE

Location and geography

Okinawa Prefecture is located south-west of mainland Japan, forming an arc between Kagoshima Prefecture and Taiwan (Ryuku Archipelago). It extends 1000 km from the east to the west and 400 km from the north to the south. It includes 160 islands—of which 42 are inhabited—spread in three groups: Okinawa, Miyako and Yaeyama. Okinawa Island is the main and largest island of the Prefecture, measuring 104 km by 10 km.

Climate

Okinawa is the only prefecture in Japan which belongs to the subtropical oceanic climate region. The sea-surface temperature ranges from 22 to 29°C. Typhoons occasionally hit the region during the summer and autumn seasons.

Population

Okinawa Prefecture includes ten cities, 15 towns and 28 villages. The total population of the Prefecture is 1.26 million, of whom 82 per cent live in the central and southern areas of Okinawa Island.

THE FAD FISHERY OF OKINAWA ISLAND

Fisheries utilising fish aggregating devices (FADs) were introduced to Okinawa from the Philippines in 1982. Since that time, the fisheries have developed rapidly. Figure 1 shows the comparative catches of bottom fish (such as snapper) and pelagic fish (such as tuna, usually caught around FADs). Bottom-fish catch has decreased since 1981, seemingly because of overfishing. On the other hand, the FAD fisheries catch has greatly increased. The FADs have played an important role not only in improving fishermen's income but also in easing the fishing pressure on bottom fishes.

Deploying FADs requires the permission of the Okinawa Marine Zone Fisheries Regulation Committee, which regulates the number of FADs around Okinawa. In 1995, 177 FADs were permitted; Figure 2 shows their locations around the main island of Okinawa only. Although fishermen prefer to set FADs well apart, in some areas they have to set them very close (less than a mile) to each other.

Generally, a FAD is made up of three sections: the buoy, the mooring line and the anchor. There are

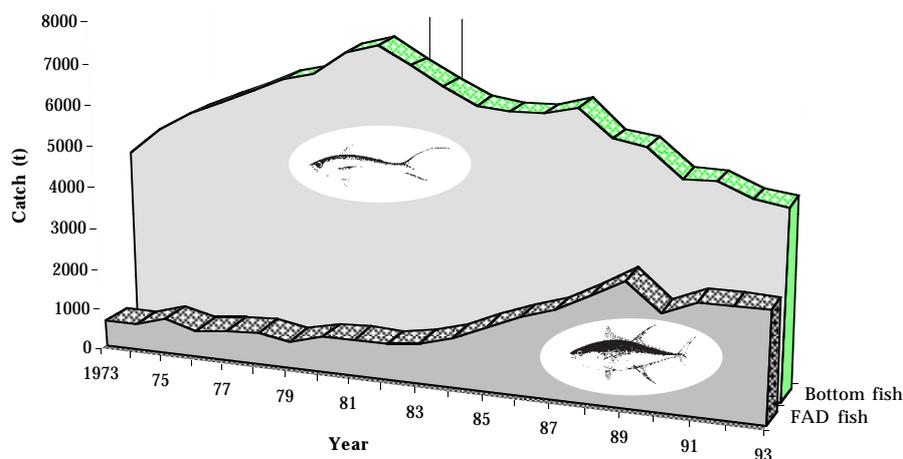


Figure 1: Comparative catches of bottom and FAD fish

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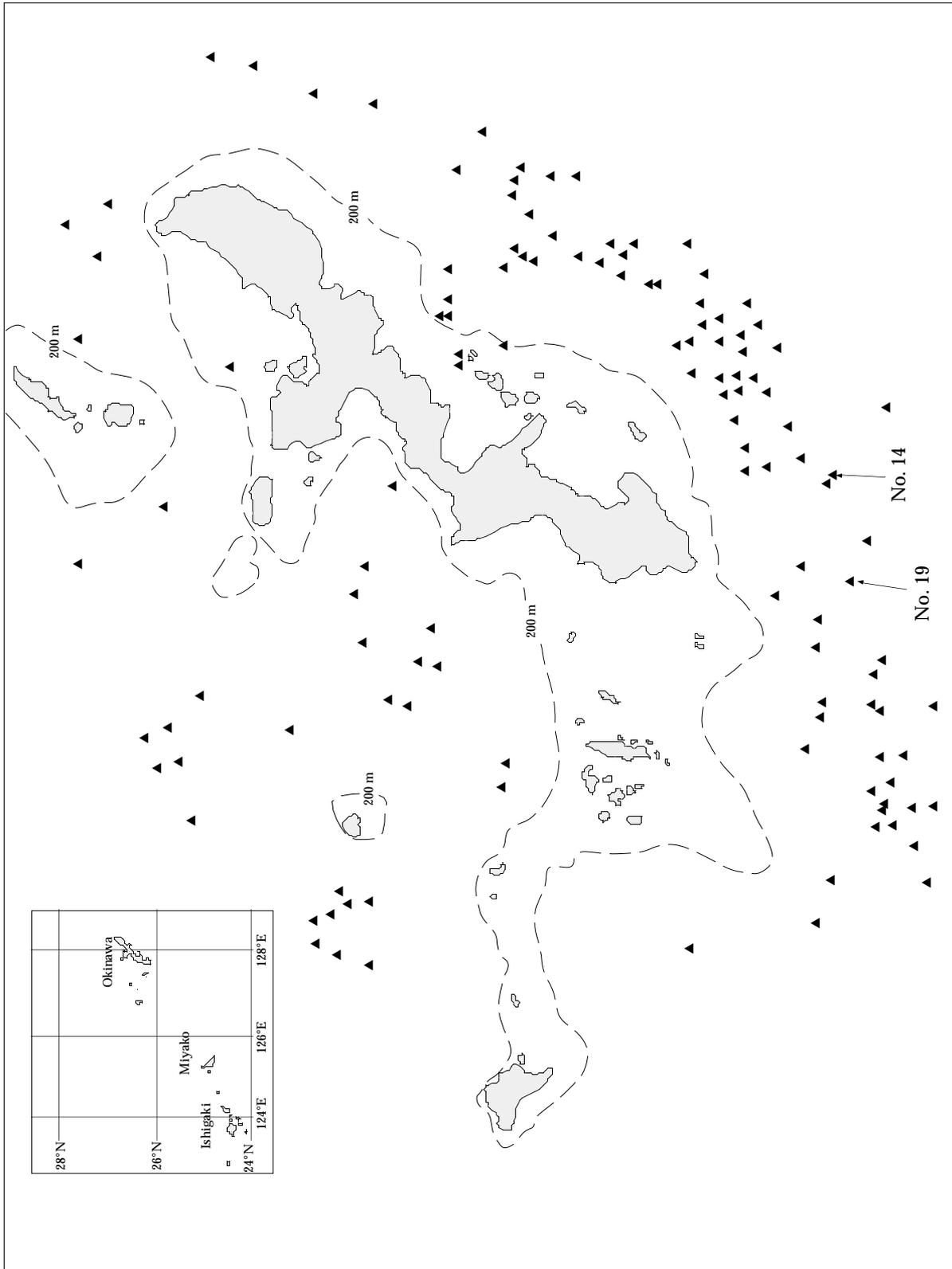


Figure 2: Location of FADs around Okinawa Island

several types of buoys in Okinawa and two of them, the vertical type and the multiple-float type, are the most commonly used. The structure of FADs has been devised by each region's fishermen. Though it is difficult to choose the best type, so called 'vertical types' (raft made of one big spherical float) have been preferred by fishermen recently.

The size of the catch that can be expected from one FAD annually depends greatly on the location of the FAD. An effective FAD can be a hundred times more productive than an ineffective one. Table 1 and figure 3 show the catch from

eleven FADs belonging to the Itoman Fisheries Cooperative (IFC) at the southern tip of Okinawa Island in 1995. It is generally accepted that the further from the coast a FAD is moored, the better its chances of being productive. The catches from FADs no.14 and no.19, which are located well offshore in depths of over 1500 m (see Fig. 2), were very good indeed (Table 1, Fig. 3).

For pelagic fish, there is a strong relation between current and catch, the depth and the current should be carefully evaluated when deploying a new FAD.

Table 1: Total catch and value of catch from 11 IFC FADs in 1995

FAD no.	Catch (kg)	Value (Yen)	Average value (Yen/kg)
3	32,441	14,904,875	459
4	5,830	2,987,452	512
11	29,959	12,956,854	432
13	4,084	1,523,652	373
14	93,253	41,369,213	444
16	17,668	8,193,524	464
17	3,054	1,182,650	387
18	8,698	4,291,018	493
19	133,778	64,864,517	485
20	35,947	12,680,221	353
21	22,268	10,202,882	458
Total	386,980	175,156,858	453

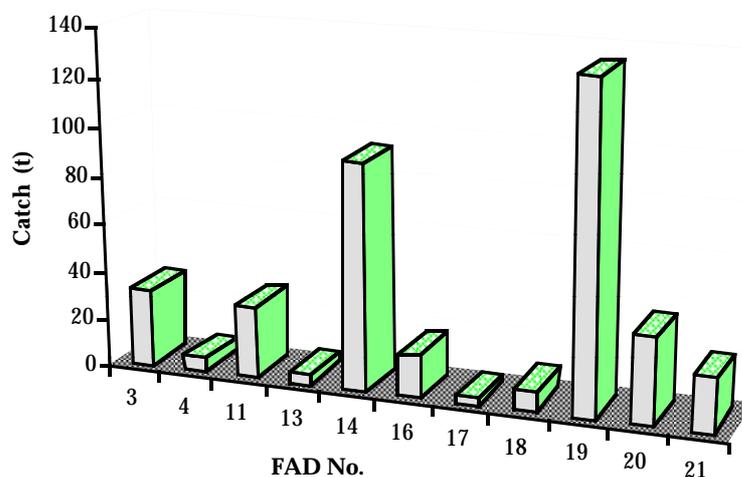


Figure 3: Comparative catches of 11 IFC FADs in 1995

One of the most important species in the Okinawan FAD catch is yellowfin tuna. Table 2 shows the catch composition of fish from FADs landed in the IFC market in 1995. Having a higher price, bigger yellowfin tuna (>10 kg) are the fishermen's main target.

Deploying one FAD usually costs 3 million yen (equivalent to US\$ 30,000), which includes the cost of the FAD itself (with the buoy, the mooring line and 2 anchors) and the deployment costs. A hand-made buoy usually costs half the price of a manufactured buoy. Some of the fisheries cooperatives are using fully 'home-made' FADs.

The lifespan of FADs on station depends on the location and the number of typhoons passing in the vicinity of Okinawa; one and a half years is said to be average. Some fisheries cooperatives check their FADs every few months and replace damaged parts to extend the FAD life.

Recently, a very strong rope material called 'Bectran' has been used. This rope is very expensive—more than 1000Y en/m—but strong enough to resist a knife-cut. Bectran has been used from the buoy down to 600 m depth, the rest of the mooring line being made with cheaper materials (e.g. polypropylene).

The total length of the ropes from the buoy to the anchor is usually 1.4 times longer than the depth, thus allowing a 40 per cent slack to the mooring line.

It would seem costly if a 3 million FAD was lost in one or two years. However, a FAD is consid-

ered to pay for itself in Okinawa. One of the characteristics of Okinawan FAD fisheries is that the subsidy from governments has tended to decrease recently. The municipal governments are still subsidising FADs, but the prefectural government no longer does so. In Itoman, the municipal government and IFC share the expenses related to each new FAD; but if the FAD is lost, the fishermen will have to deploy a substitute FAD at their own expense.

IFC fishermen have to pay two per cent of their catch from FADs and 20,000 yen annually as FAD management fees. New FAD deployment plans or management plans of FADs are authorized by the FAD Management Committee set up by FAD fishermen in the region. The Committee has now 120 members and manages 11 FADs.

There are some rules on fishing around FADs. For example, you have to round a FAD clockwise when trolling to reduce boat-clash accidents. Mooring to FADs and using wire fishing gears are prohibited.

Recently, a project to deploy huge, durable FADs (called 'Nirai' in Okinawa) is implemented by the national and the prefectural governments. The surface buoy is made of steel. It is 7 m deep and 16m wide at the base (see Figure 4 and picture on next page). The mooring line is made of chains and reinforced wire rope.

The total cost of one of these FADs is more than 100million yen (\approx US\$1 million). However, it is designed to last at least 10 years. In 1995, two of these FADs were deployed offshore of Okinawa.

Table 2: Catch and value by species from 11 IFC FADs in 1995

Name of fish	Catch (kg)	Value (Yen)	Average value (Yen/kg)
Yellowfin tuna (>10 kg)	166,549	108,927,242	654
Yellowfin tuna (<10 kg)	136,788	37,280,846	273
Dolphin fish (mahi-mahi)	28,384	6,486,844	229
Black marlin	17,580	10,229,210	582
Albacore	13,983	4,153,521	297
Skipjack	11,424	3,111,913	272
Wahoo	4,881	1,618,505	332
Bigeye tuna	3,479	1,857,745	534
Rainbow runner	2,018	718,233	356
Others	1,894	772,799	408
Total	386,980	175,156,858	453

They withstood three typhoons with no damage. Their aggregating effect has been great so far; twelve tonnes of tuna were caught from around one of them in September 1995. Recently, two

more were set around Okinawa. We will try to keep the SPC FAD Information Bulletin readers informed about this project in future issues.



A 'Nirai' being serviced

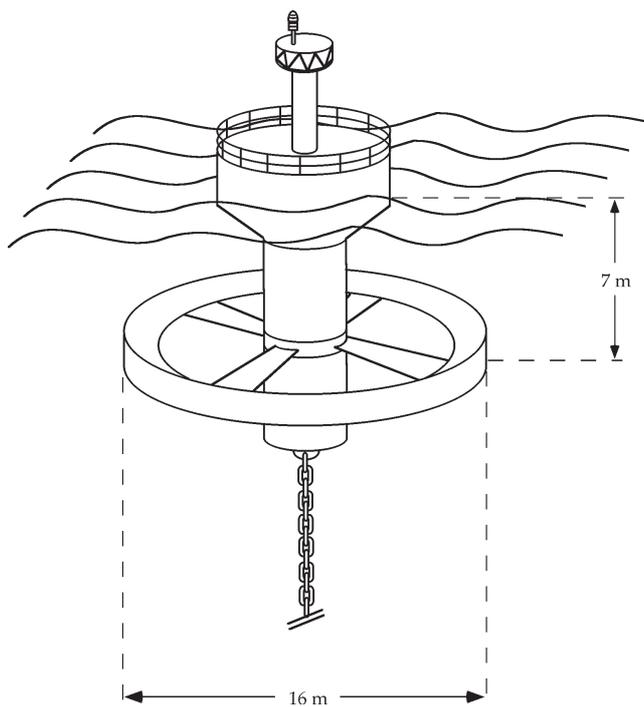
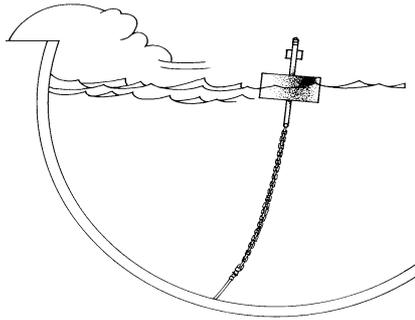


Figure 4: Details of the 'Nirai' raft



Hands-on FAD_s

Latest type of FAD used in French Polynesia

by F. Leproux¹ & A. Desurmont

INTRODUCTION

In 1981, French Polynesia set up a FAD programme to help the development of the artisanal fishery. In 1995, the local government body responsible for the FAD programme, EVAAM (Établissement pour la Valorisation des Activités Aquacoles et Maritimes), set up its 200th FAD. Like most of the other islands in the Pacific, French Polynesia is using the inverse catenary system.

Artisanal fishermen in French Polynesia have developed their own fishing techniques to capture tunas in deep waters (see the drop-stone technique described in FAD Information Bulletin #1). This has created a real problem for EVAAM, since the fishing lines often get tangled with FADs and badly damage their mooring lines.

To solve this problem, EVAAM has been trying to find ways of protecting the top 200 m of the FADs' mooring lines, (e.g. adding PVC tubing or fire-hose) but, although encouraging, results are still unsatisfactory. More experiments with other types of tubing or PVC-coated cables will be made in the near future.

Furthermore, to make sure the mooring line is as near vertical as possible to reduce the chances of it being caught by a drifting fishing line, the slack given to the mooring line has been reduced to the minimum: 100 m in depths of less than 1,500 m, 150 m for greater depths.

FAD MOORING COMPONENTS

The table on page 14, related to the figure on page 15, gives the specifications of the FAD mooring components. It must be noted that EVAAM has had components specifically made by the manufacturer to suit its needs:

- a longer shackle-pin carrying a double nut, and
- the swivel directly linked to the chain to avoid the need for a connecting shackle.

Furthermore, all hardware sizes have been standardized to simplify the work and facilitate the different connections:

- all shackles, swivels and chains are of 19 mm diameter, and
- lengths of chain used for the top and bottom parts of the mooring are the same: 6 m.

FAD RAFT

For the raft, two models of manufactured polyvinyl plastic buoys may be used. One has a tear-drop shape and a volume of 430 l. The other is spherical with a volume of 575 l.

They are filled with polyurethane foam. Although this foam is not dense enough to be totally waterproof, it maintains the shape of the buoy if it is pierced; this gives EVAAM the time to intervene.

¹ Établissement pour la valorisation des activités aquacoles et maritimes (EVAAM), BP 20, Papeete Tahiti, French Polynesia. Fax: (689) 434979, phone: (689) 428148

A 2.5 inch galvanised pipe (6 m long) is fitted through the centre-hole of the buoy and maintained in place by two welded steel plates. A steel plate (0.2 x 0.2 m) is welded to the top of the mast; it carries reflective tape. In the Society Islands, where shipping is more important, a Mac Dermott light is also fitted to the top of the mast. The padeye at the bottom of the pipe is made of 22mm mild steel rebar.

FAD ANCHOR

A concrete block is used as an anchor. It is interesting to note that of all the FADs that have been

lost since the beginning of the FAD programme in French Polynesia, there is no record of a FAD being lost because of bottom hardware or concrete anchor failure.

The concrete block's dimensions are: 0.9 x 0.9 m at base; 0.6 x 0.6 m at top; and 0.6 m high. It is made from 1.9 density concrete reinforced with a rebar cage constructed from 10 mm rebar.

It weighs approximately 950 kg. The anchor bail is made out of \varnothing 22 mm mild steel rebar.



MOORING COMPONENTS

Component	Description	Size	Material	Breaking strength
1	 Safety shackle with double nut and SS cotter pin	19 mm 5/8 in	Forged, treated, high-carbon steel (85/100 kg)	n/a
2	 Long-link chain	19 mm 5/8 in (length: 6 m)	Forged, treated, high-carbon steel (85/100 kg)	n/a
3*	 Forged swivel (chain swivel)	19 mm 5/8 in	Forged, treated, high-carbon steel (85/100 kg)	n/a
4	 Rope connector (Samson: size 3)	19–22 mm 3/4–5/8 in	Nylite	
5**	 Sinking rope 8-strand plaited	22 mm 5/8 in 0.314 kg/m (length: 200 m)	Deltaflex	10,000 kg 22,050 lb
6	 Protective tubing	32 mm (length: 200 m)	PVC	
7	 Sinking rope 8-strand plaited	22 mm 5/8 in 0.314 kg/m (length: 200 m)	Nylon	8,300 kg 18,300 lb
8	 Buoyant rope 8-strand plaited	22 mm 5/8 in 0.220 kg/m (length: depth – 300 m)	Polypropylene	5,600 kg 12,400 lb

* The forged swivel is directly linked to the chain by the manufacturer, as requested by EVAAM.

** Deltaflex is used for the top 200 m of mooring line because it has a better abrasion resistance than nylon

Jumbo trolling ¹

In the subtropical region of Okinawa in Japan, bottom longline and suspended bottom longline fishing have been used extensively, targeting deep-bottom species (snappers, groupers, etc.). However, in the late 1970s the catches of bottom fish decreased rapidly (see the article by S. Kakuma on page 8). Consequently in an attempt to stabilise the fishery over the long term, four FADs were first established in December 1984, and a new technique, called Jumbo trolling, was developed by local fishermen. The main purpose of this technique, targeting tuna and other pelagic species, is to try to keep the trolling lines out of the water and have only the lures touching the surface of the ocean.

FISHING BOAT

The size of the boats used for this technique usually averages 5 gross tons. They are fitted with 39 h.p. engines and equipped with an electrical line hauler, a VHF radio (1 W), a Loran positioner and an echo-sounder (colour). They are normally crewed by a single fisherman.

FISHING GEAR

A 16 m pole made of fibre-reinforced plastic (FRP) is fixed vertically alongside the cabin (see Figure 1 and picture on page 18). One 18–20 m leading line, made of nylon gut no. 200, is fixed to the top of the pole and another line, called a messenger, of the same characteristics is attached to the end of the first line and to the boat; this line will allow the fisherman to retrieve the leading line when a fish strikes.

The 135 m main line, made of no. 150 nylon gut, is connected to the leading line by a short breaking line made of 4 loops of no. 12 cotton thread.

The main line is stored at the stern, on an electrical line hauler (see picture on page 18). At the end of this main line a hard wooden device, called a Jumbo (see Figure 2), is attached. It creates considerable drag and keeps the main line taut whilst trolling. This one-metre-long Jumbo—also called ‘aeroplane’—is locally fabricated from a hard

wood (*Pawlonia* or Japanese cedar). It carries two 0.32 m ‘wings’ made of steel plates. A large piece of lead (0.42m long) is inserted in the ‘belly’ of the Jumbo to give it some weight and make sure it ‘digs’ into the water.

Five branch lines, made of no. 150 nylon gut, are suspended from the main line, the first being attached 30m in front of the Jumbo and the four others at 15m intervals. All five branch lines are joined to the main line by a loop and a stainless-steel snap, fitted with a bronze swivel, so they can be detached when necessary. The lengths of the respective branch lines, starting from the Jumbo, are 0.78m, 1.14m, 3.53m, 4.25m and 5.8m.

A 24 cm squid-type lure—with a 38 g lead weight fitted inside—is attached at the end of each branch line. The lengths of the branch lines are determined by the height of the upright pole and the distance between them.

Under normal circumstances, the branch lines are adjusted to have the two lures closest to the Jumbo permanently touching the surface of the water, the third lure slapping the top of the waves, and the fourth and fifth lures 1m above the top of the waves.

A 22cm diameter float is attached to the rear of the Jumbo to make sure it does not dive too deep, and an additional 15m snood, made of no.150 nylon gut, is attached to the Jumbo by a stainless-steel snap with a swivel. The lure is attached to the end of this snood, set to target large fish like marlin and big tuna.

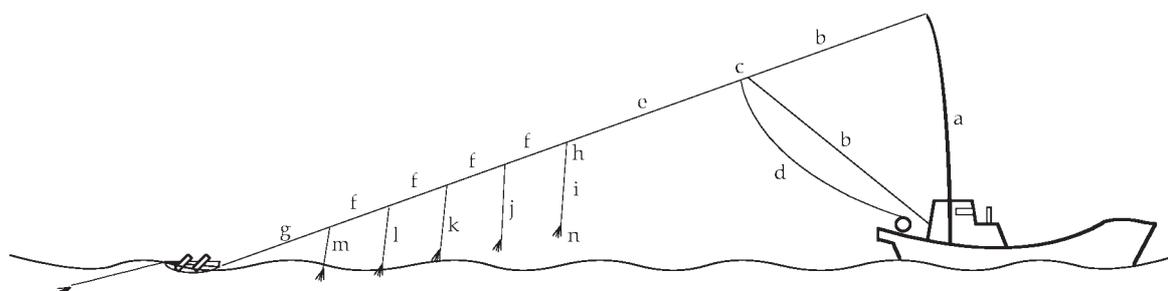
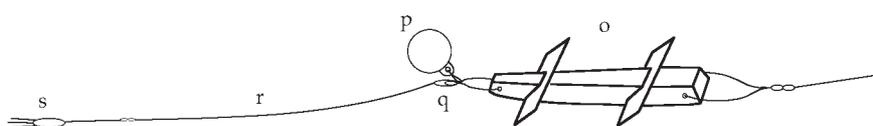
OPERATING METHOD

When the boat reaches the fishing ground at sunrise, the Jumbo is attached to the end of the main line, which is set on the electric-powered machine, and the line is cast while the boat is moving. The boat trolls at 3–4 knots and the fisherman usually waits until two or three fish have been hooked before hauling in, rather than hauling in each time a fish takes the lure. Once fish have been hooked, the boat reduces speed before hauling the main

¹ Source: Fishing gear and methods of coastal fishery in the southern waters — Fishing gear and methods in Okinawa Prefecture. Overseas Fishery Cooperation Foundation. 1988.

Table 1: Jumbo fishing gear specifications

Serial	Designation	Type of material	Standard measurements	Quantity
a	Pole	FRP	16 m length	1
b	Leading line	Nylon gut	No. 200, 18–20 m	2
c	Breaking line	Cotton thread	No. 12, 0.2 m (4 loops)	1
d	Riding rope	Nylon gut	No. 150, 20 m	1
e	Main line	Nylon gut	No. 150, 45 m	1
f	Main line	Nylon gut	No. 150, 15 m	4
g	Main line	Nylon gut	No. 150, 30 m	1
h	Snap with swivel	S. steel/bronze	12 cm	5
i	Branch line	Nylon gut	No. 150, 5.8 m	1
j	Branch line	Nylon gut	No. 150, 4.35 m	1
k	Branch line	Nylon gut	No. 150, 3.53 m	1
l	Branch line	Nylon gut	No. 150, 1.14 m	1
m	Branch line	Nylon gut	No. 150, 0.78 m	1
n	Lure	Vinyl chloride	24 cm with no. 40–45 hook	5
o	Jumbo	Hard wood/lead	1 m x 0.32 m	1
p	Float	Polyethylene	22 cm diameter	1
q	Snap with swivel	S. steel/bronze	12 cm	1
r	Snood	Nylon gut	No. 150, 15 m	1
s	Lure	Vinyl chloride	24 cm with no. 40–45 hook	1

**Figure 1: General view of the Jumbo fishing gear****Figure 2: Details of the Jumbo trolling board**

line. All branch lines forward of the ones that have hooked the fish are detached from the main line when hauling in, and the lures are hung over the side of the boat to prevent tangling.

The fisherman must be very careful when hauling in big fish, such as 20–30 kg yellowfin or bigeye tunas, as these can pull very powerfully and cause the branch lines to whip dangerously. The boats either set sail early in the morning and return at night, or spend the night offshore.

FISHING SEASON, GROUNDS AND CATCH

The fishing season extends from April to October, with the most intensive fishing being carried

out in July. The major fishing grounds are around the FADs that were established within 18–20 miles from the coast.

The main catch consists of yellowfin tuna, bigeye tuna and skipjack, with wahoo, mahi-mahi and marlin also being caught.

When yellowfin and bigeye tuna are caught, they are placed on a sponge mat, the top portion of their brain is cut and a hard nylon line is driven into the spinal cord to kill the fish quickly before it is gilled, gutted and stored in ice-water. It can then be sold on the market as sashimi-grade tuna.



Electrical line hauler

Stern view of a fishing boat carrying two Jumbo trolling poles

Drift fishing with live atule ¹

by Aymeric Desurmont

One of the most popular fishing technique used around FADs in Reunion Island is drift fishing, using a live atule (*Selar crumenophthalmus*) as bait. Like most pelagic species, atule—called ‘pêche-cavale’ by the locals—are difficult to keep alive, so fishermen need to go and catch them a few hours before FAD fishing commences..

ATULE JIG-FISHING

This very simple technique is used at night at the entrance of the bays where atule tend to gather.

The fishing gear consists of a main line made of very thin nylon monofilament (ø 0.3–0.4 mm) carrying five short snoods (0.15 m of ø 0.2–0.3 mm) with lures. Lures are made with tiny hooks and small lengths of shiny knitting wool—some fishermen even add fluorescent beads close to the hooks.

Normally the boat, which is drifting while the fishing takes place, carries a lamp hung over the side to attract the fish—this fishing technique can be used from a canoe. The line is lowered to 5–10 m

¹ Based on information given by Max Chane Tao and Emmanuel Tessier, CRPMEM, 238 rue du Maréchal Gallieni, 97820 Le Port, La Réunion, France

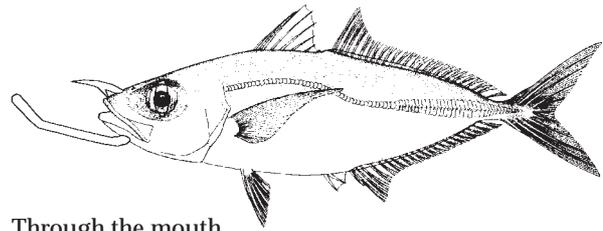
and then hand-jigged while slowly brought back to the surface.

The catch is kept in a big bucket full of seawater. On boats equipped with electrics, a pump is used to create a permanent circulation of fresh seawater in the bucket. On smaller boats, buckets are used to replace part of the water regularly.

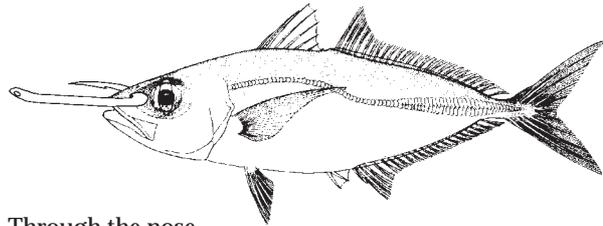
DRIFT-FISHING AROUND FADS

The fishing gear used for this technique is very basic: one man, one line, one hook. Some fishermen use rod-and-reel with a nylon monofilament ($\approx \text{ø } 0.5 \text{ mm}$) or Dacron line, others just use handlines— $\text{ø } 1.5\text{--}2 \text{ mm}$ nylon monofilament or tar-coated nylon threaded lines.

They all use 'tuna hooks' (no. 5–7/0) or 'swordfish hooks' (Eagle Claw L9014 size 8/0, or equivalent).



Through the mouth,
from underneath



Through the nose

Figure 2: Two ways of hooking the live atule for drift-fishing

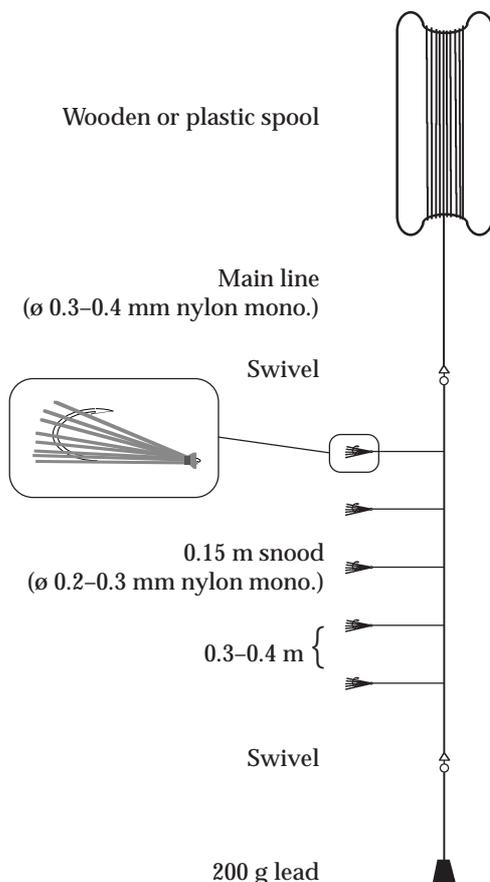


Figure 1: Fishing gear used to catch atule (*Selar crumenophthalmus*)

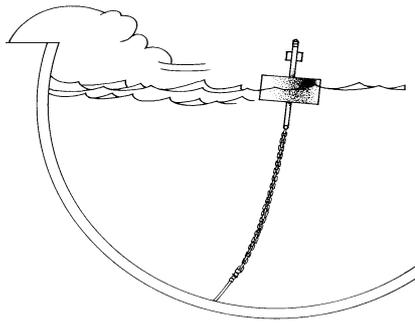
The boat is stopped up-current from the FAD, the live atule is carefully hooked through the mouth, from underneath, or sideways through the nose (see Figure 2) and put in the water. About 50 m of line are paid out and left slack.

When a fish bites, the fisherman pays out more line to allow time for the fish to swallow the bait.

Unlike trolling-lures, which are fast moving targets attacked by the fish, a drifting bait is usually carefully approached by the predator, which may 'nibble' two or three times before swallowing it. Therefore, it is very important not to strike immediately at the first bite as this may scare the fish away.

When the drift is too fast because of the wind or the current, the boat may be moved slowly—using oars on small boats or the engine on bigger boats—to try to keep the line as near vertical as possible.

As with most techniques targeting tunas or marlins, best results are obtained at dawn or at dusk. This technique is also used successfully, at any time of the day, to catch mahi-mahi (*Coryphaena hippurus*) very close (less than 500 m) to the FAD. 



Readings

Analysis of small scale movements of yellowfin tuna around fish aggregating devices (FADs), using sonic tagging

by Francis Marsac ¹,
Patrice Cayré ² & François Conand ³

The following is an abstract of a presentation made during the 6th Expert Consultation on Tunas in the Indian Ocean, Colombo, Sri Lanka, 25–29 September 1995.

The on-going ultrasonic experiments of the Regional Tuna Project Phase 2 (Commission de l'océan Indien) are reported and analysed according to the local environmental parameters. Though seven yellowfin tuna were tagged during the first three cruises of the project, only the five tracked around FADs are considered in this paper. A seasonal trend affects the horizontal movements associated with FADs: strong link and homing behaviour during the core of the fishing season, and weaker link when the fishing season comes to its end and fishes start migrating out of the area. The vertical movements are analysed in order to provide a typology of tuna distribution

according to different features (FAD association at daytime and at night, transits between FADs during day and night), following which other variables are considered: life stage (juvenile or adult), moon phase and thermal structure.



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Horizontal and vertical movements of adult yellowfin tuna near the Hawaiian Islands, observed by acoustic telemetry

by Richard Brill ¹, Barbara Block ², Christofer Boggs ³,
Keith Bigelow ¹, Ellen Freund ² & David Marcinek ²

The following is an abstract of a presentation made during the 47th Annual Tuna Conference, Lake Arrowhead, California, 20–23 May 1996.

We measured the vertical movements and horizontal displacement speeds of five adult yellowfin tuna, (*Thunnus albacares*, 64–93 kg, 148–167 cm fork

length) off the Kona Coast of Hawaii during August 1995. We simultaneously gathered data on water temperature, oxygen levels and oceanic cur-

rents. Vertical movements were monitored by Vemco ultrasonic depth-sensitive transmitters, depth-temperature and depth-oxygen profiles by a Sea Bird CTD system, and oceanic current patterns by an acoustic Doppler current profiler. Horizontal displacement speeds were calculated, based on positions of the tracking vessel recorded every 15 minutes. Individual fish were tracked from one to four days.

Adult yellowfin tuna spent approximately 60–80 per cent of their time either in or immediately below the surface layer (i.e., above 100 m, $\approx 25^\circ\text{C}$). This is similar to the depth distributions of juvenile ($\approx 2\text{--}5$ kg) yellowfin tuna, Indo-Pacific blue marlin, *Makaira nigricans*, and striped marlin, *Tetrapturus audax*, tracked near Hawaii.

The median horizontal displacement speeds of adult yellowfin tuna ranged from 72 to 154 cm/s (1.4–2.9 knots), whereas those for five juvenile (50–71 cm) yellowfin tuna tracked in earlier studies ranged from 22 to 135 cm/s (0.43–2.6 knots). This may reflect a moderate increase in the routine swimming speeds of adult fish and is consistent with the direct relationship between body size and swimming speed predicted by optimal speed models.

The median displacement speeds of adult yellowfin tuna were greater than the directly measured routine swimming speeds of roughly equivalent-sized blue marlin tracked in the same area.

During the more than 8 days covered by the combined tracks, fish remained within 14 nm of the Kona Coast of Hawaii and moved beyond 10 nm from the coast on only 3 occasions. Tracked

yellowfin tuna were often associated with porpoise pods, and in several instances the fish clearly followed the tracking vessel.

Adult yellowfin, like juvenile yellowfin tuna, also appeared to be familiar with the locations of anchored fish aggregating devices (FADs), navigated accurately between them, and repeatedly revisited FADs up to 18km (10 nm) apart.

The tight association of the adult yellowfin tuna with the coastline and FADs during the 2-week study period contrasted with the much more directed offshore movement of blue marlin and striped marlin previously tracked off the Kona Coast.

A relatively protracted residence time within the nearshore fishing grounds exploited by troll and handline fishermen could indicate the possibility of short-term depletion of localised abundance by concentrated fishing effort.



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Automated monitoring of yellowfin tuna at Hawaiian FADs

by A. Peter Klimley¹ & Charles Holloway²

The following is an abstract of a presentation made during the 47th Annual Tuna Conference, Lake Arrowhead, California, 20–23 May 1996.

We have been tagging yellowfin tuna, *Thunnus albacares*, with individually-coded ultrasonic transmitters near Kaena Point, Oahu. Automated micro-processor-based monitors that detect these tags have been attached to one sub-surface and four surface fish aggregating devices (FADs) off Kaena Point. The sub-surface FAD is located 1.9 km from shore at the shelfs edge in water 400 m deep. Three of the surface FADs (S, R, and V) are aligned north-westerly

and parallel to the coast. The buoys are 7km apart, 6–7 km from shore, and moored at depths of 560–840 m. The fourth surface FAD (CO) is situated 18.5 km west of Kaena Point at a depth of 1,850 m. Forty-five yellowfin tuna, of lengths 58.4–124.5 cm (TL) and weights 4.5–26.3 kg, have been tagged either by ourselves or by local sport and commercial fishermen under our supervision. The tuna are hooked and quickly brought to the boat, where they

are weighed and measured before an incision is made in their abdomen. Through this, a small cylindrical tag is inserted before the wound is closed with surgical staples. The whole procedure is completed and the tuna released within a minute.

We interrogate these monitors monthly for their records of tuna attendance at the FADs. These records indicate that yellowfin tuna:

- (a) return 1–10 times to the same FAD at which they were tagged, although less commonly to adjacent FADs, over periods of 1–18 days;
- (b) usually stay for intervals of less than an hour, but occasionally for periods of more than 10 hours;
- (c) often visit twice per day, once during the morning (02:00–09:00 hrs) and once in the evening (15:00–22:00 hrs), although visits do occur at other times; and
- (d) repeatedly arrive and depart from the vicinity of the FADs at the same time, indicating that yellowfin tuna can remain together within a single school on the above time

scale. For example, two tuna tagged near the sub-surface *K* FAD returned together on five separate days over an 18-day period. Yellowfin tuna tagged at the FADs have returned after intervals as long as 114 days.

We plan to upgrade the monitors to recognize the acoustic tags that are used with other local species, such as tiger sharks. This methodology will permit us to evaluate the relative effectiveness of different FAD configurations, i.e., whether sub-surface buoys are better than surface ones or in-shore FADs better than offshore ones.

Our first returns indicate that yellowfin tuna stayed only a day or two at the offshore *CO* FAD, up to a week at the three inshore surface FADs, and almost 3 weeks at the sub-surface *K* FAD.



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Daily fluctuations in the presence of *Thunnus albacares* and *Katsuwonus pelamis* around FADs anchored in Vanuatu, Oceania

by Esperance Cillauren¹

An analysis of the catches and daily observations were carried out on schools of yellowfin tuna, *Thunnus albacares*, and skipjack, *Katsuwonus pelamis*, between June 1982 and July 1985 from six small-scale fishing boats around five fish aggregating devices (FADs) anchored off Efate in Vanuatu.

One of the aims was to investigate daily fluctuations in surface school occurrence. Regularity of observation and time spent on monitoring enabled us to bring to light the more striking behavioural characteristics of aggregated schools. Ninety-one per cent of the total number of catches were skipjack (*K. pelamis*) and yellowfin (*T. albacares*).

Mixed schools of skipjack and yellowfin tuna were present within a 500 m range around the rafts just before sunrise, the yellowfin being nearer to the FADs than the skipjack. The abundance and ex-

tensiveness of surface schools diminished throughout the day.

Towards midday, the highest catches of yellowfin tuna were taken in a circle of 100m radius around the rafts, whereas an increase in skipjack yields was recorded one hour before sunset.

For both species the proportion of smaller specimens increased from dawn to sunset. *K. pelamis* did not take an obvious position in relation to the direction of the current, while *T. albacares* was mostly found in a downstream position.

Source: Bulletin of Marine Science, 55 (2–3): 581–591. 1994.



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A review of bioeconomic and sociological FAD modelling, with recommendations for future research projects

by Jim Anderson

In the first issue of the SPC FAD Information Bulletin, we presented abstracts from the first two documents of Jim Anderson's work on 'The assessment of the interaction between fish aggregating devices and artisanal fisheries'. The following is extracted from Document 5, 'A review of bioeconomic and sociological FAD modelling, with recommendations for future research projects', in which Jim Anderson briefly reviews the history of FAD research and gives directions and recommendations for future research.

RECOMMENDATIONS FOR FUTURE RESEARCH

In this section recommendations are made for the specification of projects or project components which would contribute meaningfully to FAD research and its application to fisheries development and management problems. The philosophy behind these proposals is that we should build upon the FAD work that has already been done, in ways that specifically address the most pressing open questions about the nature and use of FADs.

Dissemination of information

There should be regular projects to interpret and disseminate information related to FADs to fisheries managers.

Multi-criterion and decision making (MCDM), and expert systems

Develop MCDM based expert system to assist with all decision making relating to FAD development and planning. This could be based on the FAD Handbook and report accompanying this document. Sociological analysis using the systemic approach should be included. The system should not operate as a 'black box' but rather provide a framework within which all relevant questions are addressed while showing clearly how answers are derived and how goals and priorities affect decisions.

Analytical methods

- Develop software to do sensitivity analyses on:
 - parameters in biomass exchange models for estimating yields and optimal effort levels;
 - assumptions on which cost-benefit analyses are based; or

- Write a thorough, step-by-step description of how to implement such a sensitivity model in a spreadsheet.

Investigation of the aggregation effect

It is important to quantify how fish aggregate and disperse, so that models can be applied in fisheries management. In the process, clues as to why they behave in this way may also emerge. Two approaches are recommended here—one to examine the relationships expressed in the biomass exchange models of FADs and another to look for the effects predicted by diffusion and optimal foraging models.

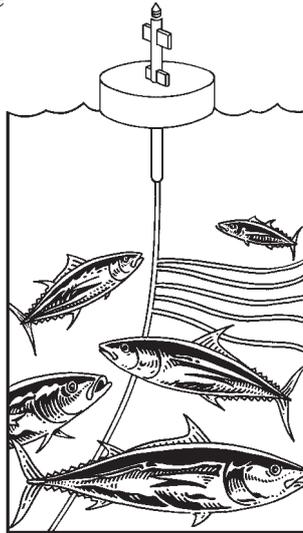
The first approach would be to try to determine at what rate fish accumulate at FADs, and what relation this rate has to the biomasses of fish at the FADs and in the underlying stock. This would include quantifying the loss of fish from the FAD to determine whether it is a constant- or density-dependent proportion of the biomass at the FAD. Seasonal effects would have to be accommodated. Different age/length classes may well aggregate in different ways, and this should be quantified.

For a start, where possible, use should be made of the data sets that exist, e.g. the data from the Solomon Islands industrial purse-seine fishery. Further data would have to be collected by monitoring a number of FADs and measuring how the number of fish (in various length-classes) at each FAD changes over time.

A good pre-FAD dataset would be useful. Measurements could be made by visual survey, sighting counts, or by taking acoustic soundings at the FADs. Water samples, plankton net samples, climatological and oceanographic data should be collected so that any correlations that exist can be detected. A series of experimental, unfished FADs would be ideal but expensive. Whether experi-

mental or commercially exploited, the FADs should be chosen/placed so as to cover as many of the following categories as possible.

- Deep water FADs that are fished by purse seiners are regularly stripped of most of their fish. The manner and rates at which those FADs are repopulated could be measured. Length and age composition of the catch could also be correlated with the number of days since it was last fished, to see what patterns emerge.
- FADs that are fairly lightly used by artisanal fishermen would be interesting because they are more likely to be close to equilibrium. Catches as well as population movements would have to be monitored.
- Neritic (shallow water) pelagics such as bonito and frigate mackerel seem to be less migratory than others. In such positions it might be possible to estimate population biomass of the base stock. Measurements of migration to and from FADs in such areas could be correlated to the base stock and FAD biomass. The FAD and species would have to be chosen carefully because the aggregation effect is likely to be weaker in these areas.
- Sites where FADs are fairly densely placed would be particularly interesting if tuna were also tagged in order to watch them move between the FADs. Commercial FADs are generally placed further apart than the 'safe distance' of about 10 miles. To measure movement between FADs that are closer than that, an experimental setup would be needed. The ideal would be to observe a matrix of FADs about four to five miles apart, and then to remove intermediate FADs and monitor the effect on distributions.
- It has been reported that tuna schooling behaviour is different in different oceans. Old fish tend to school around mammals in the Indian and Atlantic oceans whereas younger ones (and often mixed schools) are found around FADs in the West Pacific. Differences between the oceans, such as quantity of floating objects or behaviour of currents, should be investigated; any correlations could possibly provide insights into aggregation behaviour.



The second approach is aimed at testing diffusivity models and should begin with a study to estimate which of the predicted effects would be observable at all, given statistical variation. If the results are favourable, one could:

- determine whether heavy fishing in an area enhances immigration to that area i.e. whether FAD recruitment is density dependent. This could be added to the first approach, by including FADs that are heavily but continuously fished, rather than pulse fished.
- look to see whether there are fewer fish in the regions adjacent to a FAD catchment area than there are in the open ocean. This would require estimates of abundance at various distances from the FAD. Either research catches or sonar would have to be used, since fishermen will not fish in areas of known lower abundance.
- estimate deviation from constant diffusivity at certain times. The first group of biomass studies could be extended to include seasonal variation in the aggregation effect.
- determine whether there is a component of migration that is simply the result of diffusion combined with seasonal movement of the tolerable environment. This would require investigation of the oceanographic and climatological changes that take place along the known migration routes of tuna. If correlations exist, a diffusion model could be set up to try to imitate known tuna migratory behaviour using only diffusivity.
- if the structure of the model seems correct, estimate the diffusivity constant empirically for particular fisheries. Estimates of diffusivity have been reported in the literature. Methods for making such estimates should be investigated and applied adaptively to real fisheries.

Selecting figures of merit for FAD effectiveness analysis

Most bioeconomic models of conflict between user groups use optimisations based solely on the goals of economic efficiency. Other goals are harder to formulate and vary greatly between fisheries. It is recommended that an interdisciplinary team of

biologists, economists, social scientists and mathematicians investigate this issue. Goal programming, which can handle multiple goals, may be more useful than single-criterion optimisation techniques. The possibility of using multi-criterion decision-making techniques, game theory or the systemic approach as a procedure for determining goal functions should be investigated.

An adaptive research phase to implement developed techniques in specific fisheries would be important. It is possible that a weighting of objectives which is revised iteratively according to observed data may be more useful than a fixed framework.

Biological modelling

There are a number of ways in which existing biological models could be expanded to make them more representative of FAD fishing.

- Develop a bioeconomic model along the lines of the existing biomass exchange models (Samples and Sproul, Hillborn and Medley) but accounting for multiple cohorts where specific year classes are preferentially attracted to FADs. This sort of age-linked behaviour is considered very likely. The project should examine management implications of such a differentiation.

- Expand on Hillborn and Medley's model by including the spatial distribution of FADs and allowing for boats to search for the largest schools before making a set. Include a stochastic arrival and departure model, for example assuming fish come and go in schools that are small subsets of the stock population. It would be interesting to include a diffusion or optimal foraging model and see how this influences biomass equilibria.
- Look at the dynamics of games between multiple boats placing FADs with more subtle decision criteria than the ones used previously, for example each one deciding when it would be advantageous to place more FADs.
- Refine existing spatially-distributed models to include ideas and concepts which have been successfully incorporated in other types of models, such as density-dependent diffusivity, schooling and pulse fishing.

Many of these modelling projects would benefit from contributions from many disciplines. Research directions which span more than one field of technical expertise are usually the slowest to mature, but it is from such fields that whole new directions of scientific endeavour often emerge.



Fishing for tuna around floating objects

by Alain Fonteneau & Jean-Pierre Hallier

This article was published in the French magazine La Recherche in 1992, following the IATTC annual meeting. It is interesting to note that the ecological consequences of an extensive use of FADs started to be questioned at this time.

One distinguishing feature of tunas is their habit of aggregating under floating objects. A new fishing technique capitalises on this surprising and as-yet unexplained habit.

Industrial fisheries in all the world's oceans are now beginning to take the advantage of an unusual event long known to artisanal fishermen in the Philippines. Schools of tunas and other fish species tend to gather under objects floating on the ocean. In order to study this behaviour, a group of scientists, including the authors of this article as representatives of ORSTOM, met at La Jolla in the United States in February 1992 at the invitation of the Inter-American Tropical Tuna

Commission (IATTC). The meeting report, just published (Annual IATTC report, Tunas and floating objects: a worldwide review, 1992), is the first world review of knowledge on this topic.

The annual industrial tuna fishery catch worldwide amounts to over 2.5 million tons. The three main tropical species, yellowfin (*Thunnus albacores*), bigeye (*T. obesus*) and skipjack (*Katsuwonus pelamis*) are open-ocean fish and account for the vast majority of tuna landings. The skipjack is a small tuna weighing between one and five kg, while yellowfin and bigeye can weigh as much as 100 kg. Tuna is chiefly caught with the purse seine, a 1,800m-long net, which is drawn

closed, in the same way as a purse or pouch, at a depth of approximately 100 m. The fishing boats, known as purse-seiners, usually locate their tuna in schools and can take several tonnes (i.e. several hundred or several thousand fish) in each set.

What about tuna catches around floating objects?

The proportion of the total catch that is taken around floating objects varies from ocean to ocean, mainly due to the varying number of objects present. In the Western Pacific and the Indian Ocean, tunas account for the biggest proportion of landings (65% and 52% respectively of total catches, i.e. 390,000 and 104,000 t). Floating objects can be due to man's activities (various objects thrown overboard from ships) or be of natural origin (flotsam such as tree trunks, stumps, logs), carried down to the ocean by watercourses.

The movements of floating objects are currently being studied in various countries, either by tagging and tracking, or from our knowledge of wind and tide. Their exact movements, however, remain inaccurately known because there is doubt about their survival time; wood, for example, ends up becoming water-logged and sinking and is colonised by invertebrate fauna. Also little reliable information is available about where such objects come from.

One surprising fact emerges from the in-depth observations conducted over the past ten years in the Pacific by Mr Hall and his IATCC colleagues and tabled at La Jolla: it has been clearly established that the shape, nature, size (providing it is over 1 m long), colour and duration of immersion have no effect on the aggregating influence exercised by an object on tuna or on the number of tuna attracted.

In every ocean, some characteristics of schools associated with floating objects are invariable (see figure). For example, all contain a majority of skipjack (2/3 on average) followed by yellowfin and then bigeye. Small juveniles dominate where the latter two species are concerned. On average, schools around floating objects are larger than other schools, producing a yield per set of approximately 40 t rather than the 20 t fished from free-swimming schools.

In addition, schools of tuna under floating objects only escape the closing purse-seine in 10 per cent of sets, whereas the failure rate is almost 50 per cent with purse-seine sets targeting free schools.

At dawn, the biomass of tuna associated with floating objects is generally higher and the most profitable sets occur at that time of the day. Since uncaught tuna close to a floating object reclaim the space vacated by the purse-seiner within 24 hours, the same floating object can be returned to on several successive occasions, yielding catches of up to several hundred tonnes.

On the other hand, the tuna caught are smaller and do not therefore attract such a high price. Schools frequently contain a mixture of various species such as billfish, marlin, shellfish, coastal fish (carried along by drifting objects), dolphinfish, barracuda, shark and turtle. These species, however, contrary to tunas, do not aggregate.

What then is the origin of this astonishing association between tuna, a range of other species and floating objects? Clearly, it is primarily linked to social relationships between the fish and not directly due to foraging. Indeed, studies of the stomach contents of tunas caught demonstrate that they are either have an empty stomach (the most frequent scenario) or that they principally prey on oceanic or deep-swimming species, which are not observed around floating objects.

Food is, in any case, not present there in adequate quantities to attract these species: 40t of tuna, a quantity frequently counted under a floating object, would on average consume around 2t of food daily, whereas the potential available food supply would not exceed several hundred kilograms.

To preserve the ecological balance, the exploitation by fishermen of specific tuna behaviour will need to be kept under observation.

In fact, two as yet very hypothetical facts would appear to play a very important part in causing tuna to aggregate under floating objects. Firstly, the shadow of an object on the surface may give certain species, tunas in particular, a 'map of reference' in the uniform ocean; next, the few small fish in the immediate vicinity of a floating object, for example, trevallies, groupers and triggerfish, could comprise a minor food supply and act as a catalyst by 'fixing' some fish attracted by easy prey.

Tunas' natural tendency to aggregate in schools (they are the only really gregarious species around floating objects) might have a 'snowball effect' around the first arrival. Tunas do not, however, remain indefinitely under such objects. Diurnal

movements have been revealed by tagging tunas with a micro-transmitter tracked from a vessel equipped with a receiver. Tagging carried out in 1989, by K.N. Holland, of the University of Hawaii, showed that tunas may leave a floating object and swim for several miles, probably hunting for food, before returning to it.

The idea of using artificial floating objects or fish aggregation devices naturally developed in the minds of both fisherfolk and scientists. The devices are often just simple bamboo rafts from which are hung nets, which are thought to in-

crease their power of aggregation. These nets are sometimes fitted with coloured lights, while the rafts can be equipped with a radio-beacon, making it easier to locate them.

Sophisticated instrumentation is also sometimes used, consisting of an echo-sounder designed to gauge the quantity of tuna present around a FAD and a transmitter passing this information on the purse-seiner. Since 1990, these devices have come into common use with all purse-seine fleets and in all the oceans; their proliferation, however, raises two potential biological problems.

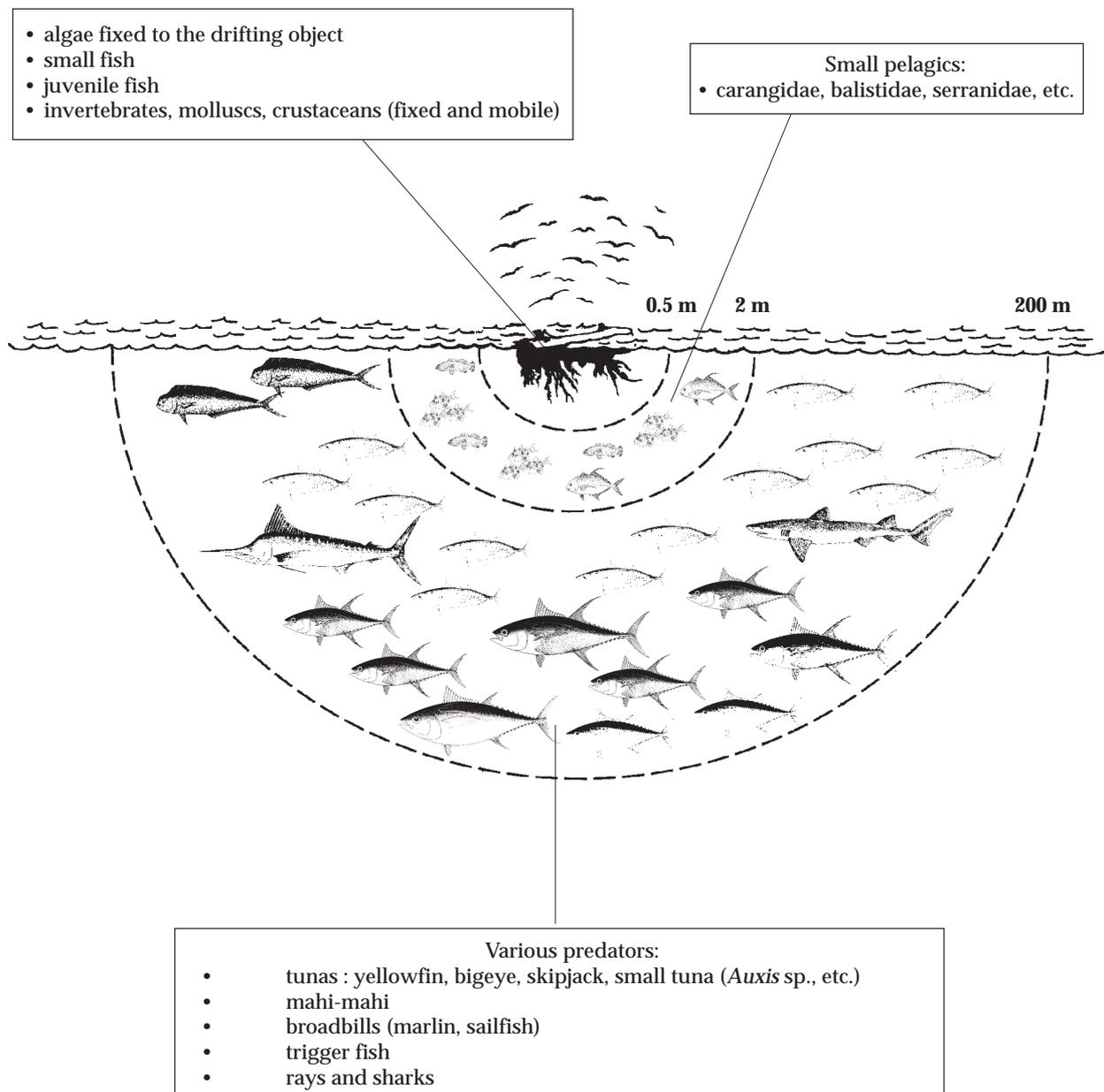


Figure 1: The marine life related to a floating object

Catching large quantities of juvenile yellowfin and bigeye may have negative consequences for the rational exploitation of these species. Also, this type of fishing cannot avoid catching the many species occurring close to the floating objects, which are then discarded; this may in the future raise as-yet inaccurately appraised ecological problems, especially if this fishing technique develops without control.

These two potential problems are currently a source of concern for the scientific community, without any estimation of their present and future severity being possible. International control over this type of fishing is envisageable through tuna fishing commissions, but was deemed premature by the experts at La Jolla.

The astonishing universality of the association between tunas and floating objects does, however, highlight the need for worldwide research coordination in this field. The La Jolla meeting was the first stage in such a process.

Experiments should be carried out at sea to gain a better understanding of this attraction and the prospects it offers fishermen. The La Jolla meeting recommended the development of a small spe-

cialised research vessel for this purpose, but it is too early to say whether the search for funding will be successful.

Scientifically-designed FAD trials, using devices equipped with light and sound sources, and the testing of objects towed by tuna boats, such as plastic mats or false whale-sharks, should also be carried out by animal-behaviour specialists.

The potential impact of artificial floating objects on tuna resources and the environment will in any event require careful appraisal, to make sure that the development of this fishing technique (which appears very attractive initially), does not have negative consequences on the ecological balances of the ocean.

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Source: La Recherche no. 248, November 1992, Vol. 23. (original in French).



FADs as a tool in Philippine artisanal fisheries

by Frederick J. Vande Vusse & Esperato Pileo¹

The 'payao', an indigenous deep-water FAD, attracts juvenile tuna and small pelagics for commercial harvest by pursing seines of varying sizes. Unrestricted use of the payao/purse seine combination contributes to overfishing. Artisanal fishermen compete for the same fish using multiple hook (200-250) hand lines trolled from outrigger canoes.

Harvests vary, averaging two kilograms per day. Net income is US\$ 1.53 per day from a US\$ 2.00 gross. Fishing at commercial payaos is good in the brief interval between attraction and a school's harvest by purse seine.

Payaos were established in municipal waters (to 5.6 km) exclusively for handline fishermen to try to provide more regular harvests while reducing direct competition with purse seines. They also

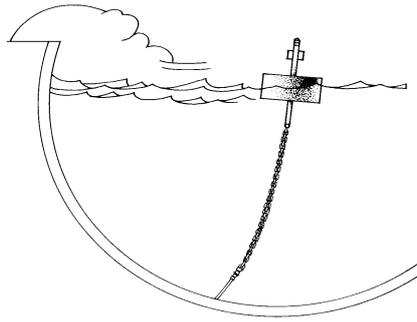
served as a community organisation focal point. As fish were not routinely caught or scattered by purse seines, hand line harvests became more regular.

Average catch doubled and costs decreased 50 per cent as fewer hooks (25-40) were needed. Average net income increased 140 per cent to US\$3.78 per day. Organised artisanal fishermen have forced purse seines offshore resulting in a redistribution of the harvest, increased fishery profit with a more equitable distribution and reduced fishing pressure in municipal waters.

Source: *Bulletin of Marine Science*. 55(2-3). 1994.



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A preliminary bibliography of FAD-related literature

compiled by Aymeric Desurmont

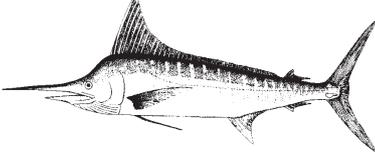
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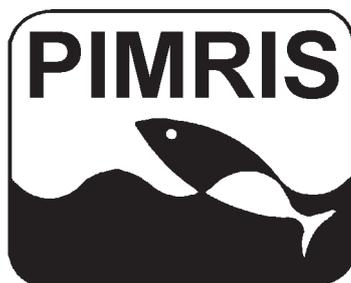
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Pacific Islands Marine Resources Information System

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