Implementation of an ongoing FAD programme in Curaçao (Netherlands Antilles) during the period 1993-2000

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Abstract

In Curaçao, deep-water FADs with GRP surface buoys were developed and tested. The first FAD was deployed in 1993. Up to now, a total of 5 FADs were deployed at the following depths: 730, 685, 700, 754 and 574 metres. Changes were made to the surface buoy, resulting in an improved design, the MKII surface buoy. One FAD lasted three years and one month. The main features of the design used are: the use of a spar-buoy design with constant tension on the moving chain to avoid slamming and jerking of the surface buoy; liberal use of sacrificial anodes, and maintenance to replace these anodes about once a year; the use of a short anchor chain with depth buoys, that does not touch bottom; a one-piece inverted mushroom anchor. With the GRP surface buoy, a reserve buoyancy of approximately 800 kg is obtained with chain as external ballast about 610 kg of net buoyancy remains (it would seem that the reserve buoyancy needed where strong currents occur, has been underestimated in many designs). Five new GRP MKII buoys are now under construction. Utilizing the experience gained with the deep-water FADs, two new types of FADs made of 500 mm diameter PVC tubes were designed to be used in waters of shallow and medium depth (150-400 m). One design uses a 3-m length of PVC tube, the other a 5-m tube (500 mm diameter). One FAD with 3-m PVC buoy has been tested succesfully, two 5-m PVC buoys are under construction. The use of PVC results in a buoy which is substantially less expensive than a GRP buoy. On the other hand, this type of buoy can probably not withstand the same forces as a GRP buoy and we assume that for use in deeper waters the GRP MKII buoy will still be needed.

Introduction

Function of FADs

In many countries, a large number of people derive either full-time or part-time income from artisanal fisheries. In addition to the fishermen themselves, some people market the fish, fishing vessels are built and maintained locally, etc., thus adding a considerable multiplier effect. Even though the fisheries sector is seldom of great importance in terms of its contribution to the Gross National Product (GNP), it does have a substantial social impact. In many countries, a considerable amount of foreign exchange is being saved which would have had to be spent on food imports. For these reasons, efforts to develop fisheries, within the framework of responsable use of existing resources, make economic sense. The use of FADs can improve the production of artisanal fishermen, lowering fuel costs and reducing the time spent loitering at sea looking for fish. The FADs act as a habitat for juvenile fishes which otherwise might have perished and probably have some positive influence on fish production. Nevertheless, the enhancement role of FADs is of very limited importance. Basically FADs do not "produce" fish, but only aggregate dispersed fish making it easier to catch them. As with all fishing methods however there are certain drawbacks. There are limitations where FADs can be placed. Conflicts can arise between fishermen from competition for space around the FADs and in some areas FADs are known to attract large numbers of juvenile fish, thus creating the problem of overharvesting a part of the population which has not yet reached its reproductive potential.

Types of FADs

FADs can vary from fairly simple payao type structures (shallow-water FADs) to more elaborate deep-water devices. Several different designs exist.

Spar buoy designs

A spar buoy design is well-suited to waters with short-length, choppy waves. Such a buoy can be constructed for a reasonable price and can withstand fairly rough weather although may be not a full-blown typhoon passing directly overhead. With a spar buoy design all the loads can be transmitted *via* the nose cone to the centrepole (a three bridle chain can be avoided). The buoy can move up and down in the water and adjust to changing loads more gradually than a flat cylinder buoy. When properly ballasted with chain as external load, the buoys have a very sea kindly motion. Even in choppy waters, the spar buoy type float will dampen motions and will not jerk or slam like a flat tyre-type buoy. This was confirmed through observations by divers on a spar buoy type FAD used in Curaçao. The spar buoy was able to withstand periods with very rough seas; we believe that the fact that this type of design was used is a decisive factor in determining the survival of these buoys in the open seas. A disadvantage is that quite some ballast is needed. In areas with short waves such as the Caribbean, the spar buoy has an obvious advantage, which may be less pronounced in areas with long waves. Nevertheless, in areas with long waves, short waves are often superimposed on the long waves, especially during periods of bad weather. In such conditions, a spar buoy design could hold a decisive advantage.

Designs that utilize a series of small buoys in the mooring line

In several areas in the Indo-Pacific region, deep-water FADs which utilize a series of small buoys in the mooring line are used. A series of small buoys is used to absorb changes in tension on the main line. As in a spar buoy FAD, it can be seen that is necessary to absorb the changing tension of the line gradually; the smaller floats have the function of dampening motions. In the Caribbean, such designs are used in Martinique and Guadeloupe. Two basic designs exist. A large deep-water FAD designed by an Ifremer team (Taquet *et al.*, 1998) and the Guadeloupe deep-water FAD of low-cost design.

When currents are strong, the whole FAD, which is built up out of depth-resistent floats will be submerged and will return to the surface when the current slacks. The design is thus well-suited for use at larger depths and in regions with strong currents. Compared to a FAD with one spar-buoy surface float, a FAD of such design can be moored easily at much larger depths. A disadvantage of the design is that the small surface buoy and its marker are not well visible from afar. Artisanal fisherman may have trouble finding the FAD. When the current is slack a row of small floats is exposed at the surface. Especially at night these can be overrun by ships. When moored in deeper waters, the radius of movement is quite large, it is thus difficult to indicate exactly where the buoy will be. This design is thus not suited for areas with a lot of shipping traffic.

Designs with taut cable, submerged-steel sphere, and surface indicating buoy

Designs exist for FADs which utilize a taut Kevlar or steel cable, a submerged-steel floating sphere, and a surface indicating buoy. There is a surface float, indicating where the submerged FAD is moored. From the submerged-steel floating body, a floating polypropylene rope, with some slack in it, runs to the surface and is connected to a relatively simple and cheap spar buoy with radar-reflector at the surface. A standard spar buoy such as those that are commonly used in longline operations can be used for this purpose. If the surface buoy is hit by a ship, there is a break-off point in the polypropylene line going to the surface. The relatively cheap surface buoy may then be lost, but a new surface buoy can easily be attached by a diver. Conceivably, a FAD of such design would be very durable, lasting many years, only the small surface indicating buoy would have to be changed at certain times. Even without the surface buoy the FAD would still be effective, allowing one to fish if the position of the FAD is known. The taut-cable design is however ill-suited for deeper waters. Divers have to be able to safely reach the submerged float and perform basic work, such as attach a new polypropylene line with surface buoy. If we assume that normal scuba equipment is used and assume that the work can be performed on days with relatively weak currents, then the submerged buoy should not exceed a depth of about 50 m on such days. Since the submerged float also has to be moored at a minimum depth of 15-20 m, in order to allow ships to pass over it safely, this leaves a fairly narrow range, say 20-50 m within which the submerged float has to fall. This requirement makes it almost impossible to use such a design in deep-waters. Since the scope of the FAD as a whole is very small, and the sources of error in accurately positioning a FAD in deep-water are many, it is almost impossible to achieve the necessary accuracy to succesfully deploy this type of FAD in deeper waters.

FAD programme in Curaçao

Deep-water FADs (500-800 m)

For the Curaçao programme, a spar buoy design was chosen for the surface buoy (fig. 1). This decision was reached after viewing a video of the Puerto Rico tyre-type FAD developed by Fiegenbaum, Friedlander and Bushing (Fiegenbaum *et al.*, 1989). In view of the short wave choppy sea conditions prevalent in Curaçao, it was felt that a spar buoy design would be more suitable than a tyre-type design.

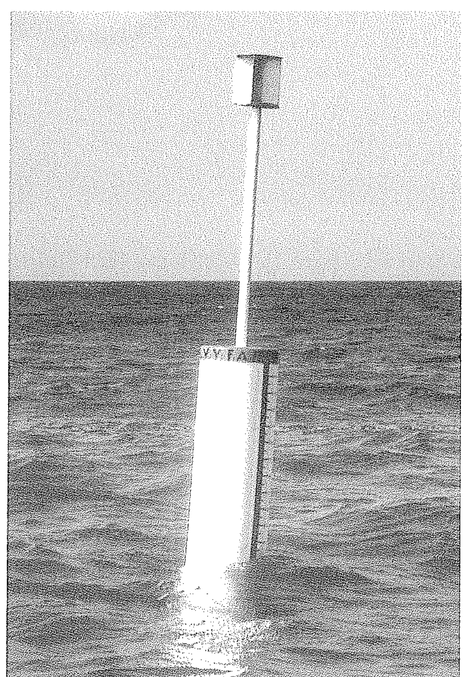


Figure 1
The 3-m PVC surface buoy, moored in water of approximately 260 m depth.

The designs which were reviewed in the 1984 South Pacific Commission Handbook (Boy & Smith, 1984) were studied. A design for Curaçao was arrived at and three deep-water FADs, using GRP (glass reinforced plastic) surface buoys (MKI buoy) were constructed. Key elements of this design are the following:
- the use of a spar buoy design, with constant tension on the moving chain to avoid slamming and jerking of the surface buoy;
- there is only one main line, attached to a single chain, a three-way bridle is avoided;

- liberal use of sacrificial anodes (at least 3 anodes of 2 or 2,5 kg each), and maintenance to replace these anodes about once a year;
- the use of a short anchor chain, with depth buoys, that does not touch bottom;
- use of a one-piece inverted mushroom anchor (fig. 2);
- ample reserve buoyancy (it would seem that the reserve buoyancy needed in areas with strong currents has been underestimated in many designs, see below).

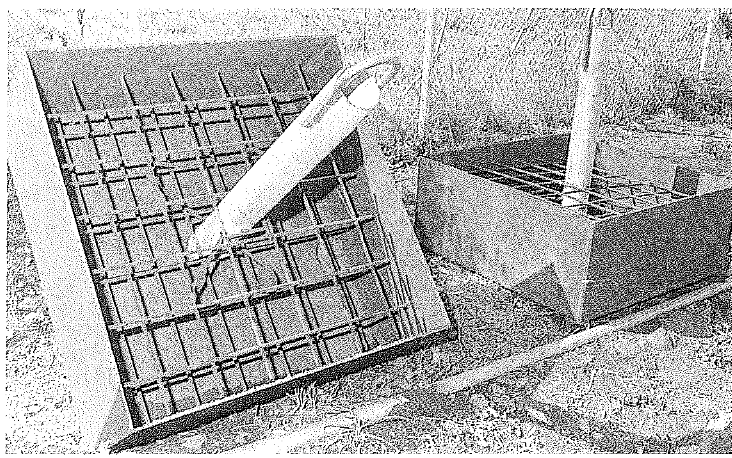


Figure 2
Anchor boxes before concrete was poured.

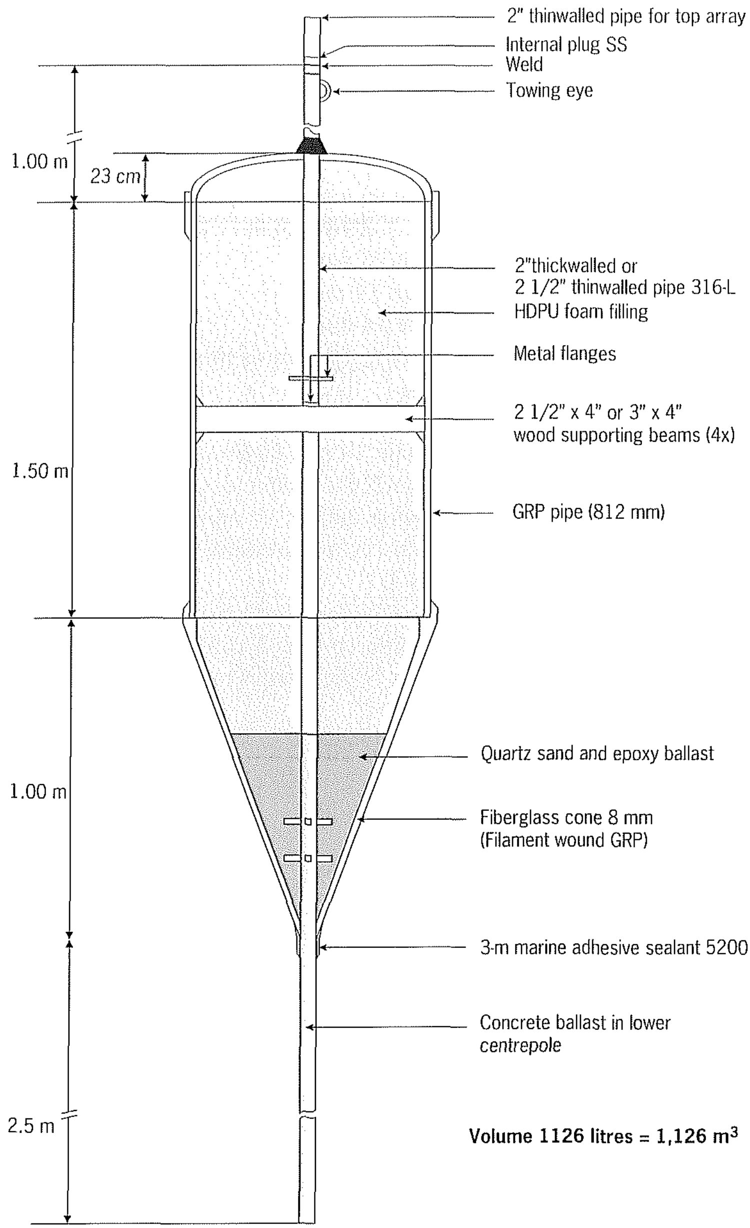
The first FAD with the MKI buoy (van Buurt, 1995) was deployed in 1993. Up to now, a total of 5 FADs were deployed at the following depths: 730, 685, 700, 754 and 574 metres. The following changes were made to the surface buoy, resulting in an improved design, the MKII surface buoy (fig. 3):
- the MKII surface buoy is slighty larger, increasing the reserve buoyancy with about 188 kg (from 426 to 614 kg). When calculating this reserve buoyancy, the submerged weight of the external chain ballast (approximately 190 kg) has already been taken into account;
- the internal battery box of the MKI buoy and its top cover were eliminated. The MKII buoy has a much stronger curved top cover;
- a flexible compound was used to seal off the through-hull passages of the centrepole.

Using this FAD design with the MKII surface buoy, it should be possible to maintain a deep-water FAD with a lifetime of three or five years. If this goal is achieved such a FAD would be economical, and also much more cost-effective than less costly systems with a shorter lifetime.

Mooring system

For a deep-water "longlife" FAD, a mooring line with a minimum diameter of about 20 mm polypropylene has to be used. The strength of such a thick mooring line is not primarily needed to hold the surface buoy but to give sufficient protection against fishbite and to help to

Figure 3
Design for MKII buoy,
longitudinal cross-section.

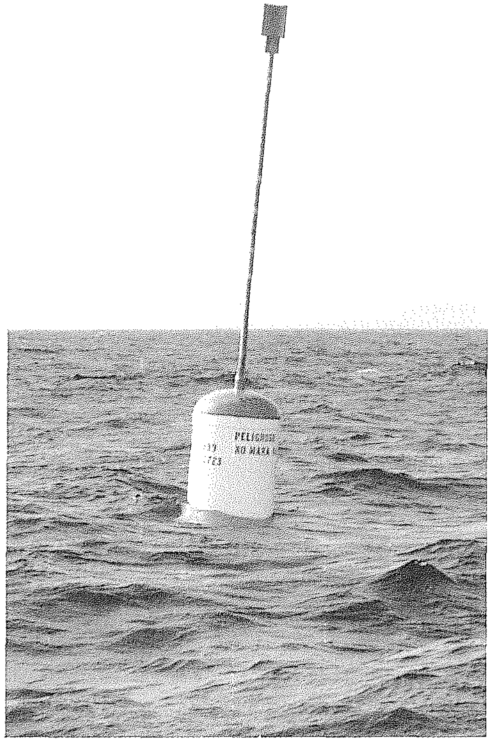


withstand illegal moorings. Even when informed and prohibited to do so, some boats will always moor to the buoy. The buoy should thus be able to withstand such illegal moorings to a certain extent. The diameter of the mooring lines and their length, along with the strength of the prevailing currents, will in turn determine a large part of the total drag and thus also determine the reserve buoyancy, the minimum size of surface buoy needed and the weight of the anchor. Quite often, it seems the reserve buoyancy needed for a deep-water FAD has been underestimated. A sizable surface buoy and anchor will be needed. An inverse catenary Nylon-propylene mooring system is usually used. In the Curaçao no. 3 and no. 4 FADs, the following fairly typical mooring system was used:

Surface buoy
1 shackle 16 mm
1 swivel 3/4" (4 kg)
1 shackle 16 mm
3 m chain 14 mm
1 shackle 14 mm
1 steel-ring 14 mm or monkey plate/fish plate (to facilitate buoy changes)
1 shackle 14 mm (items 1 to 6, approximately 22 kg)
50 m chain 14 mm (approximately 215 kg)
1 Samson-Nylite connector (3/4"-13/16") with shackle
1 rol Nylon 220 m, 20 mm
1 Samson-Nylite connector (3/4"-13/16") with shackle
1 swivel 1/2"
1 Samson-Nylite connector (3/4"-13/16") with shackle
3 rols polypropylene 3 x 220 m, 20 mm
1 Samson-Nylite connector (3/4"-13/16") with shackle
1 swivel 1/2"
1 shackle 14 mm
5 m chain 14 mm with 3 "Cies" depth floats
1 shackle 14 mm
1 swivel 1/2"
1 shackle 16 mm
Anchor

It is necessary to use shackles which use a bolt and nut with a split pen. Those shackles which need not to be opened again can be spot-welded before deploying the FAD. The surface mooring chain used in Curaçao is fairly long, usually a shorter mooring chain would suffice. Since the mooring chain is fairly expensive a shorter mooring chain is cheaper. On the other hand, there are some advantages in using a long chain. It is very difficult to steal the buoy, a diver would have to go down to approximately 55 m depth in open water to cut the rope. Since someone wanting to steal the buoy presumably would not know where the chain ends, it is likely that an unauthorized diver would turn back at the 40 m level. It is very difficult to turn loose the shackles without using a lift-bag and this can only be done in relatively calm weather. One of the disadvantages of a spar buoy design is that quite some ballast is needed. The chain acts as external ballast and is more effective in keeping the buoy upright than the internal ballast since it is attached at the end of the centrepole which works as a lever. The internal ballast can thus be reduced somewhat, making it easier to tow the buoy behind the ship in a horizontal position and leaving more reserve buoyancy since the buoy can be kept fully upright with less total ballast. The radar-reflector on the MKII buoy is 4,5-5 m above water level (fig. 4).

Figure 4
The MKII surface buoy (FAD no.3) moored at approx. 700 m of depth; the radar-reflector is approximately 4.5 m above the sea



Instead of 20 mm Nylon, 18 mm can be used, this diameter was not available locally at the time.

Radar-reflector and light

It is very important to be able to see the buoy from afar. If the top light and radar-reflector are too low, a buoy will be difficult to see even in moderate waves; such a buoy is likely to be overrun by ships. With a spar buoy the light and radar-reflector can easily be put fairly high above the water.

Underwater attractors

FADs without underwater attractors will attract fish, but underwater attractors can increase the effectiveness of FADs. Many different materials can be used to provide a sheltering structure in practice; however, one has to take the amount of drag that such materials will produce into account to avoid the surface buoy to be dragged underwater. The ideal underwater attractor should provide a sizable shelter structure while minimizing drag. Its durability and drag characteristics are very important. A main problem is that, while they can hold out for a considerable time in calm or moderate seas, most underwater attractors do not last very long in rough seas.

Plastic fibres can be used which are enmeshed in the mooring chain or mooring line of the FAD. In the no.3 Curaçao FAD, strands made of 14 mm Nylon rope, which were fastened to the mooring chain, were used. Up to now, these have outlasted all previous underwater attractors, which were used (MacIntosh, MacIntosh mounted on PVC dampening pole, Fiegenbaum attractor), none of which lasted more than three weeks. The strands have the advantage of being cheap. They do not cause much drag, and there is not much snagging of hooks. On the other hand they may be less effective as a shelter structure compared to other types of underwater attractors.

Anchor

The weight of the anchor should be designed to equal twice the reserve buoyancy of the surface buoy. The holding power of a block is about half its (submerged) weight. Even if the buoy were to be dragged below the surface by strong currents, the anchor should still hold. On the other hand, the anchor should not be excessively heavy since this will increase handling problems and costs.

A heavy one-block, inverted mushroom anchor (a one-piece concrete and iron block) was used.

When a heavy anchor of approximately 1 200 kg is needed, it can be constructed as a low box (0,4 x 1 x 1 m^3) made of steel plates which is filled with concrete (approx. 340 kg of steel, 900 kg of concrete). A reinforcement mat can also be used. Should the concrete crack from the impact of the anchor hitting the bottom, the concrete would still be contained in the steel box and the structural integrity of the anchor would be maintained. The bottom side of the anchor is provided with two 2" (5.08 cm) U beams to increase grip on the substrate and to prevent the anchor from sliding along the bottom.

Shallow and medium-depth FADs (150-400 m)

FADs with PVC (Polyvinyl chloride) pipe surface buoys

In Curaçao, various types of buoys were tried out as mooring buoys for small boats in coral reef areas. A buoy made of PVC pipe, a stainless-steel centrepole, concrete as internal ballast and some chain as external ballast was selected as being the most practical and cost-effective. The advantages of such a buoy are:

- if the buoy is hit by a ship, it will usually simply roll away;
- the buoys are easy to construct, PVC pipe is widely available in various diameters and is usually sold in 6-m length. It is of relatively low cost. PVC endcaps can also be purchased easily. For these mooring buoys 3-m length of 6" pipe were used;
- the buoy will stand high out in the water and can be easily seen from a distance. It is advisable to paint the buoy. A combination of orange and white is practical. The orange gives good visibility during the day-time, while the white stands out at night. If the PVC is painted, the paint will protect it from degradation by UV light. On thicker, larger

diameter pipes, this is less critical. The PVC will degrade somewhat on the outside, but due to the thickness of the wall the outer layer of somewhat degraded PVC will protect the rest of the material.
The same characteristics which make the PVC pipe-type buoy suitable as small mooring buoys also make them suitable as surface buoys for shallow and medium-water FADs. Since the PVC pipe buoy is a spar buoy-type float, it will adjust to changing loads more gradually than other types of buoys. When properly ballasted with concrete as internal ballast and chain as external load, the buoys have a very sea kindly motion. Even in choppy waters, the spar buoy-type float will dampen motions and will not jerk or slam like a flat tyre-type buoy. In Curaçao, a deep-water FAD that was moored only about 1,2 nautical mile offshore in water of 685 m depth has been attracting fish succesfully. In some areas, it is possible to attract fish in waters only 0,5-1 nautical mile offshore. For this reason, the Curaçao Department of Agriculture and Fisheries has been working on designs for a light shallow-water FAD (150-250 m) and a medium-depth FAD (250-400 m), based on the Goodwin (1986) design, which is cheaper to construct and can be moored nearer to shore as a supplement to the larger deep-water FADs. The main difference between this new Curaçao medium-depth FAD and the PVC spar buoys used in Saint-Kitts is the use of a centrepole. On small buoys a centrepole is not needed, but on somewhat larger buoys the centrepole will help to keep the buoy upright and will distribute forces more equally *via* endplates welded to the centrepole. Some cross members of wood are used to distribute forces to the pipe more equally. A stainless-steel centrepole with two flanges at the endcaps is used, and each buoy filled with some concrete ballast in the centrepole and HDPU (high density polyurethane) foam in the PVC pipe. A radar-reflector is added to the mast, to improve visibility. As with larger deep-water FADs, it is necessary to seal the holes where the centrepole exits through the PVC endcaps with a flexible compound. As in the larger deep-water FADs it is advisable to use sacrificial anodes on the centrepole, to protect the mooring chain. A similar Nylon-polypropylene mooring system is used. When larger buoys are needed, it is probably better not to use PVC pipes, but to use the more costly GRP, or other materials of higher strength.

The 3-m length PVC surface buoy

Two surface buoys of 3-m length can be made out of a 6-m length, 50 cm diameter standard PVC pipe (fig. 5). Each buoy has a volume of approximately 588 l (0,59 m^3). The weight of such a buoy is about 170 kilogrammes. Using only external ballast (112 kg with a submerged weight of 95 kg) a reserve buoyancy of approximately 323 kg can be achieved. Depending on the thickness of the mooring ropes used, a FAD with such a buoy as a surface buoy can probably be deployed in waters up to about 250 m depth. A sizable buoy can thus be constructed with low-cost PVC. One such FAD has been moored in water of approximately 260 m depth (14 May 1998), it lasted 582 days in the water.

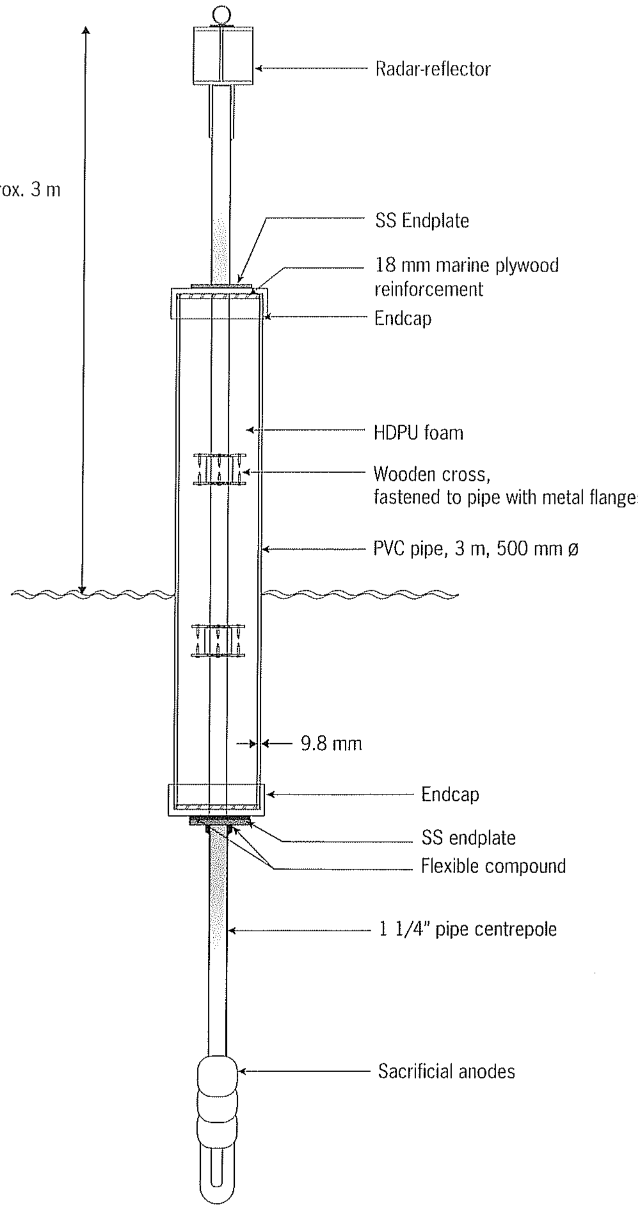


Figure 5
PVC (3 m) surface float for medium-depth FAD (approximately 250 m).

The 5-m length PVC surface buoy

The 500-mm diameter PVC pipe is also available in 5-m standard lengths. Since these buoys were still under construction at the time of writing the exact weight and net reserve buoyancy are not yet known. Based on the experience with the 3-m PVC buoy the weight of the 5-m PVC buoy is estimated to be approximately 280 kg, the net buoyancy (with 95 kg submerged weight of external ballast) will be approximately 600 kilogrammes. This buoy would thus have more or less the same reserve buoyancy of the larger and sturdier MKII buoy, which uses more ballast. However, since PVC is not as strong as GRP, we do not intend to deploy this buoy to the same depths of water.

Selection of suitable location(s)

Some criteria have to be respected:
- the FAD should be placed in an area where fish are known to occur. A FAD cannot aggregate fish if these fish are not present. A deep-water FAD should be situated in an area where migrating pelagic fish are known to pass.
- slope: steep bottom slopes are to be avoided, since the anchor could slide down into the depths taking the buoy with it;
- areas with heavy shipping traffic should be avoided;
- the FAD should lie within reach of the artisanal fishermen who are going to use it;
- deep-water FADs should be moored some distance offshore. The South Pacific Commission Handbook advises to keep a mininum distance of two nautical miles offshore. In areas with very deep-waters nearshore deep-water FADs can sometimes be employed succesfully nearer to shore, in areas where pelagic fish are known to pass;
- there should be a minimum of 3-5 nautical miles spacing between deep-water FADs. A line of FADs can sometimes be used to deviate migrating fish from their normal routes and "guide" fish towards certain areas.

If the above criteria have been met, other less critical criteria determining the choice of the location are:
- a more protected environment, for instance at the leeward side of an island;
- selection of an area from which a buoy that works loose from its mooring would most likely be driven towards the shore, or towards an other island and would stand a chance of being recovered.

When all the above criteria have been taken into consideration, it can usually be seen that the limitations on where FADs can be placed will result in a few areas only being available. The importance of such sites should be taken into account when coastal management studies are done.

Deployment of FADs

Accurate depth measurement

To deploy a medium or deep-water FAD, a fairly accurate estimate of depth is needed. In some areas where accurate nautical maps exist and depth contours are far apart, which is the case where a broad underwatershelf exists, the use of an echosounder is less critical and the depth could be taken from the map, using one's position. In areas with a sloping bottom topography, the nautical maps give depth contours which have been extrapolated from a grid of fairly dispersed readings, and thus, cannot be relied upon for the precise positioning of a deep-water FAD. As mentioned earlier, steep slopes are to be avoided, since the anchor could slide down into the depths taking the buoy with it. If an anchor scope of 1.2 to 1.3 is to be kept, and we assume the FAD to be moored at a 1 000 m depth, then the anchor should fall within approximately plus or minus 40 m of this depth. In order to deploy deep-water buoys, an echosounder which can give fairly accurate readings in deeper waters is needed.

It is necessary to adjust or correct for variations in sound velocity. Sound velocity in sea water is a function of temperature, salinity and pressure. The relation between sound velocity and these parameters is given by Wilson's equation. Sound speed tables based on Wilson's equation can be found in the Handbook of Oceanographic Tables (Bialek, 1966). Using data from the National Oceanic Data Center (NODC), oceanographic database at the Scripps Institute of Oceanography or other available data, a depth-vertical sound velocity calibration curve can be established. A calibration curve should be made plotting harmonic mean vertical sound velocities against depth (Maul & Bishop, 1970). From such a depth-sound velocity calibration curve, it can be seen that some adjustment is indeed necessary to obtain accurate results (fig. 6). In view of the other abundant sources of errors in precisely positioning the FADs, it is imprudent to add others that require little effort to eliminate.

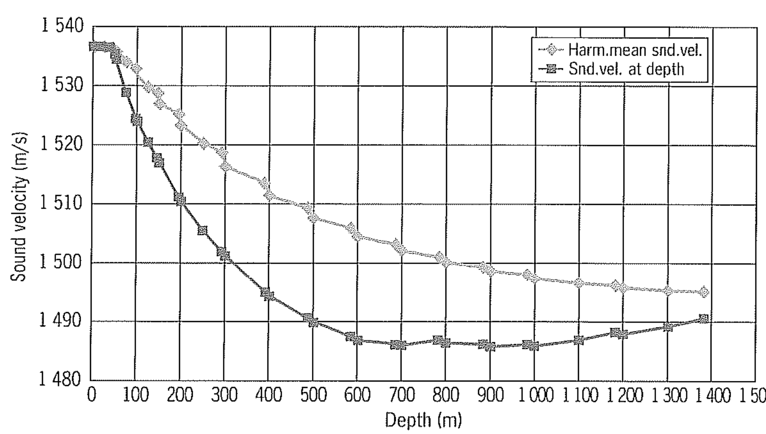


Figure 6
Sound Velocity-depth calibration curve for waters around Curaçao.

Launching of FAD

When launching the buoys two vessels were used: a launching vessel and a marker vessel.

In Curaçao, the current is usually strong, also the depth contours are quite variable. Under these conditions, it was found to be absolutely necessary to put the depth sounder on a marker vessel instead of the launching vessel. Also, it was found to be necessary to calibrate the echo-sounder as described above. Conceivably in areas with weak currents and gently sloping bottoms, or where the plateau bottoms out, it may not be necessary to use such procedures.

All lines will be paid out. The vessel with the depth-meter will act as the marker vessel and stay put at the correct position where the buoy is to be set. The launching vessel will move about 200 m upstream of the marker vessel and launch the buoy, both the buoy and the launching vessel will then start to drift toward the marker vessel, the buoy drifting faster; when the buoy reaches the vicinity of the marker vessel the anchor is also launched. This way fairly accurate positioning can be achieved even when currents are strong.
The "anchor first" method is an option if one has a larger vessel available, with a winch that can hoist and lower the anchor. Usually, it is fairly expensive to rent such a vessel from a civil engineering contractor. If such a vessel were available at a reasonsable price then the "anchor first" method is preferable. In such case, it is not necessary to use a separate "marker vessel" either. When launching FADs from a smaller vessel without a crane the "anchor first" method is not an option, if only for safety reasons. In such case, the "anchor last" method should be used.
If the size of the vessel used will allow, it is preferable to use a one-piece anchor. When handling a heavy one-piece anchor, such as is needed for deep-water FADs, an anchor release ramp should be constructed to facilitate launching of the anchor. Such a ramp can be constructed in such a way that it can be attached to a rented vessel. The anchor could be jettisonned by releasing a handle. In Curaçao, the tourist-party boat MS *Mermaid* is used for launching the FADs and the anchor ramp is constructed with a bracket that can be easily secured to the stern of the MS *Mermaid*. The vessel is rented at the normal tourist-party tariff of NAf 600 = US$ 327 per trip. In addition to the MS *Mermaid*, a small "marker vessel" is also rented at a much lower price. If the vessel available for launching FADs is too small to safely allow for use of a one-piece anchor then the following technique can be used. Two oil drums filled with concrete are used, one on either side of the vessel, with the chain connecting them already passing below the keel of the vessel (Ben-Yami, 1989). Both are then thrown off at the same moment.

Maintenance

With any "longlife" FAD programme some maintenance is necessary. Longevity of FADs can only be achieved if maintenance constitutes an integral part of the programme.

Sacrificial anodes

If sacrificial anodes are used to protect the mooring chain, then it will be necessary to change these about once a year (the FAD in Curaçao was found to use approximately 200 g of sacrificial anodes per month). This can be done as follows. Divers release the tension on the mooring chain by attaching a lift bag to the mooring chain at about 7-m depth. Subsequently, the bag is filled with air. The anodes on the spar buoy can now be changed.

Leaking buoys or buoys otherwise damaged

If leaks develop the surface buoy can be detached, replaced by another buoy and towed away for repairs. Again a lift bag is used. If a monkey plate (also known as fish plate) is incorporated in the mooring design, then it is fairly easy to change buoys. A piece of chain attached to the new buoy is bolted to the monkey plate in the mooring chain of the old buoy. By incorporating the necessary mechanisms to replace leaking buoys in time, these can be recovered before they are lost taking the whole FAD with them. In any FAD programme, there should always be at least one spare buoy available at all times. Over the duration of the programme, this will generate considerable savings. Buoys that are replaced are repaired, repainted, etc.

Light, solar panel, electrical system

To increase its visibility at night, the FAD can be equipped with a top light. Kerosene or gas lamps can be used but these are not very practical since the fuel does not last very long. The top light can be powered by batteries. If a photocell is used to turn on the light at nightfall and turn it off at daybreak, then the batteries will last longer. Nevertheless, it will be necessary to replace the battery quite frequently. The batteries can be charged with solar panels or a small wind generator. More sophisticated marine lamps exist that automatically replace a burnt-out lightbulb with a new one, the system holds six lamps. This way the lights can last a long time, but the price increases quite a lot. A system of this type, consisting of top light, solar panel and batteries is quite expensive, without it the whole FAD would be significantly cheaper. The range and power of an industrial-type marine lamp is not really needed. The lamp and solar panel are relatively vulnerable to rough handling. When the buoys are loaded on the ship and when they are launched into the water, great care has to be taken to avoid smashing the lamp and/or solar-reflector against the ship. When buoys are launched or changed, great care has to be taken not to submerge the lamp and solar panel; although these are watertight they were not designed to withstand full submersion. While it should be possible to service the electrical system, in practice this can be quite a problem. Even a simple change of batteries can be achieved only during very calm weather, in rough or even moderate weather any maintenance becomes quite impossible. In practice, in many areas, calm weather conditions may not occur very often. The solution to this problem would be to have a relatively low-powered fluorescent light (daylight) which can serve as an anti-collision light enclosed in a fairly small watertight housing together with its battery, photocell and solar panel as an integral unit. Ideally, such a unit should be detachable to the mast of the surface buoy of the FAD. A bayonet-type fitting could be used. This way the whole array of top light, solar panel, and batteries can be taken off and replaced for service, and new FADs can be launched without them, the array being attached to the FAD when it is in the water.

The question can also be raised whether it makes sense to have a top light at all. The buoy could do without a lamp and have the radar-reflector and centrepole covered with reflective materials such as Scotch tape. Also the buoy itself can be painted with reflective materials. This will lower the price of the buoys considerably, and will greatly facilitate their handling while launching, changing or retrieving. A buoy without light (or with a completely detachable lighting system) can be completely submersible. Such a buoy can be towed behind the vessel. When the buoy is launched, the vessel will only have to carry the anchor and mooring lines. It would seem best to use buoys with lights only in those areas where the light is really needed, such as areas with a lot of sea traffic. Buoys without a top light, having a radar-reflector and reflective materials would be used in areas with less sea traffic.

FADs and the current

After the first experiences with the MKI buoy in Curaçao which had a net reserve buoyancy of approximately 400 kg (including the external ballast), it was felt desirable to increase the reserve buoyancy somewhat in the newer MKII buoys. The new MKII buoy has about 680 kg of net reserve buoyancy. On some days with strong currents the buoys were leaving a wake and if approached by boat it would seem as if they were slowly moving ahead under power. On such days, the buoy would be drawn down considerably and with the MKI buoys waves would sometimes wash over its top cover.

In Curaçao, currents are measured by the Curaçao Port Authority at the south coast near the harbour entrance. Current-meters are situated at a depth of 5 and 10 m below the surface and are attached to a platform which stands in 12 m of water. A mean current value of 0,5 knots is recorded with maximum values up to 2,5 knots. Almost every year there will be some days when the strength of the current ranges from 2 to 2,4 knots. About once every two or three years the current will be above 2,4 knots. Usually this will last for only a few hours. Once a current of 2,6 knots was recorded. Further out from the coast, a mean current of about 1-1.5 knots flowing W-NW is usually encountered. It is not known how the strength of this current is related to the current measured at the harbour entrance.

We assume that in the areas where our FADs are moored a 2,7 knots (approximately 1,35 m/s) surface current can be reached, if only for a few hours once every two or three years. We also assume that this current will affect the whole layer of surface water above the thermocline, say the upper 150 m of depth. During any year there will be currents of about 2,4 knots (approximately 1,2 m/s). It could very well be that currents in Curaçao can be much stronger, if only for a short peak period, than anything similar FADs would have encountered out in the open sea near oceanic islands in the Indo-Pacific. This observation draws us back to the observation in the 1984 South Pacific Commission Handbook on deep-water FADs where it is stated that "the passage of typhoons in the Pacific area has been a major problem, making it difficult to achieve the goal of developing permanent deep-water FADs". According to the Handbook even the best designs do not fare too well when a typhoon passes. When a typhoon passes, short-wave length choppy waves are suddenly superimposed on the long waves. It is also likely that a passing hurricane or typhoon can generate surface currents of abnormal strength, if only for a relatively short period. Several of the designs discussed in the SPC Handbook and also those in the later 1996, volume II of the Manual (Gates *et al.*, 1996), would certainly have insufficient reserve buoyancy for the Curaçao environment, and could probably not be expected to last more than a few months at most in our waters.

Once a cylindrical buoy is drawn below the surface, the drag increases and the hydrodynamic forces will usually pull it down to its collapsing depth (Taquet, pers. comm.). Thus, usually the buoy will not resurface. It is thus important to moor the buoys at such a maximum depth that it is unlikely that currents could ever pull them down.

It should be possible to calculate the maximum mooring depth for each type of FAD at the maximum current strength that can occur at a given site over say a five-year period. Each FAD can than be "rated" to a certain maximum depth, and one would make sure not to moor the FAD any deeper. In practice however it is difficult to do this. Too many assumptions are involved such as the exact maximum current strength, the current strength with depth and the actual drag of the surface buoy and its mooring chain. Even though computer simulations cannot thus be used to determine a precise maximum mooring depth "rating", they are nevertheless very usefull since they do give a basic idea of the operating limits of the FADs.

Economics

There are few detailed discussions on the economic performance of FADs. Usually there are not sufficient data available to justify a detailed discussion of economic performance. Economic performance depends, among others, on the following factors.

Location

The location of a FAD is very important. The FAD should be placed in an area where fish are known to occur. A FAD cannot aggregate fish if these fish are not present.

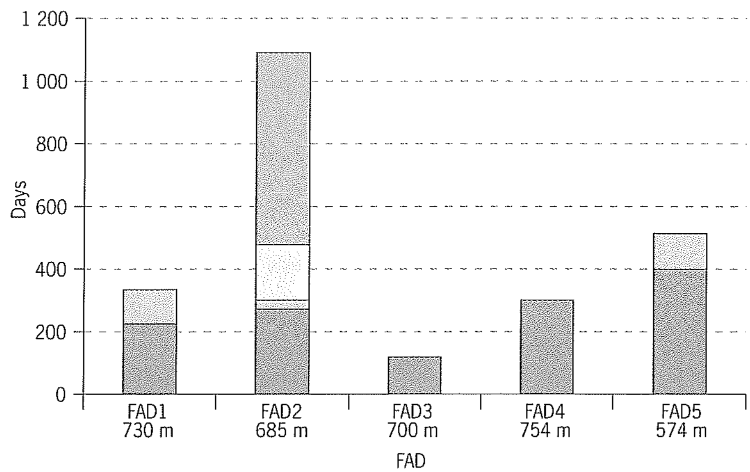
Catches around FAD

For a proper evaluation of the effectiveness of FADs monitoring of catches is necessary. Accurate catch and effort data around FADs are often lacking. One of the main problems with FADs used in artisanal fisheries is that it is usually quite costly to collect such data. In the Caribbean, the most extensive studies in this field were made by Ifremer in Martinique (Battaglia *et al.*, 1991) and Guadeloupe (Lagin *et al.*, 1993). In Saint-Kitts and Nevis data were collected by Goodwin (Goodwin, 1986). Fiegenbaum *et al.* (1989) collected data around a FAD in Puerto Rico. These studies all indicate that the FADs do increase catches significantly.

Costs versus longevity

The ratio of costs versus longevity of a FAD is one of the most important economic factors, once we assume that a suitable location has been found. On one hand, we have the costs of construction, deployment and maintenance, on the other hand the expected longevity (fig. 7).

Figure 7
Longevity of FADs in Curaçao. The FADs were moored at 730, 685, 700, 754 and 574 m respectively. The different blocks within the columns of the histogram represent periods with a different surface buoy on the FAD.
FADs that lasted longer (FAD 2 and FAD 5) are those that were moored in waters which are somewhat shallower.



Deployment costs

The cost of deployment would depend in a large measure on the price of the vessel used (as discussed above). The weight of the FAD and its anchor will influence the size of the vessel needed and thus the deployment costs.

Costs of maintenance

This includes the cost of sending a vessel with divers to change the sacrificial anodes, the cost of the anodes, the cost of refitting, painting and effecting small repairs to the buoys. In case an electric top light is used the (sometimes quite considerable) costs of servicing this light, such as for example the cost of new batteries should also be included.

Lifetime costs for the GRP (MKI and MKII) FADS

Costs approximate in US$, estimates are for the year 1995 and cost per month are based on a 3-year lifespan.

GRP-FAD	
Construction costs	10.500
Deployment costs	500
Maintenance costs	2 x 400 = 800
Total costs	11.800
Costs/month	327

The costs of research and development and the costs of certain equipment that is used while deploying the buoys, such as the cost of the depth-meter, the liftbags, the anchor launching ramp and the buoy launching ramp have not been taken into account. These should be incorporated in the cost of a large number of FADs.

Ownership and rules governing the use of FADs

In Curaçao FADs are owned by the Curaçao Island Government and maintained by the Department of Agriculture and Fisheries (Dienst LVV). The FADs are deployed after consultation with the harbour master (Curaçao Port Authorities), who is in charge of shipping activities around the island. Vessels are not allowed to moor on the buoy except in case of emergency. In practice, however, this cannot be avoided and the mooring system of the buoy should take this into account, to a certain extent.

Conclusion

FADs in the Caribbean have developed from the early pioneering tyre-buoy type (Fiegenbaum *et al.*, 1989), work with FADs using tyres and old netting (Goodwin, 1986) and experiment with FAD designs from the Indo-Pacific Ocean (Ifremer), to a series of FADs that are practical to use in the Caribbean environment. Several different designs exist, each has its own niche, and may be best suited to particular areas in the Caribbean or elsewhere. In Curaçao, there is quite some shipping traffic around the island, waves are choppy and currents can be strong. On the other hand, the waters are deep near the island and in some areas migrating pelagic fish move along the island not too far from shore. In such an environment, it is probably best to use FADs with a spar buoy-type surface buoy.

The use of several FADs, rated to different mooring depths is probably more cost-effective than the use of one single standard design. Considerable progress has been made towards the goal of developing long-lasting FADs. The strength of the currents has originally been underestimated and this has been one of the main problems encountered. In view of the strength of the current in Curaçao the maximum mooring depth for the deep-water FAD with the MKII surface buoy should probably be limited to around 600 metres. Under such conditions and with some maintenance, a lifetime of three years or more for each FAD can be realized. The original design goal of a long-lasting FAD that could be deployed up to about 800 m depth cannot be attained with the present design. It is possible to construct an even larger surface buoy with even higher reserve buoyancy. However, this does not seem to be a practical solution to the problem.

In many areas around the island, it may not be necessary to reach 800 m of depth since FADs closer to shore were not necessarily found to be less effective in attracting fish. Nevertheless, a maximum mooring depth of

600 m only will result in some restrictions as regards optimum mooring sites available. It may be possible to extend mooring depths up to the 700 m level by reducing the drag on the mooring line. A smaller diameter Nylon mooring line of a plaited type can be used (16 mm plaited instead of 18 mm three-strand) and the high drag mooring chain, which serves as external ballast can probably be somewhat shortened.

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