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Manual on anchored fish aggregating devices (FADs): An update on FAD gear technology, designs and deployment methods for the Pacific Island region

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Preface

This manual updates the SPC 2005 FAD manual (Chapman et al. 2005) by drawing on experience and lessons learned by FAD practitioners across the Pacific over the past decade. Practitioners include individuals from regional organisations, national and provincial governments, non-governmental organisations, and fisher associations and communities. The requirement for an updated technical manual emerged from a regional FAD expert consultation held in 2016, where Pacific FAD practitioners came together to share knowledge and experiences in FAD designs, innovation and implementation. As the title suggests, this manual provides an update on FAD gear technology, designs and deployment methods for the Pacific Islands region. The SPC 2005 FAD manual contains important and relevant technical information for FAD practitioners. This information has not been repeated here but there are references to the 2005 manual throughout where relevant.

The authors wish to acknowledge the cooperation and assistance of all the experts, in particular the national fisheries agencies technical FAD staff, who gave their time to share insights into key lessons and developments on anchored FADs, and options for more cost-effective FAD designs. Those insights and experiences are included in the manual. In particular, the authors would like to thank Anne-Maree Schwarz, Samol Kanawi and Mainui Tanetoa for taking the time to review the manual. This manual has been made possible through the financial assistance of the Australian Government through ACIAR project FIS/2016/300 and the French Pacific Fund.

1 Introduction

National FAD programmes are increasingly important to support fisheries management and development aspirations in Pacific Island countries and territories (PICTs). While the overarching objectives of national FAD programmes differ across PICTs, anchored FADs have a role in supporting coastal fisheries management activities, enhancing food security and livelihoods, increasing economic return for fishers and improving sea safety.

Since the 2005 SPC FAD manual (Chapman et al. 2005) was published, SPC and national fisheries administrations have deployed hundreds of the so-called artisanal anchored FADs (as opposed to the industrial drifting FADs used by purse-seine fishing companies, see SPC 2012). Much has been learnt from those deployments, resulting in technological modifications and innovations in FAD designs. Several social issues with FADs (e.g. vandalism) have also been highlighted during this period, leading to the introduction of new designs, such as subsurface FADs to reduce vandalism impacts (SPC 2012; Albert et al. 2015).

The purpose of this manual is to provide national FAD technicians with an updated technical manual to assist them to choose and/or adapt the most suitable FAD design for a given context. It highlights technological developments and learning from what has, and has not, worked over the past decades. The manual is specific to the Pacific Island region and focuses on anchored FAD designs for coastal environments, as they support the food security and livelihoods of small-scale fishers in the region.

2 Standard anchored FAD designs

An outcome of the evolution of anchored FAD designs over recent decades is a realisation that there is no one-size-fits-all FAD design. This means that national FAD technicians can get confused when faced with selecting the most appropriate FAD design/s to deploy in their country. This manual recommends six standard anchored FAD designs for use in different coastal environments (Table 1). These six designs are by no means the only options but they are proven standard designs that can be deployed and/or modified to be fit for purpose by national agencies. Such modifications have already been undertaken by several PICTs (see section 3). Any modifications to the standard designs provided in this manual should pay attention to the technical considerations outlined in section 4.

The physical environment in which a FAD will be deployed influences the design choice. Here we describe three main environments:

- lagoons and bays: close to communities, characterised by shallow, calm waters with low current;
- nearshore: usually <800 m deep, areas that are close to the coast accessible by paddle fishers; and
- offshore: deep waters with high currents and waves; these locations are usually accessible only by motorised vessels.

Table 1. Optimal FAD design across three environments (🟩 = optimal; 🟦 = sub-optimal; 🟧 = ok, but not recommended; 🟥 = not appropriate).

	Lagoons and bays (<100m)	Nearshore (<800m)	Offshore
Lagoon FAD	🟩	🟧	🟥
'Bamboo' FAD	🟩	🟦	🟥
Indo-Pacific FAD	🟧	🟩	🟩
Sub-surface FAD	🟦	🟩	🟧
Lizard FAD	🟧	🟩	🟧
'SPAR' type FAD	🟥	🟦	🟩

In addition to the environment in which FADs are deployed, the performance and choice of FAD designs are further influenced by several key parameters including:

- cost (low, moderate, high);
- seabed (flat/sandy bottom, rocky with slight slope, steep slope);
- sea condition (calm, moderate seas/current, rough seas/high current);
- degree of boat traffic (low, moderate, high);
- risk of vandalism (low, moderate, high); and
- the boat size available for deployments (small boat, small barge, large vessel).

For each of the FAD designs described in this manual we have provided guidance on its appropriateness, based on these parameters, using the icons shown in Figure 1.

Figure 1. Icons used to describe key parameters considered for each of the standard FAD designs.

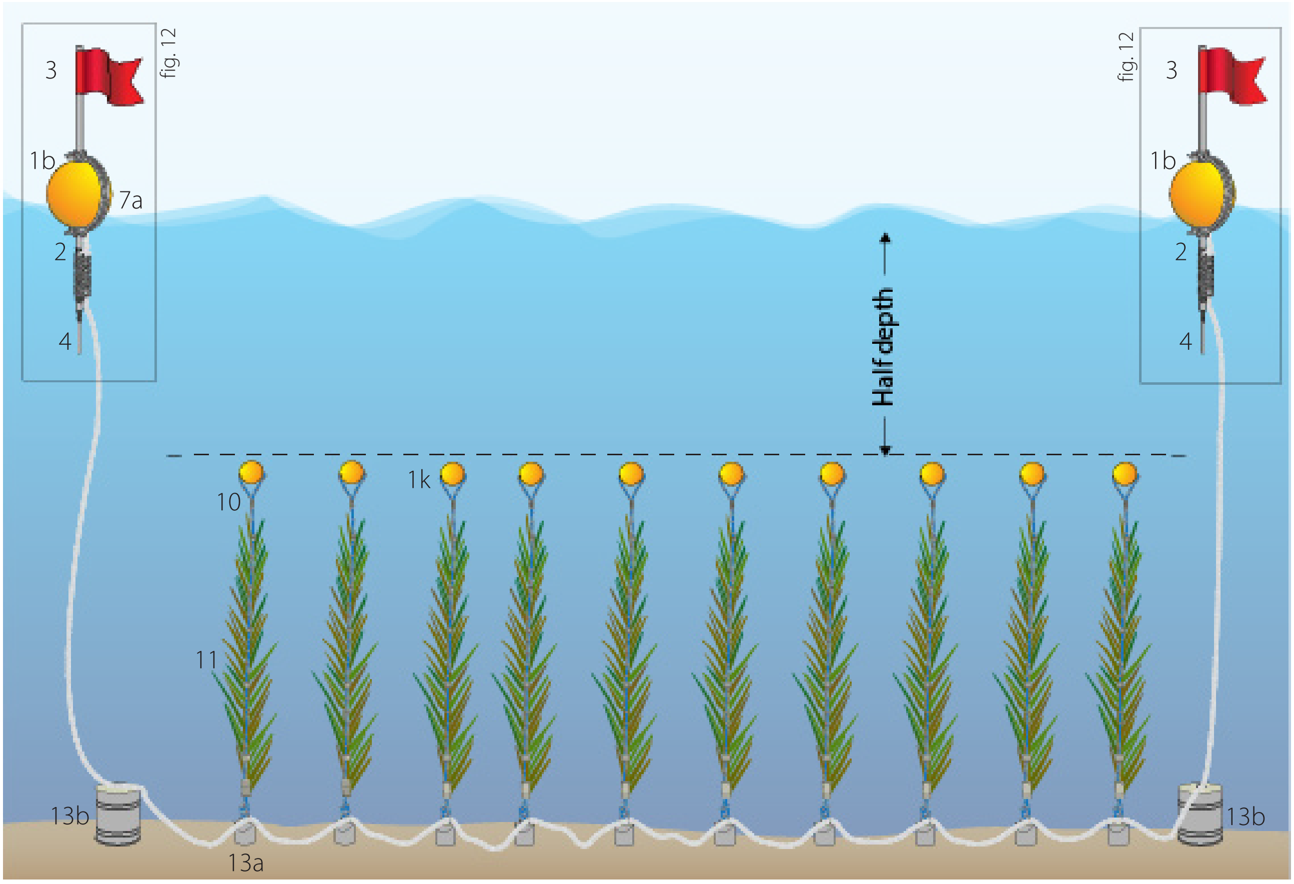


Figure 2. Lagoon FAD design showing the series of coconut fronds, with surface markers at either end.

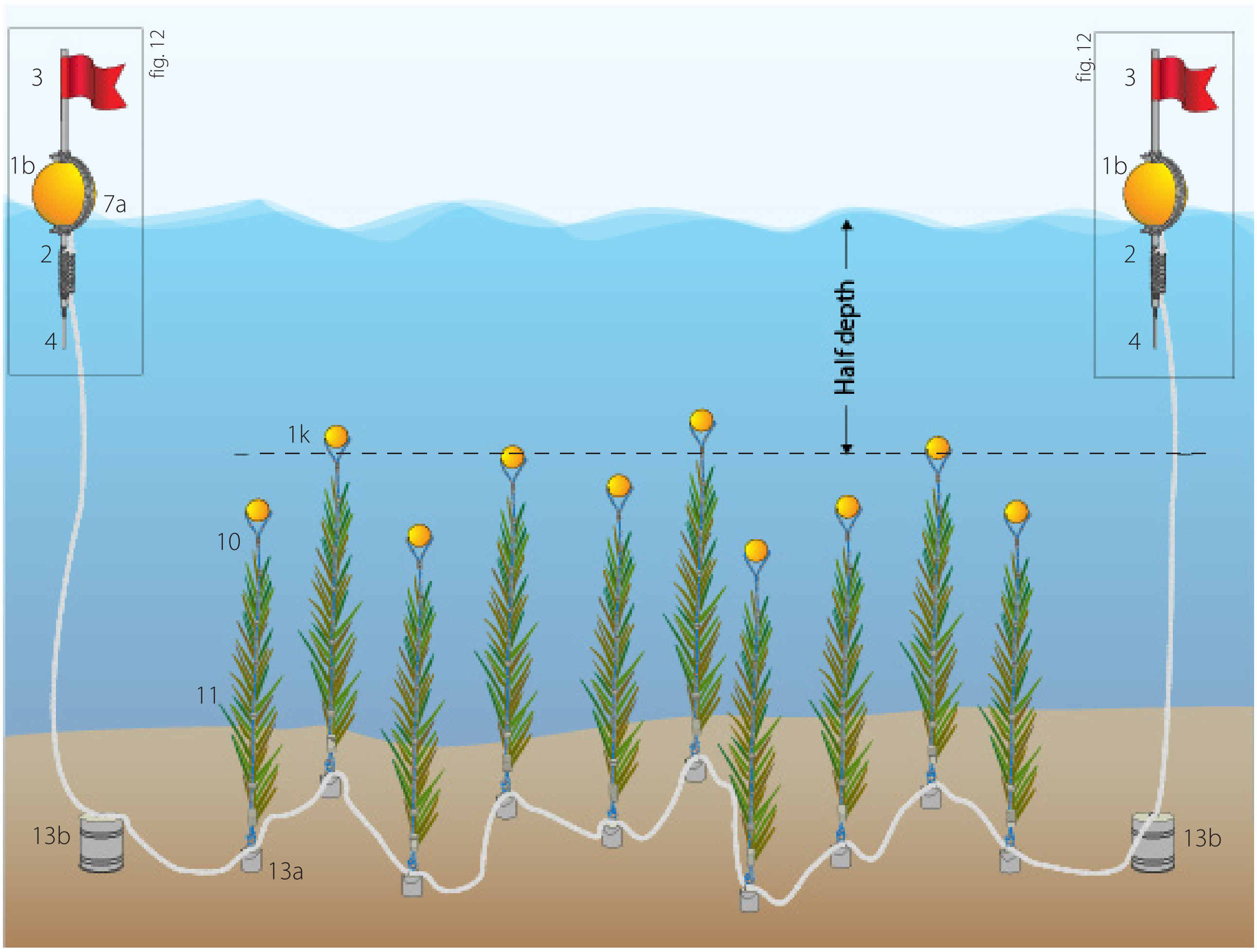


Figure 3. Modified lagoon FAD design showing the coconut fronds in a cluster.

2.1 Lagoon FAD

Being deployed close to shore in lagoon systems or bays, lagoon FADs are generally close to villages and may provide an effective and inexpensive FAD design for food security outcomes. Made from locally available materials and with the ability to aggregate fish rapidly, lagoon FADs are also promoted as a post-disaster tool. Lagoon FADs aggregate coastal pelagic fish, such as scads and trevally, which are common food fish targeted by small-scale fishers. These FADs can, however, attract demersal reef fish (e.g. grouper and snapper), and so they should be deployed in a large, flat, sandy area away from reefs to reduce the aggregation and overfishing of reef fish.

Design and deployment notes

- The lagoon FAD is comprised of a series of 10 or more coconut fronds, held vertically in the water column by mid-water floats and connected in a line via ropes (Figure 2).
- The top of the mid-water floatation should be located at half water depth (at low tide).
- Lagoon FADs should not be deployed in areas that are less than 5 m at low tide as they can become a hazard for boat engines.
- The surface markers and flags at either end of the FAD provides navigation caution marks for fishers and boats.
- The lagoon FAD can also be deployed in a cluster (Figure 3).
- Figure 2 and 3 illustrate the complete lagoon FAD. Technical components required for the lagoon FAD (refer to the numbers on the illustration) can be found in Table 2. More detail on the boxed inset (fig 12) shown in Figures 2 and 3 can be found in section 4 –Anchored FAD technical considerations (page 29).

Key features of lagoon FADs

- Aggregate small coastal pelagic fish.
- Highly accessible by fishers (including paddle fishers) due to their close proximity to coastal villages.
- Very low cost – traditional ropes can be used to construct these FADs rather than modern ropes. Small re-used floats can be used for mid-water buoyancy. Anchors required are small and low cost, e.g. sandbags, recycled (clean) paint tins and drums filled with cement, or small cement blocks.
- Very low technology, making lagoon FADs easy to construct, deploy, monitor and replace by community members.
- Good option for establishing a habitat in low productive areas, such as sandy lagoon areas.

> Illustrations 2 and 3 do not show aggregators – for further information on aggregator attachment, see section 4 – Anchored FAD technical considerations (page 31).

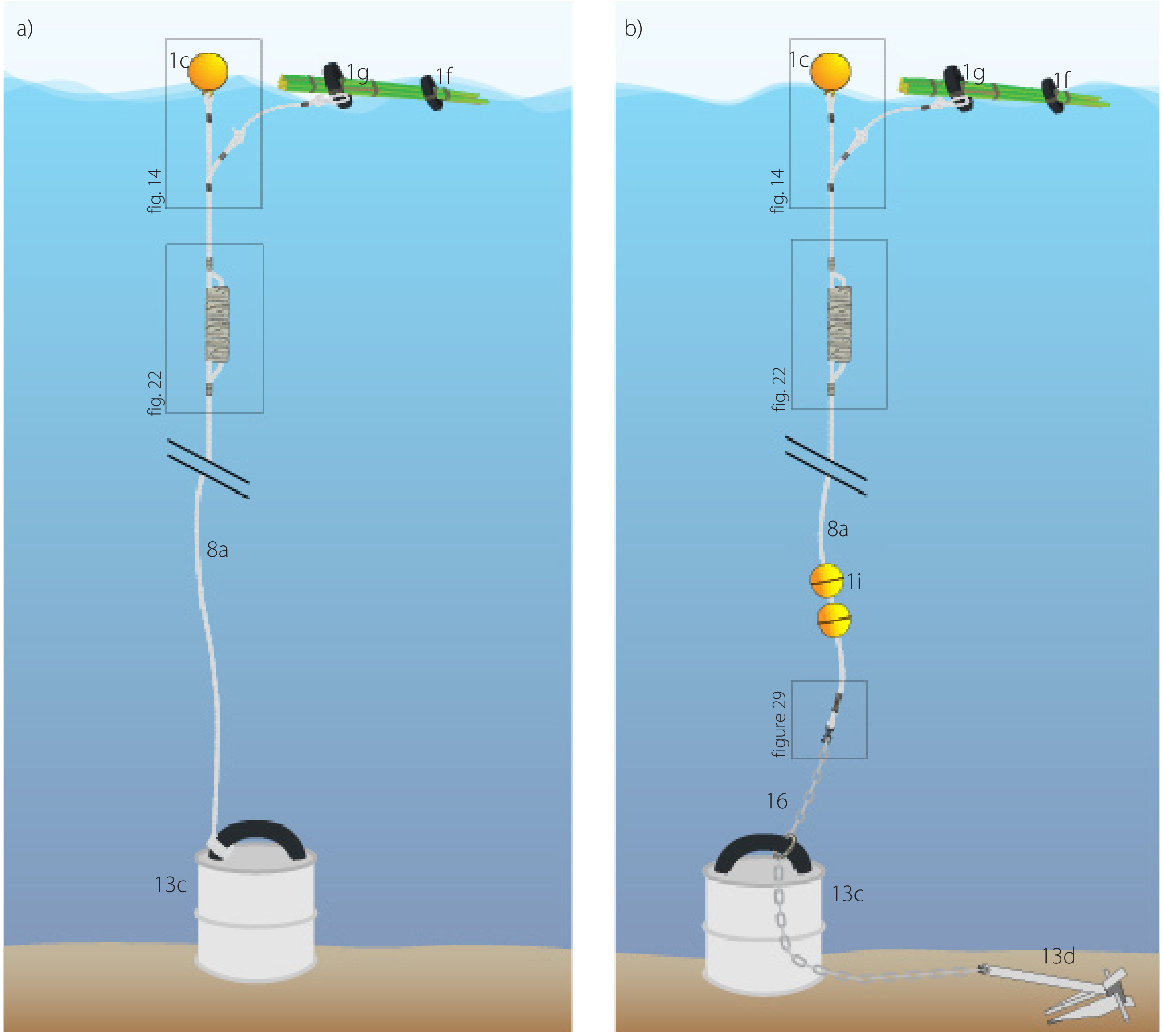


Figure 4. Bamboo FAD design showing: a) the basic version suitable for lagoons and bays; and b) the advanced version with additional anchor capacity being more suitable for nearshore environments. More detail on the components in each of the boxed inserts can be found in section 4.

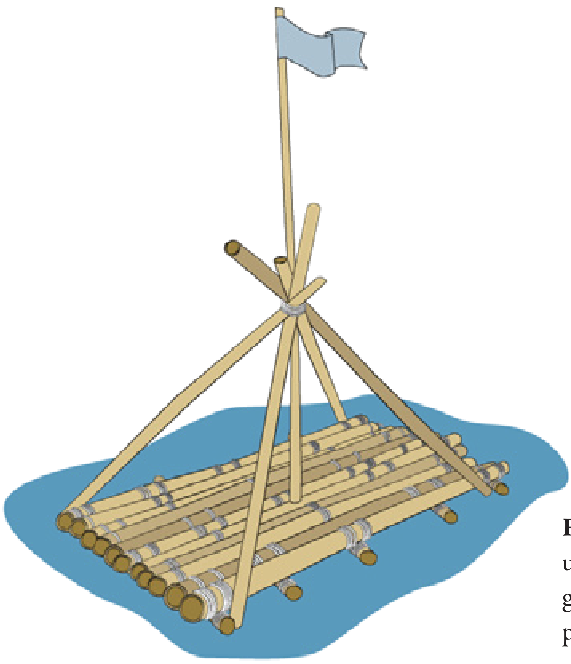


Figure 5. Large bamboo rafts are often used for the upper floatation of bamboo FADs, which can place greater stress on the mooring system and result in premature loss.

2.2 Bamboo FAD

Bamboo FADs (Figure 4) are a low technology FAD, generally deployed close to shore in lagoon systems or bays but can also be used in nearshore environments. Like lagoon FADs, they are also an attractive design for programmes targeting food security because they utilise low cost, readily available materials and are easily accessible by fishers. Bamboo FADs are also designed with a detachable bamboo upper floatation section (see section 4, Figure 14) that can be removed for replacement or maintenance. It can also be removed prior to the onset of rough seas to make sure the anchor system is not lost.

Design and deployment notes

- The bamboo FAD comprises lengths of bamboo, bound together with rope and held in place with a car tyre (Figure 4).
- Bamboo is not readily available across the region and can be replaced with other light timber (e.g. balsa), or polyvinyl chloride (PVC) pipes (enclosed with end caps).
- Regular monitoring for defects (and replacement) of the FAD upper section is required (e.g. bamboo splitting and filling with water).
- The bamboo FAD main line consists of polypropylene rope. As this is buoyant, ensure that a counterweight is secured to the main line to prevent fishing gear entanglement and reduce navigational hazard.
- The advanced bamboo FAD (Figure 4, right), while requiring more advanced (and costly) components, has a greater anchor capacity (with the inclusion of chain and danforth anchor). The advanced design is a better option for nearshore environments.
- The bamboo upper floatation can be a navigational hazard and this FAD should not be deployed in high traffic areas.
- Large upper floatation (e.g. large bamboo raft, Figure 5) while an attractive option for fishers, can cause greater stress on the mooring system. If rafts are used, ensure that the anchor has adequate weight, design a streamlined raft and avoid deploying in areas of high current or rough seas.
- Figure 4 illustrates the complete bamboo FAD. The technical components required (refer to the numbers on the illustration) can be found in Table 2. More detail on the boxed insets (fig 14, 22 and 29) in Figure 4 can be found in section 4 –Anchored FAD technical considerations (page 29, 33 and 45 respectively).

Key features of bamboo FADs

- Aggregate small coastal pelagic fish.
- Highly accessible by fishers (including paddle fishers) due to their close proximity to coastal villages.
- Bamboo section detachable – can be removed during cyclone season or periods of rough sea.
- Relatively low cost, although when used in nearshore environments, more robust anchors are required and the bamboo upper section will need to be regularly replaced (Figure 4, right).
- Low technology, making bamboo FADs easy to construct, deploy, monitor and replace by community members.
- Bamboo FADs are more suitable for calm areas.
- Good option for establishing an artificial fish habitat in low productive areas.
- Less prone to vandalism than some other designs.

Illustration 4 does not show aggregators – for further information on aggregator attachment, see section 4 – Anchored FAD technical considerations (page 31).

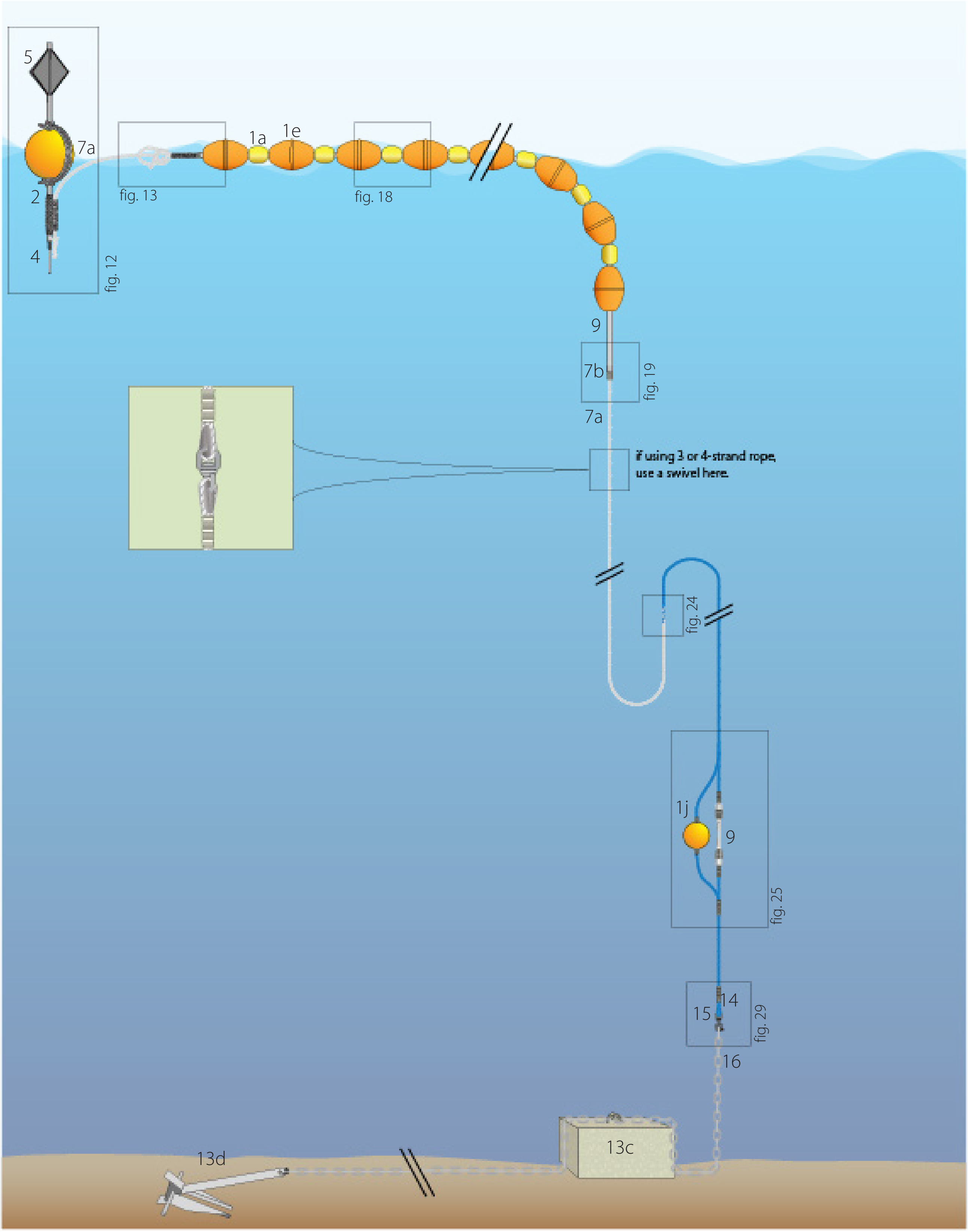


Figure 6. Indo-Pacific FAD design showing the upper floatation system used in offshore areas. More detail on the components in each of the boxed inserts can be found in section 4.

Illustration 6 does not show aggregators – for further information on aggregator attachment, see section 4 – Anchored FAD technical considerations (page 31 and 32).

2.3 Indo-Pacific FAD

The Indo-Pacific FAD (Figure 6) is a renaming of the previously known SPC Indian-ocean FAD. The new name accounts for the design's origin (Indian Ocean) as well as the modifications to the design by Pacific Island FAD technicians. The Indo-Pacific FAD is a robust FAD design that can be deployed in strong currents and has been developed primarily as a tool to support small-scale commercial fishing. In this context, the Indo-Pacific FAD provides a centralised fishing location to improve safety and reduce fuel consumption. There have been a number of updates and modifications to the Indo-Pacific FAD since the 2005 SPC FAD manual was produced. The increased availability of multistrand rope in the region has largely replaced the use of three-strand rope and related hardware (shackles and swivels). Cost being previously one of a FAD's most vulnerable points, a reduction in hardware also means a reduction in cost. In recent years the Indo-Pacific FAD has been successfully deployed in nearshore environments, using fewer floats in the upper floatation section.

Design and deployment notes

- The Indo-Pacific FAD is made of a series of surface floats, connected via a combination of multistrand nylon and multistrand polypropylene rope to the anchor system.
- The combination of nylon (sinking) and polypropylene (floating) ropes creates a catenary curve in the mooring system, which acts as a shock-absorber to counter elements of the sea (storms, waves, currents).
- The numerous high-quality floats are attractive items for other purposes and mean that the Indo-Pacific FAD is frequently subject to vandalism. For this reason, it is more suitable for places with strong community ownership and/or heavy reliance on FADs. It is not suitable for use near urban areas due to both vandalism and high boat traffic.
- A flagpole or IALA-recognised (International Association of Marine Aids to Navigation and Lighthouse Authorities) Special Mark buoy with appropriate radar reflector and strobe light are required to assist in locating the low profile upper floatation system and to reduce its navigational hazard.
- The upper floatation of the Indo-Pacific FAD (Figure 6) uses 15 acrylonitrile butadiene styrene (ABS) floats with 14 purse-seine buffer floats. This upper floatation system is suitable for offshore, high current deployments. If deployed nearshore in lesser currents, the upper floatation can be reduced to six ABS floats with five purse-seine buffer floats.
- If the floats used for the upper floatation system have a sharp centre hole edge (e.g. 30G-2 buoys), ensure that a poly pipe sheath encases the main float line to reduce rope abrasion.
- Supplementary buoyancy is required when deployed at depths less than 1,500 m to lift the mooring line from the seabed. Ensure that the supplementary buoyancy floats are placed below the catenary curve. (Table 6 provides the appropriate location to place supplementary buoyancy.)
- If deployed on steep slopes, there is a need to reduce the scope, as there is an increased risk of entanglement with reefs. (See section 4.2.3 for further information.)
- When used further offshore, there is an increased need for appropriate boating safety equipment and training.
- Figure 6 illustrates the complete Indo-Pacific FAD. The technical components required (refer to the numbers on the illustration) can be found in Table 2. More detail on the boxed insets (fig 12, 13, 18, 19, 24, 25 and 29) shown in Figure 6 can be found in section 4 – Anchored FAD technical considerations.

Key features of the Indo-Pacific FAD

- The Indo-Pacific FAD can be used offshore as well as nearshore.
- The use of a supplementary danforth or grapnel anchor allows the FAD to be deployed on steeper slopes (up to 30°).
- The upper floatation system is streamlined, which reduces drag and resistance to currents/waves, allowing it to cope with areas of high current.
- The Indo-Pacific FAD is ***not*** part of the IALA marine buoyage system, so it may not be approved for use in some countries. However, it can be adapted to conform to IALA standards by tagging on a recognised Special Mark buoy to the system.

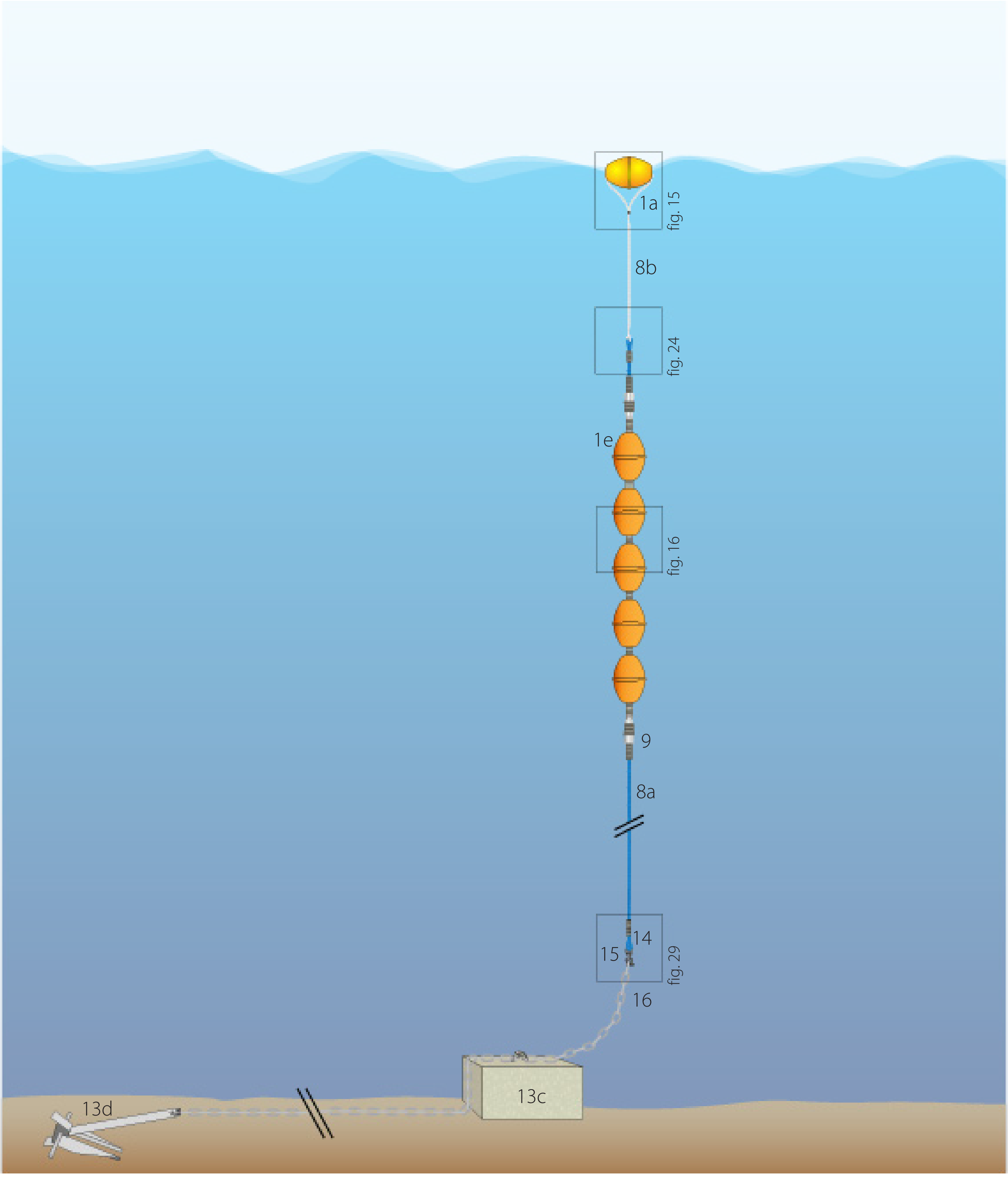


Figure 7. Subsurface FAD design showing the temporary surface marker to aid fishers to locate the FAD initially. More detail on the components in each of the boxed inserts can be found in section 4.

Illustration 7 does not show aggregators – for further information on aggregator attachment, see section 4 – Anchored FAD technical considerations (page 31).

2.4 Subsurface FAD

The subsurface FAD is a relatively new design that has gained traction across the Pacific region in recent years. The entire upper floatation section is located below the surface of the water (Figure 7), a technological attribute developed to address the issue of sabotage and to enable deployment in areas of high boat traffic, such as close to urban centres.

Design and deployment notes

- A surface marker buoy is usually connected to the main upper floatation system to allow fishers to locate the FAD prior to establishing landmarks and/or GPS location, after which it can be removed. The surface buoy also acts as an initial surface aggregator. Lightweight nylon rope is used to hold the surface marker in place to reduce the risk of damage to the FAD due to entanglement with boats and, if the buoy is removed through vandalism, the main floatation system will not be disturbed.
- By design, the underwater floatation system places a constant upward pull on the main line and anchor system. For this reason, the weight of the anchor needs to be at least three times the buoyancy of the floatation system.
- Subsurface FADs are best deployed in depths of 300–500 m in areas with a flat bottom surface.
- Deployment depths > 500 m have a greater chance of deployment errors. This, along with the elasticity of polypropylene rope, which ranges from 5% to 10%, can result in the floatation being located in a less than ideal location.
- Requires accurate site assessment using the best available bathymetry charts, an echo-sounder and a GPS to do pre-deployment bathymetry survey.
- Requires care during main rope line calculations and deployment to ensure that the top of the upper section ends up below the surface of the water (ideally between 20 m and 40 m below the surface).
- Deployments should be undertaken during perfectly calm weather and low current conditions.
- As the subsurface FAD does not look like the typical surface FAD (with a visible upper floatation section) that fishers may be used to, ongoing communication may be required for them to accept the subsurface FAD design.
- Figure 7 illustrates the sub-surface FAD. The technical components for the subsurface FAD required (refer to the numbers on the illustration) can be found in Table 2 . More detail on the boxed insets (fig 15, 16, 24, and 29) shown in Figure 7 can be found in section 4 – Anchored FAD technical considerations.

Key features of the subsurface FAD

- Vandalism-proof (floatation section below the water surface).
- Can be deployed in high boat traffic areas and near urban centres.
- No further maintenance, supposedly long lifespan, cheaper than Indo-Pacific FAD (less rope, fewer floats).
- Can incorporate a surface floatation system if desired (see section 2.5 Lizard FAD).

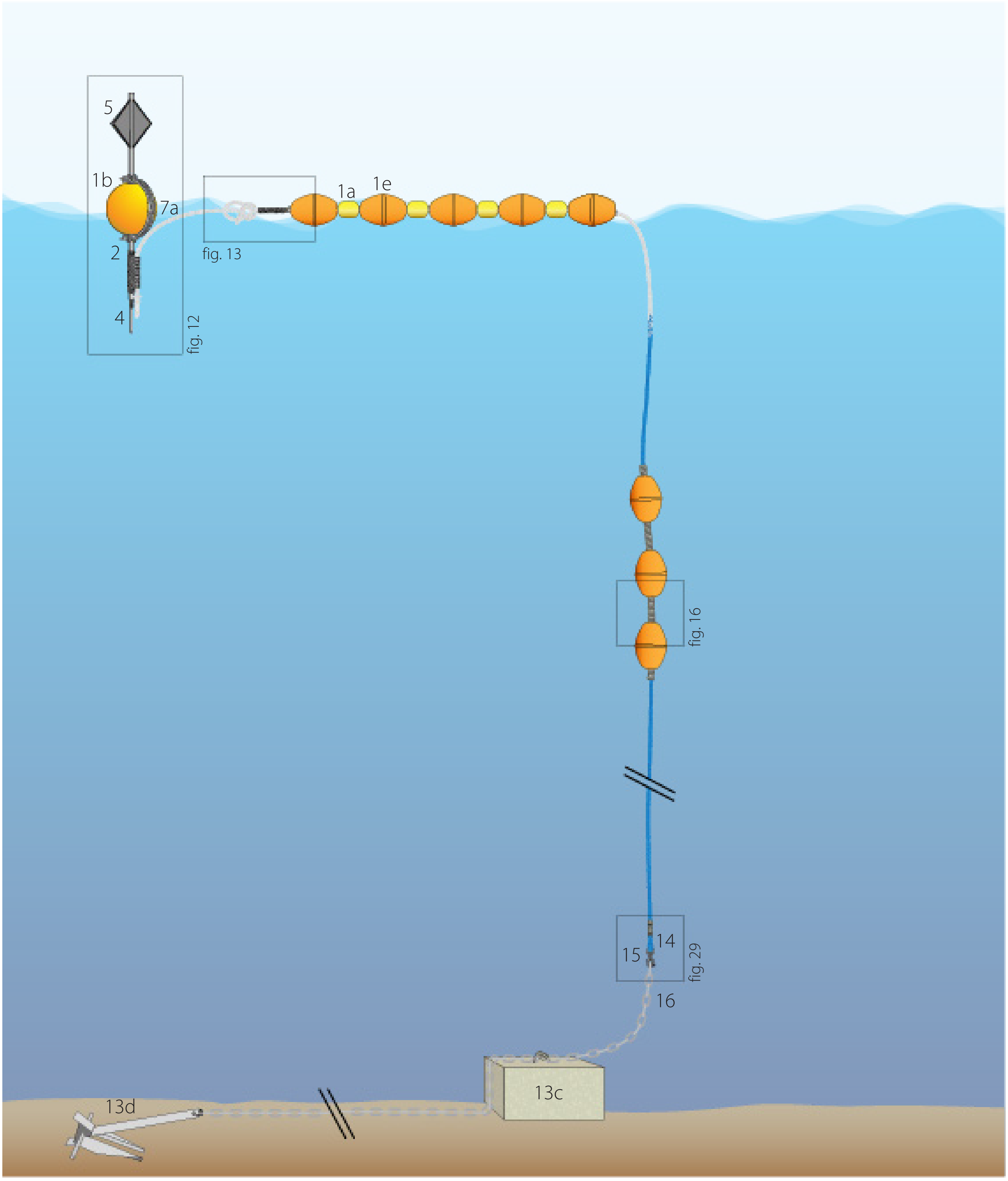


Figure 8. Lizard FAD design. More detail on the components in each of the boxed inserts can be found in section 4.

Illustration 8 does not show aggregators – for further information on aggregator attachment, see section 4 – Anchored FAD technical considerations (page 31).

2.5 Lizard FAD

The lizard FAD is a combination of a subsurface and surface FAD (Figure 8), where the surface section of the FAD (its tail) provides additional aggregation to the subsurface FAD, while at the same time being a more recognised design for fishers. As the surface component of anchored FADs is the weakest link, in effect the lizard FAD can lose its tail (the upper surface FAD section) but remain in the water as a sub-surface FAD. The lizard FAD design has been included in this manual as there has been increasing interest in its design in the region and there are some specific techniques relating to its deployment (see section 5.4.2 Sub-surface and lizard FAD deployment sequence).

Design and deployment notes

- Best deployed at a depth of 300–500 m in a flat bottom area (can be deployed up to 800 m but this can be risky and requires experienced FAD technicians).
- Requires care during main rope line calculations and deployment to ensure that the top of the upper section ends up below the surface of the water (ideally 40 m below).
- If the surface component (tail) of the lizard FAD is lost, it may be replaced by diving down and reconnecting the surface floatation or, if this is not possible, the lizard FAD effectively becomes a subsurface FAD and is still able to aggregate fish.
- Requires accurate site assessment using the best available bathymetry charts, an echo-sounder and a GPS to do a pre-deployment bathymetry survey.
- Deployments should be undertaken during perfectly calm weather and low current conditions.
- Requires a specific deployment technique – see section 5.4.2 Sub-surface and lizard FAD deployment sequence.
- Figure 8 illustrates the lizard FAD. The technical components required for the lizard FAD (refer to the numbers on the illustration) can be found in Table 2. More detail on the boxed insets (fig 12, 13, 16, and 29) shown in Figure 8 can be found in section 4 –Anchored FAD technical considerations.

Key features of the lizard FAD

- Integrated subsurface and surface components of the lizard FAD make it a recognised FAD design for increased longevity by retaining the subsurface component (when its tail is lost).
- Maintenance is required only on the surface component.

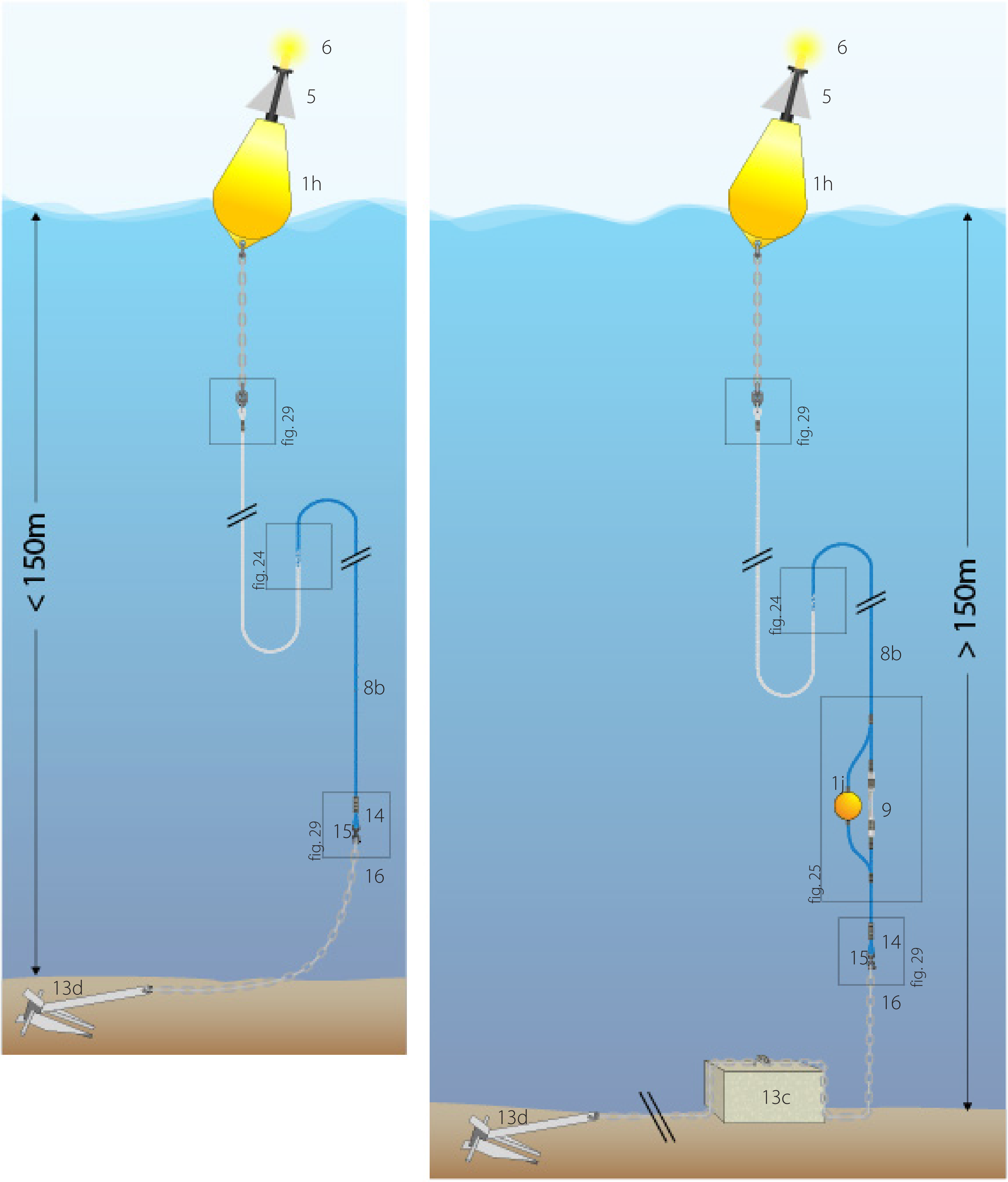


Figure 9. NSW DPI FAD design (left – NSW DPI design for shallow water; right – modified anchor system). More detail on the components in each of the boxed inserts can be found in section 4.

Illustration 9 does not show aggregators – for further information on aggregator attachment, see section 4 – Anchored FAD technical considerations (page 31 and 32).

2.6 Spar buoy type FADs

Spar buoy type FADs are heavy-duty and long-lasting, with large marker buoys designed to enable the connection of radar reflectors and strobe lights for navigational safety in offshore areas (Figure 9). In the Pacific region spar buoy type FADs are typically used in the US territories, where they are the only design accepted by the US Coastguard. The existing recommended SPC spar FAD design (Chapman et al. 2005) is very heavy and expensive to make and deploy. In an attempt to streamline existing designs, reduce costs and improve ease of deployment, this manual provides the specifications for a spar buoy type design that has been effectively used off the east coast of Australia since 2003 by the New South Wales Department of Primary Industries (NSW DPI). This FAD is designed with a light-weight anchor (25 kg danforth) to allow for annual retrieval and shallow (100–150 m) deployments (Figure 9 left). To enable deeper depth deployment, this manual includes a modified anchor design (Figure 9 right). Due to the additional anchor weight, the modified complete unit (including mooring and anchor) cannot be retrieved.

Design and deployment notes

- The design presented in the manual has not yet been tested in any PICT.
- The upper surface floatation is an 800 mm rotationally-moulded polyethylene buoy fitted with a navigational light (yellow Special Mark) and radar reflector.
- The galvanised chain joining the surface float and the main rope line provides a downward pull to maintain the vertical positioning of the buoy on the water surface, reduce vandalism and minimise spoilage of the rope due to fishing line entanglement.
- The mooring section follows the same protocol as the Indo-Pacific FAD design – the combination of nylon (sinking) and polypropylene (floating) ropes to create a catenary curve which acts as a shock absorber to counter elements of the sea (storms, waves, currents).
- Figure 9 illustrates the NSW DPI FAD. The technical components required for it and the modified NSW anchor design (refer to the numbers on the illustration) can be found in Table 2. More detail on the boxed insets (fig 24, and 29) shown in Figure 9 can be found in section 4 – Anchored FAD technical considerations.
- Detailed information on previous spar buoy type FADs and their deployment can be found in the SPC, 2005 FAD manual (Chapman et al. 2005).

Key features

- A greatly reduced risk of vandalism, since the buoy is identifiable as Special Mark and is therefore traceable to anyone who possesses it.
- Compliant with IALA marine buoyage system requirements.
- Lighter and more easily deployable than other spar type buoy designs.

Table 2. FAD components required for the six standard FAD designs.

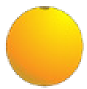
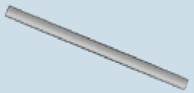
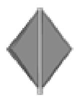
	Diagram		Lagoon	Bamboo basic	Bamboo advanced	Indo-Pacific	Sub-surface	Lizard	NSW DPI (retrievable)	NSW DPI (deep)
Surface marker										
1a		**Purse-seine float** (7 kg bouyancy)	2				1 (optional)			
1b		**ABS float with c/hole** (290 mm dia, 20 kg bouyancy)				1		1		
2		**PVC pipe** (2 m x 24 mm dia)	2			1		1		
3		**flag** (400 mm x 300 mm)	2			1		1		
4		**weight to counter-balance flag pole** (rebar or weight)	2 x 2 kg			1 x 5 kg		1 x 5 kg		
5		**radar reflector**				1		1	1	1
6		**strobe light**	1			1		1	1	1
7a		**16 mm multistrand nylon rope** (connector rope to flag)				2 m		2 m		
	Diagram		Lagoon	Bamboo basic	Bamboo advanced	Indo-Pacific	Sub-surface	Lizard	NSW DPI (retrievable)	NSW DPI (deep)

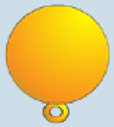
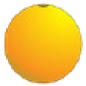
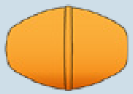
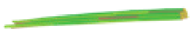
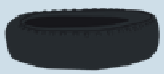
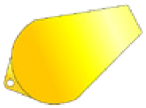
	Diagram		Lagoon	Bamboo basic	Bamboo advanced	Indo-Pacific	Sub-surface	Lizard	NSW DPI (retrievable)	NSW DPI (deep)
Floatation										
1a		**Purse-seine float** (7 kg buoyancy)				14		5		
1c		**ABS float with c/hole** (360 mm dia, 24 kg buoyancy)		1	1					
1d		**ABS pressure float** (290 mm dia, 800 m working depth, 11 kg buoyancy)			2	see table 7				see table 7
1e		**ABS float with c/ hole** (290 mm dia, 300 m pressure rated)				15	5	8		
1f		**Bamboo culms** (3 m long)		to fit tyre	to fit tyre					
1g		**Car tyre**		2	2					
1h		**Yellow Special Mark –** 800 mm rotationally-moulded polyethylene							1	1
7a		**16 mm multistrand nylon rope**				see table 7		50 m		
	Diagram		Lagoon	Bamboo basic	Bamboo advanced	Indo-Pacific	Sub-surface	Lizard	NSW DPI (retrievable)	NSW DPI (deep)

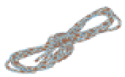
	Diagram		Lagoon	Bamboo basic	Bamboo advanced	Indo-Pacific	Sub-surface	Lizard	NSW DPI (retrievable)	NSW DPI (deep)
7b		**whipping rope** (4 mm nylon preferred)				>20 m	5 m	>20 m		
8a		**16 mm multistrand polypropylene rope** (whipping between buoys)						8 m	6 m	
8b		**8 mm polypropylene rope**		> 6 m (lashing bamboo)	> 6 m (lashing bamboo)		30 m+ (if sur-face marker)			
9		**Plastic hose sheath** (20 mm dia)				15 m	5 m	8 m		
16a		**10 mm ballast chain**							10m	
Aggregators										
10		**biodegradable aggregator rope** (~4 m in length)	as appropriate	as appropriate	as appropriate	as appropriate	as appropriate	as appropriate	as appropriate	as appropriate
		**4 mm multistrand rope** (secondary line for aggregators)	20 m	20 m	20 m	50 m		50 m		50 m
11		**coconut fronds**	10	5+	5+	5+	5+	5+		5+
FAD mooring section										
8a		**16 mm multistrand polypropylene rope**		see table 4.2	see table 4.2	see table 4.3	see section 4.2.2	see section 4.2.2		see table 4.3
	Diagram		Lagoon	Bamboo basic	Bamboo advanced	Indo-Pacific	Sub-surface	Lizard	NSW DPI (retrievable)	NSW DPI (deep)

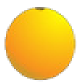
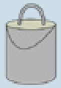
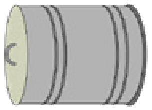
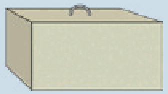
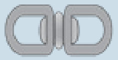
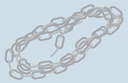
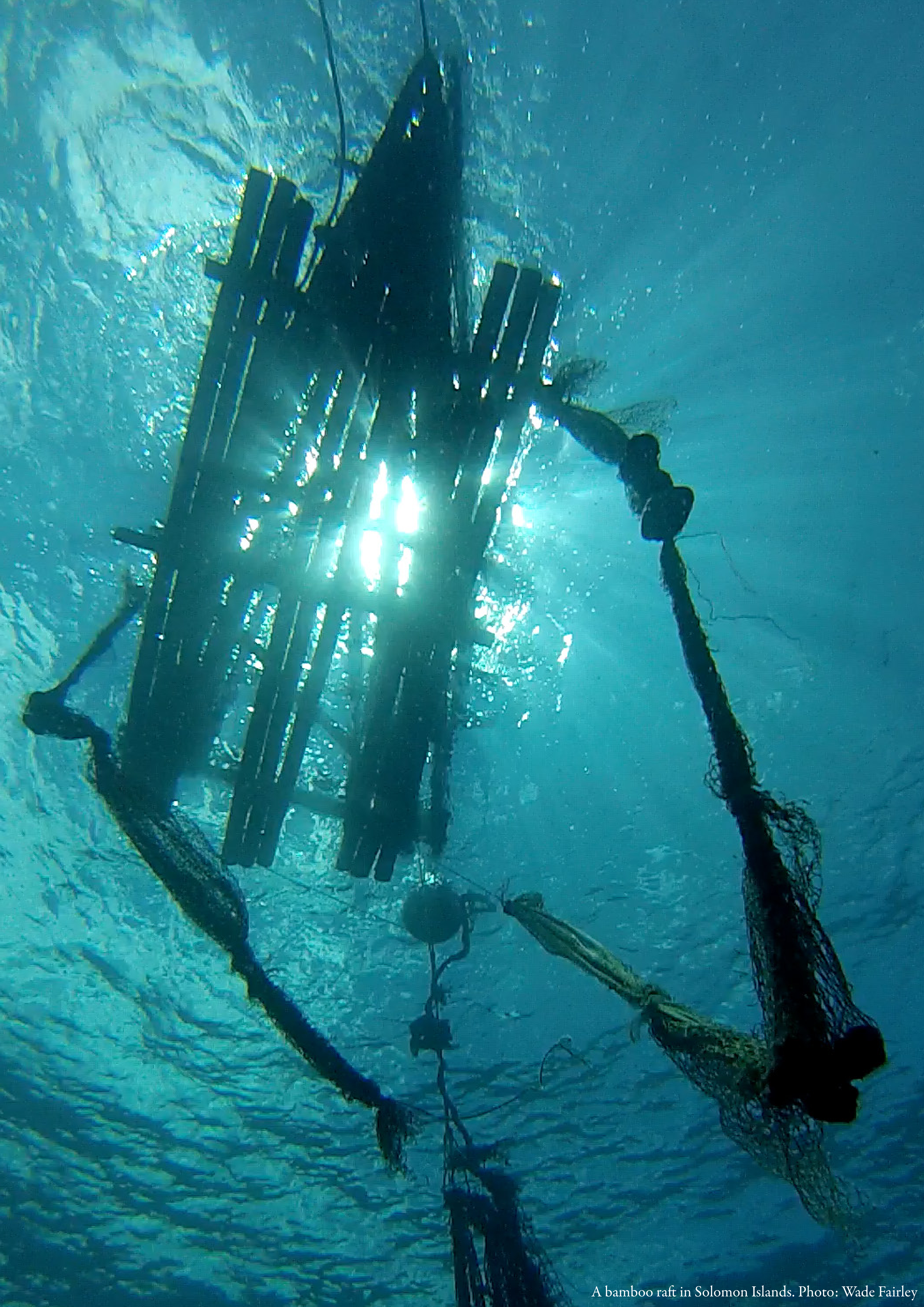
	Diagram		Lagoon	Bamboo basic	Bamboo advanced	Indo-Pacific	Sub-surface	Lizard	NSW DPI (retrievable)	NSW DPI (deep)
8b		**8 mm polypropylene rope**	depth dependent						See table 4.3	
8c		**12 mm three-strand nylon rope**							See table 4.3	
8d		**12 mm three-strand polypropylene rope**								
12		**Counter-weight**		> 5 kg	> 5 kg					
Supplementary buoyancy										
1k		**ABS pressure float** (200 m pressure rated)	10 x 2 kg							
1i		**ABS pressure float** (800 m pressure rated)			21 kg					
1j		**ABS pressure float** (1,200 m pressure rating)				see table 6				see table 4.3
9		**plastic hose sheath** (20 mm dia)				2 m				2 m
	Diagram		Lagoon	Bamboo basic	Bamboo advanced	Indo-Pacific	Sub-surface	Lizard	NSW DPI (retrievable)	NSW DPI (deep)

	Diagram		Lagoon	Bamboo basic	Bamboo advanced	Indo-Pacific	Sub-surface	Lizard	NSW DPI (retrievable)	NSW DPI (deep)
Anchor										
13a		**4 L paint tin** (filled with concrete)	10							
13b		**20 L drum** (filled with concrete)	2							
13c		**anchor block/drum**		see section 4.2.2	see section 4.2.2	see section 4.2.2	see section 4.2.2	see section 4.2.2		see section 4.2.2
13d		**danforth anchor**			25 kg	25 kg	25 kg	25 kg	25 kg	25 kg
14		**swivel 16 mm** (hot dipped galvanised)			1	1	1	1	1	1
15		**shackle 16 mm** (hot dipped galvanised)			3	3	3	3	1	3
16b		**16 mm chain** (hot dipped galvanised)			10 m	10 m	10 m	10 m	5 m (with 1 m stud link)	1 0m
	Diagram		Lagoon	Bamboo basic	Bamboo advanced	Indo-Pacific	Sub-surface	Lizard	NSW DPI (retrievable)	NSW DPI (deep)



A bamboo raft in Solomon Islands. Photo: Wade Fairley

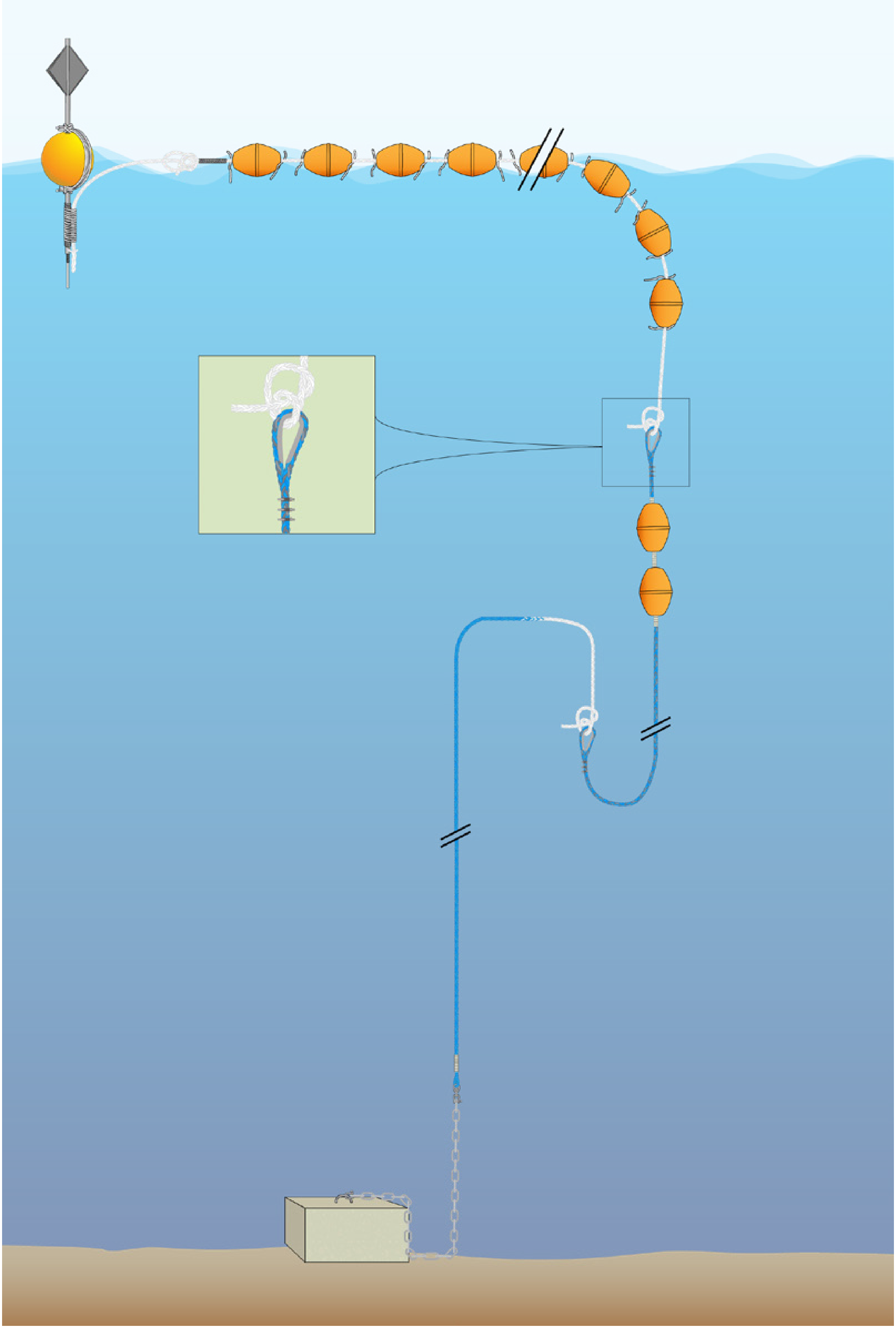


Figure 10. French Polynesia FAD design showing modifications.

3 Regional FAD design modifications

3.1 French Polynesian FAD

Over the past three decades, French Polynesia has deployed hundreds of spar and Indian-ocean type anchored FADs. During this time, numerous FAD design and deployment modifications have been tested. The development of the small barge for safe deployment of heavy anchors (see 5.3 Small barge deployments) is an innovation originating in French Polynesia that has gained traction across the region in the past few years. The main design modifications made to the Indian-ocean FAD (Figure 10) are listed below.

- Surface floatation changed to 10B/12B pressure floats (with centre hole and 600 m pressure rating) as it was found that at some sites the 30G buoys imploded when they plunged to deep depths during periods of high current.
- 24 mm braided nylon rope used through the surface buoys, negating the need for a plastic hose sheath.
- Buffers between surface floats changed from purse-seine buoy to polypropylene rope twisted into the braided nylon rope on either side of the 10B/12B pressure floats.
- Fishing techniques used in some areas of French Polynesia, e.g. drop stone and vertical longlining, resulted in entanglement of fishing line, which cut through the nylon rope used in the upper part of the mainline. At locations where such fishing techniques are common, the nylon rope is replaced with 16 mm twisted polypropylene/cable. As the twisted combined polypropylene/cable rope cannot be spliced, this rope also required the use of 18 mm galvanised thimble loops, held in place with 16 mm wire grips at the top and bottom rope joins.
- Anchors used at some deployment locations have been modified to smaller (50 kg) cement blocks connected by a galvanised chain. Multiple small blocks can enable deployments from small boats (see 4.3.1 Anchor types).

Design and deployment notes

- Polypropylene/cable rope is not readily available across PICTs and requires the use of thimble loops.
- Polypropylene/cable rope is heavy and makes deployments difficult – a maximum length of 300 m is recommended.
- The calculation of lengths of polypropylene/cable rope and polypropylene rope, required to ensure that an appropriate catenary curve is created, requires a skilled technician. (Note: the mooring length calculation tables provided in section 4.2.3 of this manual do not include polypropylene/cable ropes.)

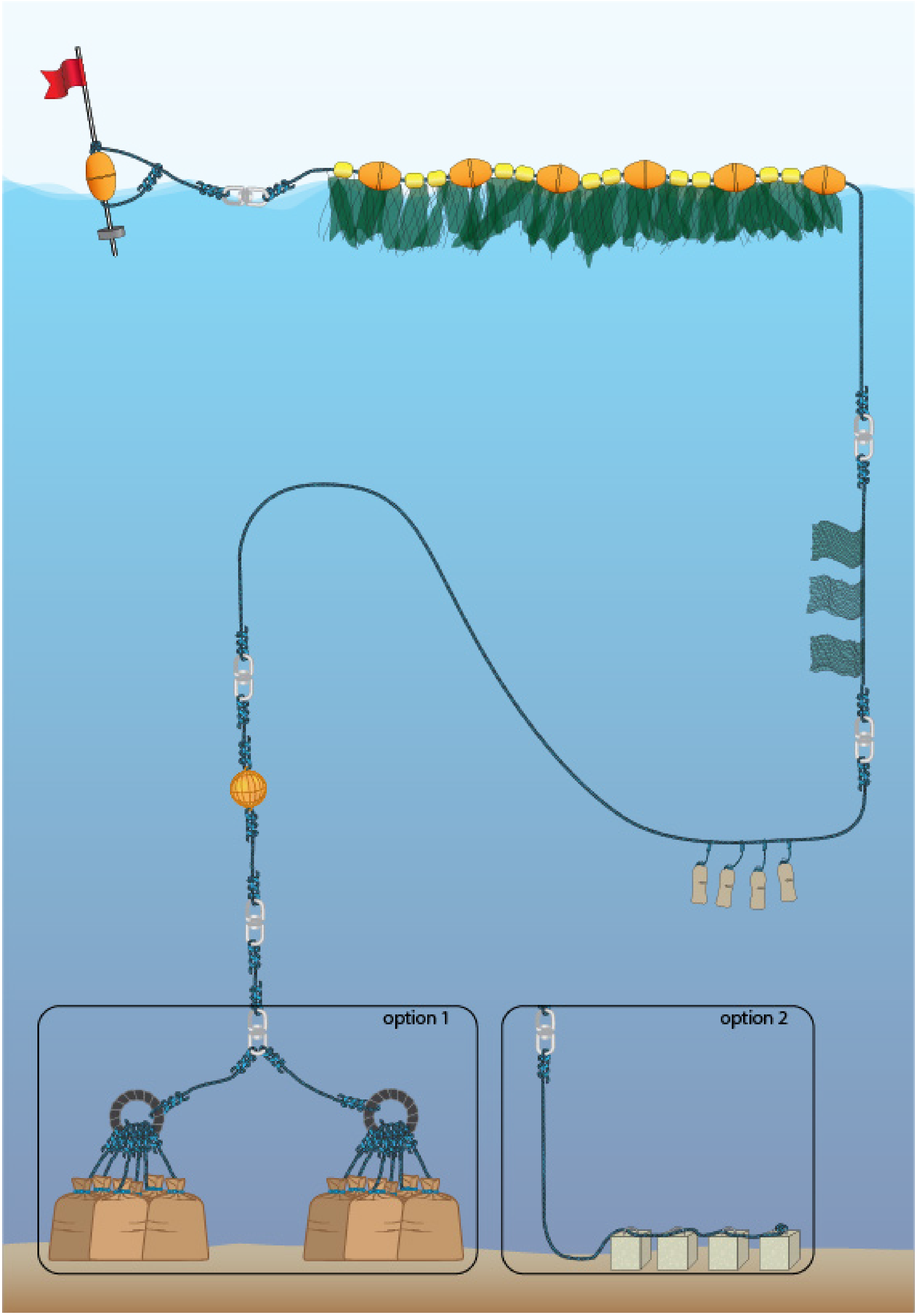


Figure 11. Vatuika FAD design modification.

3.2 Vatuika FAD

Anchored FADs were first introduced to Vanuatu by SPC in 1980, mostly using the spar buoy type FAD and then the Indian Ocean design primarily for commercial and charter fishing. From 2010, several other designs were introduced to Vanuatu that were targeted more towards small-scale fishers. These included the sub-surface FAD, the Okinawa bamboo FAD and the Japanese International Cooperation Agency (JICA)/Caribbean FAD design. During this time, several issues were faced, including vandalism, high FAD costs, and difficulty deploying FADs due to limited availability of large vessels and irregular shipping between remote islands. Between 2012 and 2014, the Vanuatu Fisheries Department, with the cooperation of the JICA's Grace of the Seas Project, developed the Vatuika FAD – a lower-cost FAD designed to be deployed safely from small vessels (Figure 11). The Vatuika FAD is a combination of the upper floatation section of the SPC Indian-ocean design and the mooring and anchor section of the Caribbean design, with a few modifications. The Vatuika FAD has been described in detail in a SPC newsletter article (Amos and Nimoho 2015) and a copy of the Vatuika technical manual can be obtained from the Vanuatu Fisheries Department.

Key design features of the Vatuika FAD.

- The upper FAD section comprises 5–6 pressure floats, buffered with purse-seine floats (the number of floats was reduced to minimise cost and strain on the mooring line).
- The main line uses only 12 mm three-strand polypropylene rope to reduce water resistance and is readily available in Vanuatu. To create a catenary-like curve and sink down the mooring line (to reduce boat/fishing gear entanglement) sand-filled bottles are placed on the mooring line.
- The anchor system is comprised of a series of sand-filled bags, to enable deployment from small vessels and in remote locations (where sand is readily available).

Design and deployment notes

- The Vatuika FAD uses materials that can be sourced locally and enables deployment in remote locations.
- Able to be deployed nearshore or offshore.
- The three-strand rope tends to twist and kink, which weakens the rope, so swivels in the mooring line are required to prevent this. Hardware, such as swivels in the upper section of anchored FADs, has been identified as a FAD weak point, due to corrosion.
- Accurate placement and weight of the sand-filled bottles is required to ensure the polypropylene mooring line sinks at the surface and the catenary curve is created (see Table 6 on counter-weights when using only buoyant rope).
- The use of sandbag anchors is not appropriate where the sea floor surface is rocky, as the bags will quickly wear and break.

4 Anchored FAD technical considerations

The basic design of an anchored FAD consists of an upper floatation (buoyancy, rope and aggregators), the main line (main line rope, connections and supplementary buoyancy) and the anchor (chain and anchor/s). In this part of the manual we have separated these sections to identify the technical considerations of the components used in each section, highlighting some of the common errors made during the construction and deployment of FADs.

4.1 FAD Upper floatation technical considerations

The upper floatation of an anchored FAD provides the buoyancy to keep the main line ropes from tangling and to keep the FAD system vertical. This floatation can be on the sea surface (e.g. bamboo, Indo-Pacific and spar buoy type FADs) or below the surface (e.g. lagoon and sub-surface FADs). Sabotage or vandalism of the upper floatation has been identified as one of the major factors resulting in premature FAD losses across the Pacific region (Sokimi and Albert 2016). Surface floatation can also be a navigational issue, resulting in boat entanglement and premature FAD losses. The evolution of the sub-surface FAD has largely come about in response to these issues.

Upper floatation used for both surface and sub-surface FADs are designed to ensure that: a) minimal strain is placed on the main line because drag is reduced; b) floatation is retained, even in situations where currents drag the upper floatation section to deep depths; and c) the design is suitable to the characteristics of the site, i.e. considering boat traffic and risks of vandalism.

4.1.1 Buoyancy type

The buoyancy used for FADs may be either locally obtained materials (bamboo/balsa wood) or synthetically produced products (foam or hard plastic floats, e.g. ABS floats). Floats are the most common buoyancy used for anchored FADs, apart from low-cost designs, where bamboo or other locally derived materials are used.

As a general guide, the buoyancy of the upper floatation section needs to increase as you move further offshore, as wave and currents are stronger and the deployment depth (and strain on the mooring line) increases. This is exemplified by the Indo-Pacific FAD, which uses 15 ABS floats with 14 purse-seine buffer floats when deployed offshore and six ABS floats with five purse-seine buffer floats when deployed nearshore.

Table 3 highlights the optimal buoyancy type based on some key parameters.

Table 3. Optimal buoyancy type based on some key parameters (🟩 = optimal, 🟦 = sub-optimal, 🟧 = ok, but not recommended, 🟥 = not appropriate).

	Bamboo	Surface floats	Sub-surface floats	Spar type buoys
Strong current or rough seas	🟥	🟩	🟩	🟩
High boat traffic	🟧	🟧	🟩	🟩
High vandalism	🟩	🟥	🟩	🟩
Low cost	🟩	🟧	🟩	🟥
Commonly avail-able in PICTs	🟩	🟧	🟧	🟧

When choosing floats it is necessary to know their floatation capacity (or buoyancy) and their working depth. The working depth of a float is the ability for the float to maintain integrity due to the increased pressure with increasing depth. It is recommended to use a float with a working depth at least double that of the actual depth of the float, as there will be times when the float is pulled into deeper water, for example during deployment and during periods of high current. Table 4 provides the floatation capacity (buoyancy) and working depth of some common floats used for FADs in the region.

Table 4. Common floats used, their floatation capacity (buoyancy) and working depth.

	Dimensions (mm)		Buoyancy	Working depth	Notes
Float	Diameter	Length			
Purse-seine (oval, Ethylene Vinyl Acerate (EVA) float)	220	250	7 kg	surface	Crushes when constantly submerged
30G-2 (oval ABS float)	290	437	20 kg	300 m	Found to implode when constantly plunged to deep depths over long periods. Sharp centre hole edge can cut float rope
10B (round ABS float)	290		10 kg	300 m	Replaced 30G-2 in French Polynesia
12B (round, ABS float)	360		20 kg	300 m	A larger, more buoyant alternative to 10B
Aquafloat-800 (cone, rotationally-moulded foam filled with closed-cell polyurethane)	800	1,260	100 kg	surface	

4.1.2 Surface markers

Surface marker floats, or buoys fitted with flags, provide a navigational aid for fishers to locate nearshore FADs (surface and subsurface). For offshore FADs, the use of special marker buoys, reflectors and strobe lights are required for maritime navigation and to be compliant with International Maritime Organization regulations. In some countries this may include the use of IALA approved buoys, such as a Special Mark buoy.

A common flagpole design used for nearshore FADs (Figure 12) consists of a 2 m length of PVC pipe (minimum 24 mm), inserted through the centre hole of an ABS float (290 mm diameter and 20 kg buoyancy) and held in place with at least four rounds of rope (8 mm), clove-hitched at the top and bottom of the float. A piece of re-bar (5 kg) is inserted into the bottom of the PVC pipe and whipped to the pipe to give weight to the flagpole and ensure it stands vertically in the water column. Multistrand nylon rope (16 mm) is whipped to the PVC pipe to connect the flagpole to the main float line. Alternative poles can also be used (bamboo, fibreglass or timber) as long as the diameter is less than the internal diameter of the float centre hole.

4.1.3 End point connections

The end point of the main float line (at the end of the floats) is an important connection point to enable the attachment of a flag or surface marker and is the final point that stops the floats from coming off. A common end point connection is the eye loop (Figure 13). The loop acts a back-up float stopper and provides an easy connection point for the attachment of flags and aggregators. Ensure that the main float line is spliced back on itself and whipped well. Take particular care with binding the end connection of the Indo-Pacific and subsurface FAD designs that have a poly pipe sheath encasing the rope (see also Figure 19).

An alternative end point connection (Figure 14) is the detachable loop, used for example in bamboo FAD designs. The main line is spliced directly to the surface float, while an additional line is spliced and whipped to the main line about 1 m below the surface float, with an eye loop at the end. This eye loop provides the point for the connection and detachment of the bamboo raft to easily enable its removal for replacement or maintenance, or prior to the onset of the cyclone season.

Surface marker floats (e.g. for sub-surface FADs) with a centre hole can be attached by threading the rope through the float and splicing it back onto itself (Figure 15). This marker float is not intended to last, but provides the location of the FAD, prior to fishers marking the FAD with a GPS or using traditional navigational marks.

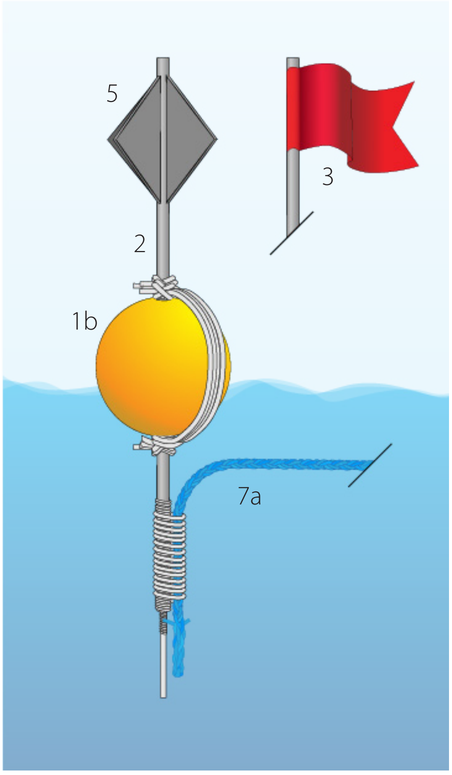


Figure 12. Diagram showing the rope connection to the flagpole.

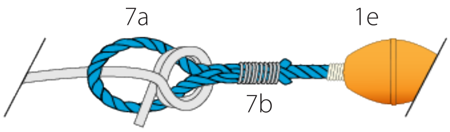


Figure 13. Diagram showing the end loop connection on the upper floatation.

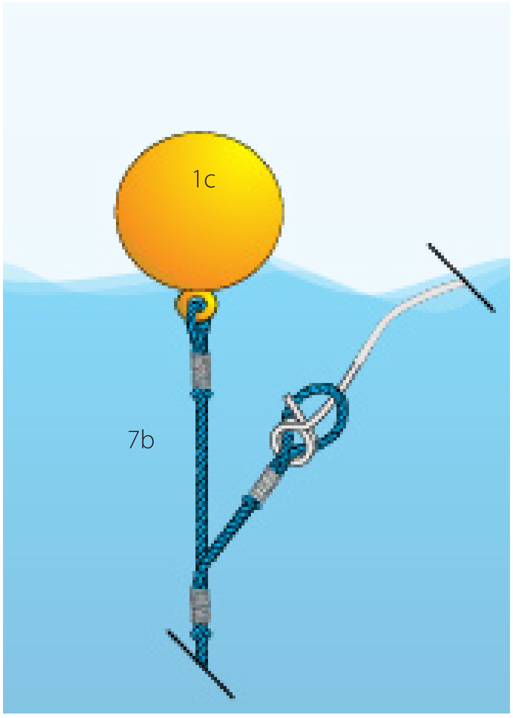


Figure 14. Diagram showing the detachable loop on the upper floatation for the bamboo FAD.

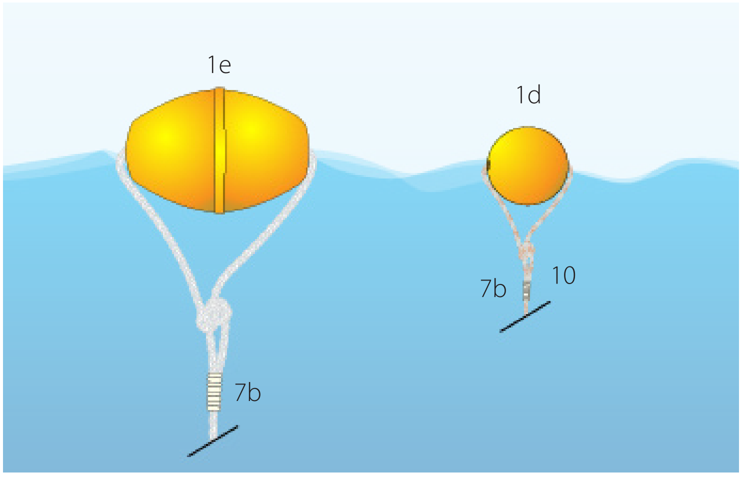


Figure 15. Diagram showing the end connection to a surface float with a centre hole.

4.1.4 Float buffers

Due to the intense pressure on the upper floatation section, buffers between floats are required to stop the floats from rubbing against each other. This constant friction can weaken the main float rope and result in the loss of the FAD.

Buffers can be achieved through several techniques:

1. whipping (Figure 16) between the buoys with polypropylene rope (16 mm) using six turns around the main line (e.g. sub-surface FAD);
2. twisting (Figure 17) multistrand rope (12 mm) through the main line close to each float to block the float (e.g. French Polynesia FAD); and
3. using purse-seine buffer floats (Figure 18) between the larger 30G-2 oval floats for surface FAD designs (e.g. Indo-Pacific and lizard FAD designs).

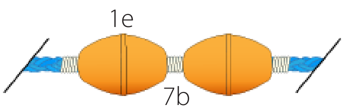


Figure 16. Diagram showing the whipping between buoys, e.g. sub-surface FAD.

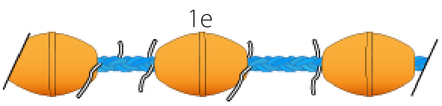


Figure 17. Diagram showing the twisting rope between buoys to block buoys from moving.

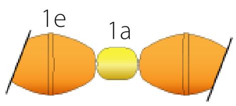


Figure 18. Diagram showing the use of a purse-seine float (yellow) as a buffer between 30G-2 (orange) floats.

In the Indo-Pacific, lizard and sub-surface FAD designs, the main float line is also encased in a plastic tube sheath (20 mm diameter) in the float section. This is especially important when using 30G-2 floats, which have a jagged join line near the centre hole. Extreme care needs to be taken at the two tube end points to ensure that the edge of the tubing is rounded – if the edge of the tubing is sharp, it will cut the rope at that point.

To ensure the main line is protected at the end of the tubing;

- split the tube slightly at the end to fold the tubing back onto itself (this creates a rounded smooth edge);
- gently push back the tubing and whip the rope underneath (about 20 cm either side of the pipe end point);
- bring the tubing back over the whipping and whip the end part of the tubing (where it is folded back on itself) to hold it in place; and
- repeat for the other end of the plastic tube.

Image 1 shows a FAD that was poorly constructed. The FAD was in the water for less than one month before washing ashore. While the FAD was lost due to a different connection than the one pictured here, you can see that the whipping around the plastic tubing was not tight or long enough to hold the tubing in place. If other sections of this FAD did not break, eventually the tube would have cut the rope at this point.

Image 1. Plastic tube that has not been constructed appropriately.

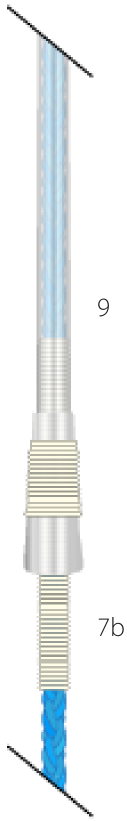


Figure 19. Diagram showing the binding onto the poly pipe sheath.

4.1.5 Aggregators

It is widely accepted that the attachment of aggregators to the FAD upper floatation system can increase the effectiveness of the FAD for aggregating and retaining fish. A wide variety of materials have been used to rig FADs in the past, including coconut fronds, plastic strapping, fish netting and shade cloth. Plastic strapping and fish netting are no longer recommended, as the strapping contributes to plastic pollution and fish netting has been found to entangle marine life and places undue stress and weight on the system.

Aggregator designs should be streamlined so that they create little resistance on the anchor system. This manual recommends the use of biodegradable aggregators, including coconut fronds, jute, hessian bags (cut into strips), manila, hemp, sisal, bamboo strips or pandanus strips (like those used for weaving mats). The use of materials such as pandanus strips provides an opportunity for all members of the community to participate in the FAD planning and rigging process.

The attachment methods for aggregators have also evolved over the past few decades. In the past, aggregators were attached directly to the main line, but in some situations this resulted in entanglement or friction with the main line, causing weakness in the system. For surface FADs, a secondary aggregator rope line is now recommended (Figure 20, left). This rope runs parallel to the main mooring line and is spliced and whipped to the main line at the top, bottom and at various points along the extent of the rope to prevent the aggregator line twisting and interfering with the main mooring line. For sub-surface FADs that use a plastic tubing buffer between the main rope line and the buoys, the aggregators can be attached directly onto the whipping between the buoys (Figure 20, right).

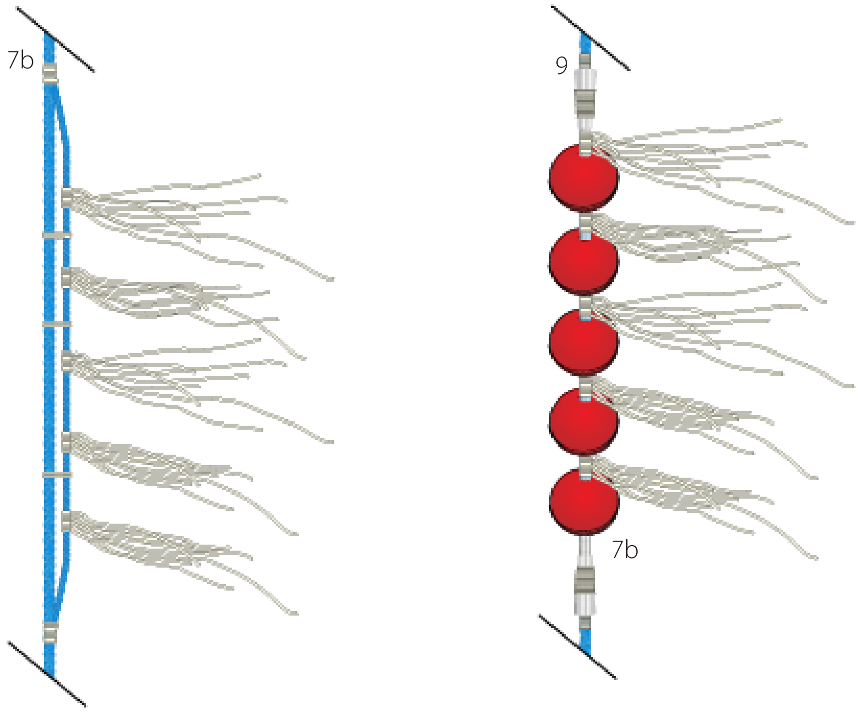


Figure 20. Diagram showing the attachment of aggregators using a secondary rope (left) and to the plastic tubing sheath on a sub-surface FAD (right).

Surface aggregators are also extremely effective. Coconut fronds are one of the most commonly available and effective surface aggregators. The fronds provide protection for small fish and are covered quickly with a film of algae, which provide food, thus creating a small ecosystem around the FAD. The surface aggregator is made up of 5–30 m of coconut fronds, connected to the upper FAD section at the end loop, either end-to-end (Figure 21, bottom diagram) or bunched (Figure 21, top diagram). More coconut fronds can be connected when in series, but in low currents it has been found that the coconut fronds can tangle with the upper floatation. A 5 kg weight (e.g ½ bag of sand) is attached at the end of the coconut fronds to help them sink slightly in the water. The coconut fronds should be replaced regularly, although experience from a number of countries shows that this often does not happen.

A common error amongst FAD practitioners in the region is the use of burdensome aggregators, e.g. large bamboo rafts with extensive amounts of purse-seine net attached underneath. While this type of aggregator is effective to aggregate fish, it substantially shortens the life of the FAD system and will result in premature loss. Bamboo raft aggregators should be used only in areas of low current (e.g. lagoons and bays).

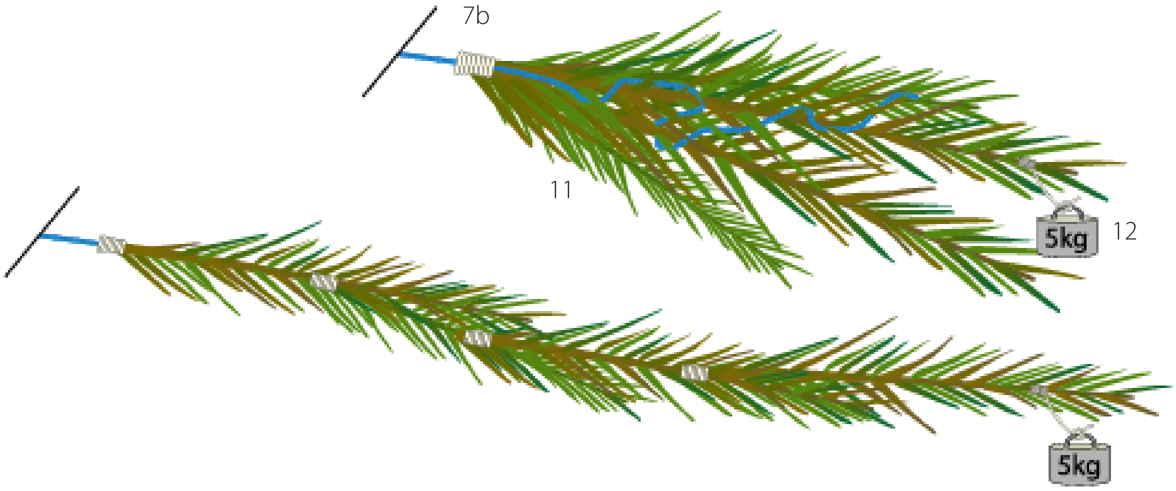


Figure 21. Diagram showing streamlined bamboo aggregators connected end-to-end in series (bottom) and bunched (top).

4.2 FAD main line technical considerations

The main line of an anchored FAD is the link between the upper floatation and the anchor system. It includes the main line rope, connections and supplementary buoyancy. The main lines that are recommended for anchored FADs in this manual have been designed to cope with the forces produced by waves and currents, taking into consideration aspects such as rope entanglement due to boat traffic and/or fishing methods.

Over the past few years, multistrand ropes have become increasingly available in the region and so are now preferred for all FAD construction. Multistrand ropes have a greater holding strength and do not twist, knot or hockle like three-strand ropes. The shift to multistrand rope has reduced the amount of hardware required in the mooring section, which has been identified as a weak point of FAD designs. An increased holding strength has also enabled the use of 16 mm multistrand rope instead of 18 or 20 mm three-strand rope, as recommended in previous manuals (16 mm multistrand rope is also cheaper and often more available in PICTs). The main line rope calculations provided in this manual are based on the use of 16 mm multistrand rope. If 18/20 mm rope is used, follow rope length calculations provided in Chapman et al. 2005.

The catenary curve is an important aspect of surface FAD designs, as it provides the elasticity in the system to cope with tide, currents and wave action. The catenary curve is a theoretical U-shaped curve, created using the combination of sinking (e.g. nylon) and buoyant (e.g. polypropylene) ropes – the catenary curve centres around the point where the two ropes are spliced together. Unfortunately sinking rope is expensive and not readily available in all PICTS. Consequently, low-cost designs (e.g. the lagoon FAD and the bamboo FAD) have been developed with buoyant rope only. Several countries have also modified Indian-ocean type surface FAD designs to use only buoyant rope in the main line (e.g. Vatuika FAD).

This manual provides technical information for calculating main line rope lengths when using a combination of sinking and buoyant rope and for when using only buoyant rope. Sub-surface FADs use only buoyant rope and are considered separately in this section of the manual.

Table 5. Optimal FAD mooring system designs based on different parameters (green = optimal, blue = sub-optimal, orange = ok, but not recommended, red = not appropriate).

	Buoyant rope without counterweight (surface FAD)	Buoyant rope with counterweight (surface FAD)	Buoyant rope (sub-surface FAD)	Combination sinking and buoyant rope (catenary curve)
Strong current	not appropriate	sub-optimal	sub-optimal	optimal
Proximity to reef or slope	not appropriate	sub-optimal	optimal	sub-optimal
High boat traffic	not appropriate	sub-optimal	optimal	sub-optimal
Rope availability	optimal	optimal	optimal	sub-optimal
Low cost	optimal	optimal	sub-optimal	ok, but not recommended

4.2.1 Buoyant rope main line: Surface FADs

Buoyant rope is typically used for the main line rope of low-cost surface FADs anchored close to shore (e.g. lagoon and bamboo FADs). The standard calculation for the length of the main line rope is deployment depth plus 25% to allow for scope (see section 4.2.3) and elasticity in the system. Table 6 provides a guide for the lengths of buoyant rope (16 mm polypropylene) required for deployment depths between 50 m and 3,000 m.

Limitations of using only buoyant rope in surface FADs, particularly those located further from shore, are the reduced elasticity in the system (a catenary curve is not created) and the increased potential for boat/fishing line entanglement in the main line near the surface. To avoid these issues, a series of counterweights can be attached to the main line to produce a quasi catenary curve. It is important that the weight and location of the counterweight is appropriate for the deployment depth and type of counterweight used (Table 6) to ensure that the catenary curve created is at a safe depth.

Two common counterweights used are short lengths of cement-filled pipes and lengths of galvanised chain. Cement-filled pipes can be constructed by cementing a piece of rope through a length of poly pipe. Counterweights should be rigged to reduce entanglement with the main line by whipping them alongside the main line, rather than letting them hang from one point (Figure 22).

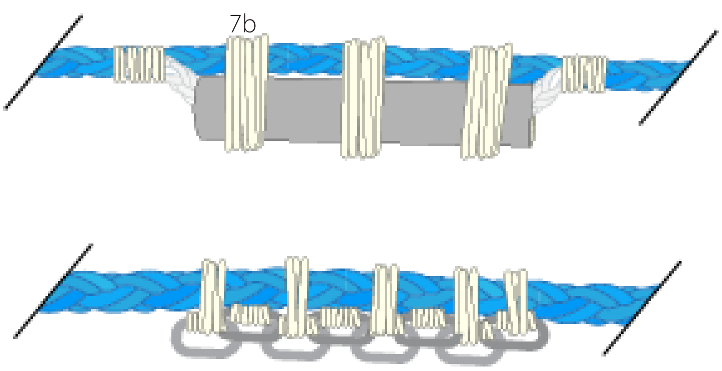


Figure 22. Diagram showing two counterweight options – cement tube (top) and galvanised chain (bottom) – and how they are rigged to the mooring line.

Table 6. Buoyant rope mooring section showing rope length (using 16 mm polypropylene), counterweight required and placement of counterweight.

DEPTH (m)	Length (m) of polypropylene main line rope (16 mm) required	Placement of counterweight (distance [m] from surface)	Underwater counterweight required (kg)	Concrete counterweight (weight in air [kg])	Galvanised chain counterweight (weight in air [kg])
50	65	20	5	9	6
100	125	40	6	10	6
150	190	60	6	11	7
200	250	80	6	11	7
250	315	100	6	12	7
300	375	120	7	12	8
350	440	140	7	13	8
400	500	160	7	13	8
450	565	235	8	15	10
500	625	245	9	15	10
550	690	255	9	16	10
600	750	265	9	16	10
650	815	270	9	16	10
700	875	280	9	16	11
750	940	290	9	17	11
800	1,000	300	9	17	11
850	1,065	310	10	17	11
900	1,125	320	10	17	11
950	1,190	325	10	18	11
1,000	1,250	335	10	18	11
1,100	1,375	355	10	18	12
1,200	1,500	375	11	19	12
1,300	1,625	390	11	19	12
1,400	1,750	410	11	20	13
1,500	1,875	430	11	20	13
1,600	2,000	445	12	21	13
1,700	2,125	465	12	21	14
1,800	2,250	485	12	22	14
1,900	2,375	500	12	22	14
2,000	2,500	520	13	23	15
2,100	2,625	540	13	23	15
2,200	2,750	555	13	24	15
2,300	2,875	575	14	24	16
2,400	3,000	595	14	25	16
2,500	3,125	610	14	25	16
2,600	3,250	630	14	26	16
2,700	3,375	650	15	26	17
2,800	3,500	665	15	26	17
2,900	3,625	685	15	27	17
3,000	3,750	705	15	28	18

4.2.2 Buoyant rope only main line: Sub-surface FADs

Only buoyant rope is used for the main line rope of sub-surface FADs, as the upper floatation section is submerged. The standard calculation for the length of main line rope required for sub-surface FADs needs to take into consideration the deployment depth, the settling location of the top of the buoyancy section (typically 20 to 40 m below the surface), the stretch in the rope (as a result of the positive buoyancy pressure on the mooring system), as well as other components included within the overall deployment depth, such as anchor height and chain length.

Figure 23 shows the components required for the calculation of subsurface main line length. The calculation is shown below.

Main line rope length (MRL) = deployment depth (d) – (settling depth of top float (a) + height of anchor block (c) + length of anchor chain above anchor (b)) + (stretch of main rope x length of the rope (r)

$$MRL = d - (a + c + b) + (stretch\% \times r)$$

Different rope types and diameter have different stretch. Nylon rope is not recommended for sub-surface FADs as it has sinking properties that will require more floats to hold up the system and it has greater stretch than polypropylene rope at 15% to 25% during usage. Polypropylene rope has 5% to 10% stretch during usage. Stretch properties for the rope used for the main line of sub-surface FADs can be confirmed with the rope supplier.

Experience shows that the buoyancy typically used for subsurface FADs will stretch the rope up to an additional 5% and so this is what is used in calculations. An example is given below.

A subsurface FAD is being deployed at a depth of 500 m. The mooring section will use 16 mm multistrand polypropylene rope (which has 5% stretch). The anchor block used is 0.6 m high and there is 3 m of galvanised chain above the anchor, connecting it to the main line rope. Once deployed, you want the top of the buoyancy section to settle at 20 m below the surface.

$$MRL = d - ((a + c + b) + (stretch\% \times r))$$

$$MRL = 500 – ((20 + 0.6 + 3) + (0.05 \times (500 – (20 + 0.6 + 3))$$

$$= 452 \text{ m}$$

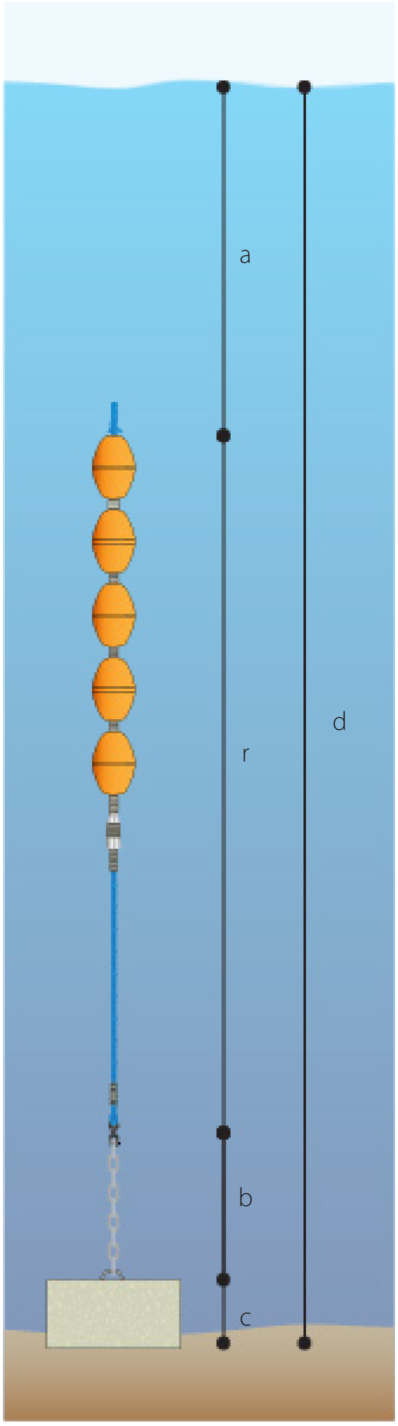


Figure 23. Diagram showing the components required for the calculation of subsurface main line rope length (a = floatation settling depth, b = chain length, c = block height, = deployment depth, r = main rope).

4.2.3 Combination rope main line

A combination of sinking and buoyant ropes is the most common main line system for anchored FADs, particularly those deployed further offshore, as the catenary curve provides elasticity in the system to enable the FAD to withstand the forces produced by waves and currents. The use of sinking rope at the surface also keeps the main line from floating on or near the water surface, thus reducing the chance of entanglement with boats and fishing gear.

The length of sinking (e.g. nylon) and buoyant (e.g. polypropylene) rope required to rig a catenary curve mooring depends on the deployment depth, the length of the catenary curve, the weight of the nylon rope and the buoyancy of the polypropylene rope used. Table 7 summarises the rope lengths required for FADs deployed with 16 mm rope from 50 m to 3,000 m depths.

Hardware

Hardware (swivels and shackles) has been identified as one of the weak points of anchored FADs across the region. As a result, there has been a shift away from the extensive use of hardware connectors, with a preference to splice or use knots for the connections between ropes (Figure 24). This has been aided by the increased availability of multistrand rope (which does not require the use of a swivel between the upper floatation and the main line). If three-strand rope is used, a swivel is required in the connection between the upper floatation and mooring system (e.g. see insert in Indo-Pacific design, Figure 6).

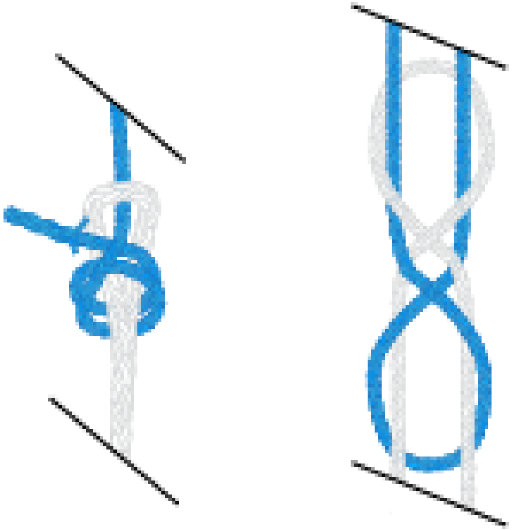


Figure 24. Diagram showing three options for connecting nylon and multistrand rope (left – double sheet bend; middle – monofilament carrick bend; right – splice).

Supplementary buoyancy

Supplementary buoyancy is required for FADs deployed in depths less than 1,500 m to lift the 3 m anchor chain and rope clear from the seabed to reduce the possibility of entanglement with any rocks or other substrate. The buoyancy and positioning of the supplementary floats is dependent on the deployment depth. Table 7 shows the total amount of buoyancy required, which can be made up by using multiple floats. For example, 21 L supplementary buoyancy can be made up of 2 x 11 kg buoyancy floats. It is important that the supplementary buoyancy floats have the appropriate working depth (which can be calculated from Table 7, column 5). It is recommended that centre-hole pressure floats, with a working depth twice their depth position, are used for supplementary buoyancy.

When rigging supplementary buoyancy, splice each float on a separate rope to the main line rope (Figure 25). It has been found that, due to the constant friction of the float against the main line, the supplementary buoyancy can damage it. The main line rope can be encased in plastic tubing and whipped, prior to the supplementary buoyancy being spliced to the mooring (as per Figure 19).

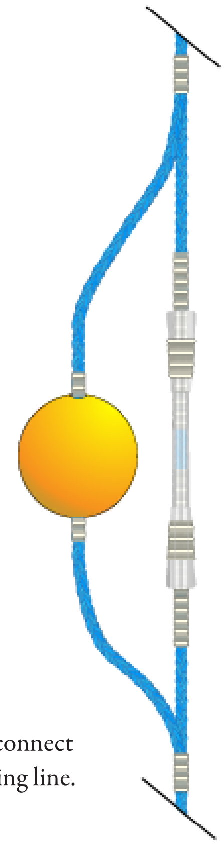


Figure 25. Diagram showing how to connect supplementary buoyancy to the mooring line.

Scope

As anchored FADs are anchored at one point, the upper floatation can swing around the anchor point in a circle, depending on tides and currents. The radius of this circle is referred to as the scope (Figure 26) and depends on the deployment depth and the total mooring lengths. The scope of a FAD is required for navigational purposes, particularly for offshore FADs, and the scope is usually required by maritime authorities, along with the FAD's deployment location. Scope is also important when deploying close to a coastline, as the gradient of the coast from the shoreline to the FAD anchor point may mean the sea floor ends up within the scope of the FAD, resulting in entanglement of the mooring line.

Scope is calculated using the depth and total rope length as:

$$\text{scope} = \sqrt{(\text{total rope length}^2 - \text{depth}^2)}$$

Table 7 provides the scope for different deployment depths using combination mooring system.

Where deployment is close to coastlines or where fishers use deep drop-stone fishing methods, the scope can be reduced by reducing the recommended additional length of rope down from 25% (as per Table 7) to 15% or 10%.

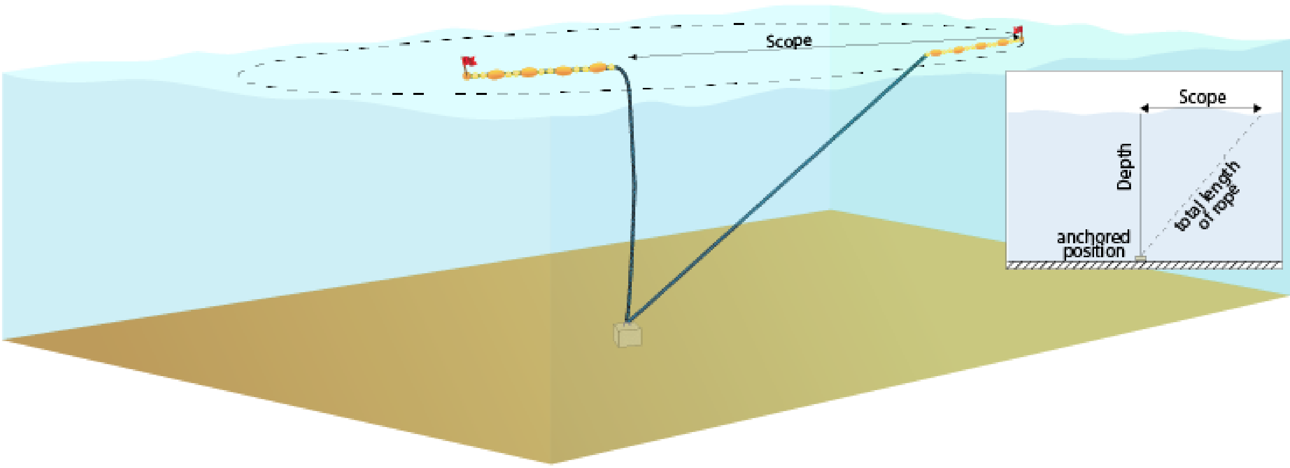


Figure 26. Diagram showing a FAD's scope.

Table 7. Rope lengths needed for FAD site depths from 50 m to 3,000 m.

Depth*	Total length of rope (m): Site depth + 25%	Length of nylon rope (m)	Length of polypropylene rope (m)	Minimum supplementary buoyancy (litres)	Distance of float from sea floor	Scope (m) radius from anchor
50	65	20	45	21	3–13	42
100	125	40	85	21	7–37	75
150	190	60	130	20	40–70	117
200	250	80	170	20	68–98	150
250	315	100	215	19	100–130	192
300	375	120	255	18	132–162	225
350	440	140	300	18	164–194	267
400	500	160	340	17	196–226	300
450	565	235	330	17	228–258	342
500	625	245	380	16	260–290	375
550	690	255	435	15	292–322	417
600	750	265	485	15	324–354	450
650	815	270	545	14	356–386	492
700	875	280	595	13	385–415	525
750	940	290	650	13	428–458	567
800	1,000	300	700	12	470–500	600
850	1,065	310	755	11	513–543	642
900	1,125	320	805	11	555–585	675
950	1,190	325	865	10	598–628	717
1,000	1,250	335	915	9	640–670	750
1,100	1,375	355	1,020	8	725–755	825
1,200	1,500	375	1,125	6	810–840	900
1,300	1,625	390	1,235	5	895–925	975
1,400	1,750	410	1,340	3	980–1,010	1,050
1,500	1,875	430	1,445	2	1,065–1,095	1,125
1,600	2,000	445	1,555	NO SUPPLEMENTARY BUOYANCY REQUIRED		1,200
1,700	2,125	465	1,660			1,275
1,800	2,250	485	1,765			1,350
1,900	2,375	500	1,875			1,425
2,000	2,500	520	1,980			1,500
2,100	2,625	540	2,085			1,575
2,200	2,750	555	2,195			1,650
2,300	2,875	575	2,300			1,725
2,400	3,000	595	2,405			1,800
2,500	3,125	610	2,515			1,875
2,600	3,250	630	2,620			1,950
2,700	3,375	650	2,725			2,025
2,800	3,500	665	2,835			2,100
2,900	3,625	685	2,940			2,175
3,000	3,750	705	3,045			2,250

* if deployment depth is in between, always use the deeper depth

4.3 Anchor technical considerations

In the past, massive cement block anchors were used for anchored FADs to ensure their holding power, even under intense waves and currents. These blocks were extremely heavy and required a large boat and winch for safe deployment. Over the past decade, the evolution of anchor system design has been driven by the need to find more cost-effective designs to enable deployment by small boats and in remote island locations.

Despite the desire for lighter anchors, anchor weight remains important and is dependent on the buoyancy of the upper floatation section of the FAD and the deployment depth. The anchor weight needs to be calculated so that the upper floatation cannot lift it, nor can the anchor slip on the seafloor as a result of current. As a rule, anchor weight (when in the water) should be at least three times the buoyancy. This is particularly important for sub-surface and offshore FADs (deployed at deeper depths). Nearshore FADs (<500 m depth) can have a reduced anchor weight (equivalent to buoyancy) if combined with a danforth or grapnel anchor.

4.3.1 Anchor types

FAD anchors can be made from a variety of materials, including concrete, steel or sandbags. Different types of anchors perform better than others, depending on a number of factors, including slope, bottom substrate and water depth. Other factors can also influence anchor choice, such as availability and small boat deployment. Common anchors used in the region are described below and Table 8 provides an overview of the recommended anchors to use, based on different parameters.

Table 8. Recommended anchor types for different parameters (green = optimal; blue = sub-optimal; orange = ok, but not recommended; red = not appropriate).

	Anchor type						
	Large cement block*	Dual half drum	Smaller cement blocks	Sand bags	Danforth anchor	Grapnel	Reused steel
Steep slope	optimal (with gripping anchor)	sub-optimal (with rebars stabilisers)	optimal	sub-optimal (if sandy bottom)	optimal	not appropriate (unless rocky bottom)	optimal (with gripping anchor)
Coral/rocky bottom	optimal	optimal	optimal	not appropriate	not appropriate	optimal	optimal
Sand/mud bottom	optimal	optimal	optimal	optimal	optimal	not appropriate	optimal
Deep depth	optimal	sub-optimal	optimal	ok, but not recommended	optimal	not appropriate	optimal
Small boat deployment (min 23 ft)	ok, but not recommended (max 500 kg)	ok, but not recommended	sub-optimal	ok, but not recommended	optimal	optimal	ok, but not recommended (max 500 kg)
Ease of safe deployment*	ok, but not recommended	ok, but not recommended	ok, but not recommended	ok, but not recommended	optimal	optimal	ok, but not recommended

* Safe deployment possible for all anchors using a small barge (see section 5.3 Small barge deployments)

Large cement block

Large cement blocks are wide (typically 1.2 m x 1.2 m x 0.6 m), made with the correct mix of concrete, sand, aggregate and water (Image 2). The cement blocks are constructed with internal reinforcing and a steel anchor attachment point. Large cement block anchors are strong and heavy (underwater weight ~1120 kg) giving them a high holding power, even at deeper deployments. Cement anchors require 30 days' curing time before they can be deployed. Due to their size and weight, large boats with a crane or winch are required for deployment.

Image 2. Large cement block anchor being lifted by crane for deployment.

Dual half drum

The dual half drum anchor is constructed from a clean petrol drum cut in half and filled with cement (Image 3). Re-bars inserted through the sides of the drum act like stabilisers to stop them rolling if deployed on a slope. Using two drums (that are connected) reduces the weight of each individual drum, enabling the anchors to be lifted using a lift bar, rather than a crane or winch, although they remain quite heavy, so care must be taken when lifting. Prior to deployment, the two drums are connected using galvanised chain, and 30 days' cure time is also required for this anchor.

Image 3. Dual drum anchor showing the internal set-up (left) and prior to being deployed (right).

Small cement blocks

Small cement blocks follow the same concept of the large cement block design, except that the blocks are significantly smaller (~50 kg). Being smaller and lighter, they can be lifted by two people using a lift bar and can be deployed from small boats. The small cement blocks are joined with galvanised chain. Care needs to be taken in deployment to ensure that they are deployed as one unit. These anchors are usually deployed using a deployment table (Image 4). Ensure that the total number of blocks required for one FAD will fit onto the table.

Image 4. Anchor deployment table on a small boat showing multiple small cement blocks attached in series.

Danforth and grapnel anchor

Danforth and grapnel anchors are generally used as supplementary FAD anchors to increase the holding capacity and reduce the weight of the main anchor block (Image 5). Danforth anchors are a common, general-use fluke type anchor. They perform best in mud or sand, where the fluke digs into the sea bed and has strong holding power (20:1 weight to holding power ratio in sand and 9:1 in mud). A 25 kg danforth anchor is usually used, which has an equivalent holding power of ~500 kg in sand.

Grapnel anchors are light-weight anchors that can provide additional holding strength on certain substrates. These anchors perform best on rocky substrates, where one or multiple flukes grip the rock. The grapnel anchor does not perform well in sand or mud, as there is nothing for the anchor to grip onto. Grapnel anchors can be constructed by inserting and bending lengths of re-bar through a steel pipe and cementing them in place.

Image 5. A 25 kg danforth anchor (left) and a constructed grapnel anchor (right).

Recycled steel anchor

Anchors can be made from recycling old disused steel (e.g. engine blocks) that are located close to the proposed FAD deployment location. Such items are common across the Pacific, particularly in locations with limited refuse options. Due to the high density of steel, these anchors are lighter in air and often smaller than cement anchors. While recycled steel anchors significantly reduce the cost of a FAD, care must be taken to ensure that old engines are depolluted prior to deployment to avoid oil contamination. The calculation of anchor weights can also be a challenge (see 4.3.2 Anchor weight calculations).

Image 6. Anchor constructed from a recycled engine block.

Ultimately, the choice of anchor, or combination of anchors, will depend on a number of factors and different anchor types will perform better than others under different scenarios. Table 8 provides a guide on the performance of different anchors under different parameters.

Sandbag anchor

Sandbag anchors can be an option for FADs in remote locations where cement is not available and transport options are minimal. Bags are filled with sand, weighing ~20 kg each bag. The anchor is then made up of a series of connected sandbags (Image 7). Due to the low density of sand, the overall weight in air of all sandbags combined is much greater than cement anchors. Sandbag anchors are effective on sand but can be damaged quickly on rocky substrates. The Vatuika FAD design uses sandbags that have been specifically developed in Japan, using materials that are more resistant to decay.

Image 7. Anchor constructed from sandbags.

4.3.2 Anchor weight calculations

The weight of an anchor in the water is subject to Archimedes' principle, which states: *"an object immersed in a fluid is subjected to an upward force equal to the weight of fluid it displaces"*. This principle dictates whether an object sinks or floats and means that the weight of an anchor *under water* is less than its weight in air. The density of the materials the anchor is made of dictates the weight of fluid displaced and therefore its weight in water.

With the evolution of different materials being used for FAD anchors and different combinations of floats for the FAD upper floatation, FAD technicians need to be able to accurately calculate the weight of anchor required.

Based on Archimedes' principle, the underwater weight of an anchor can be calculated using the following formula:

$$\text{anchor weight}_{(in\ water)} = \text{anchor weight}_{air} \times (\rho_{anchor} - \rho_{seawater})/\rho_{anchor}$$

(where ρ=*density*) and the density of seawater is 1025 kg/m^3. The approximate density of common anchor types is provided in Table 9.

Table 9. Approximate density of common anchor materials.

Anchor material	Density (kg/m^3)
Cement (varies, based on sand: gravel: cement ratio)	2,330
Steel	7,800
Sand	1,600

Note: If the anchor weight in air is unknown, it can be calculated by the anchor's volume and density using the equation:

$$mass = volume_{anchor} \times \rho_{anchor}$$

Example 1:

A cement block is 1.2 m wide x 1.2 m long x 0.6 m high. The density of cement is ~2,330 kg/m^3.

$$\begin{aligned} mass &= volume_{anchor} \times \rho_{anchor} \\ \text{anchor weight}_{air} &= (1.2\ m \times 1.2\ m \times 0.6\ m) \times 2{,}330\ kg/m^3 \\ &= 0.864\ m^3 \times 2{,}330\ kg/m^3 \\ &= 2{,}013\ kg \end{aligned}$$

$$\text{anchor weight}_{in\ water} = \text{anchor weight}_{air} \times (\rho_{anchor} - \rho_{seawater})/\rho_{anchor}$$

$$\text{anchor weight}_{in\ water} = 2{,}013 \times (2{,}330 - 1{,}025)/2{,}330$$

$$\text{anchor weight}_{in\ water} = 2{,}013 \times 0.56 = 1{,}128\ kg$$

Example 2:

Two half petrol drums, filled with cement. A petrol drum is 0.8 m high (so half a drum is 0.4 m high) and the inside drum diameter is 0.57 m.

$$\begin{aligned}
\text{Drum volume} &= \text{Volume of a cylinder} = \pi r^2 h \\
&= \pi \times 0.285^2 \times 0.4 \\
&= 0.1\ m^3 \\
\text{anchor weight}_{air} &= (\pi \times 0.285^2 \times 0.4) m^3 \times 2{,}330\ kg/m^3 \\
&= 237\ kg\ (\text{per half drum}) \\
\text{anchor weight}_{in\ water} &= 237 \times (2{,}330 - 1{,}025) / 2{,}330 \\
\text{anchor weight}_{in\ water} &= 237 \times 0.56 = 132.7\ kg\ (\text{per half drum})
\end{aligned}$$

Example 3:

Calculation of recycled steel anchor

For the example of recycling an old steel engine block, the first step is to calculate the volume of the block, excluding the empty space (Figure 27). For example, an engine block is 1.2 m x 0.6 m x 0.5 m. It has six internal 'empty' cylinder spaces (0.6 m long, 20 cm in diameter). The volume of the block is 1.2 x 0.6 x 0.5 = 0.36 m^3. The volume of one cylinder is π x 0.012 x 0.6 = 0.019 m^3, so six 'empty' cylinders have a volume of 0.113 m^3. The total volume of the engine block is equal to 0.36 m^3 – 0.113 m^3 = 0.247 m^3.

$$\begin{aligned}
\text{Anchor weight}_{air} &= 0.247\ m^3 \times 7{,}800\ kg/m^3 \\
&= 1{,}926\ kg \\
\text{Anchor weight}_{in\ water} &= 1{,}926 \times (7{,}800 - 1{,}025) / 7{,}800 \\
&= 1{,}926 \times 0.87 = 1{,}672\ kg
\end{aligned}$$

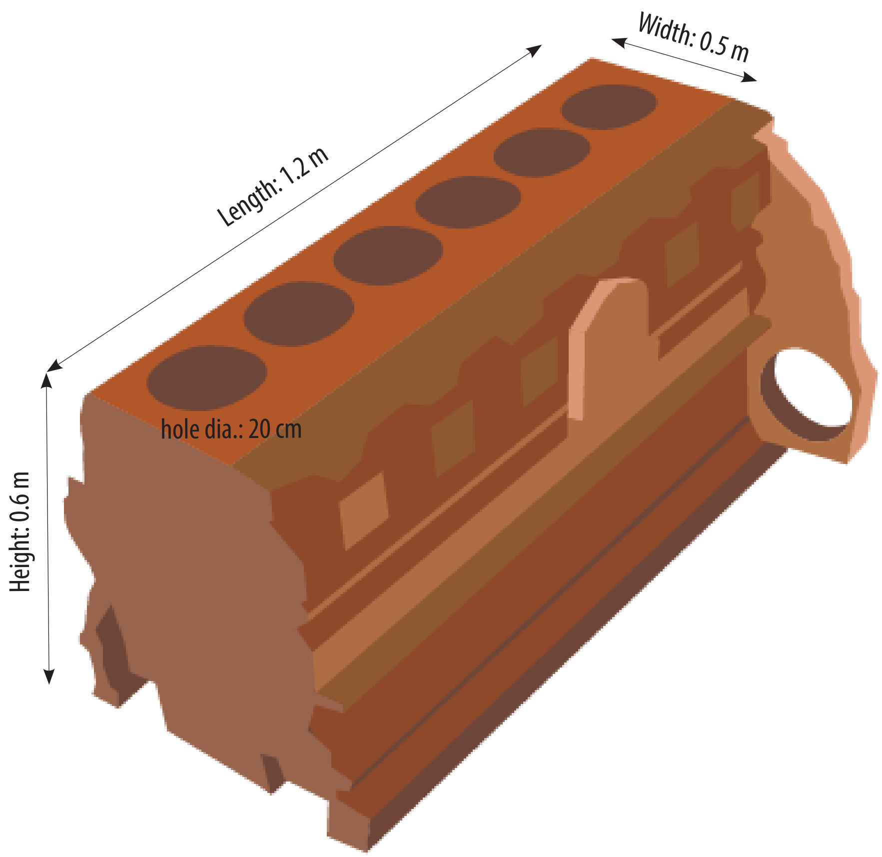


Figure 27. Example of calculating the volume of a recycled steel engine block anchor.

4.3.3 Anchor chain

Galvanised steel chain (16 mm) connects the anchor system to the main line. FADs that use a standard single block anchor with an additional danforth/grapnel anchor require 10 m of chain: 3 m above the anchor block (between the anchor and the main line rope) and 7 m between the anchor block and the gripping anchor.

If multiple (9) small blocks are used, a total of 10 m of chain is required: 3 m above the first block with 0.5 m between blocks and 3 m between the end block and the danforth anchor

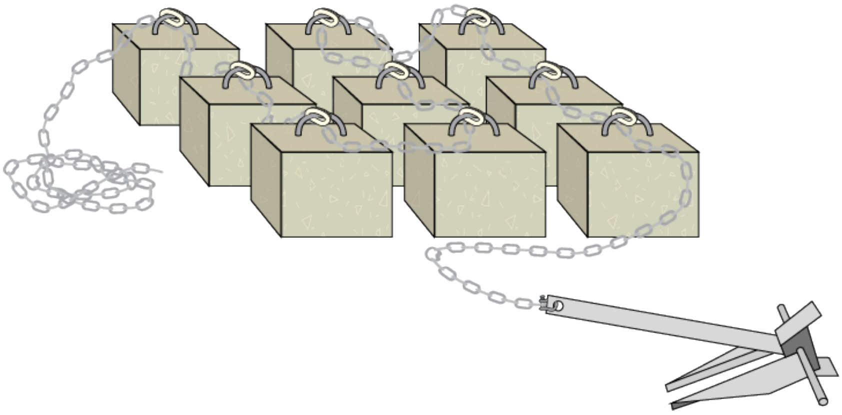


Figure 28. Diagrammatic representation on connecting multiple small blocks with galvanised chain.

4.3.4 Anchor chain and anchor block connections

The anchor chain is connected to the main line using a shackle and swivel (Figure 29). The swivel allows the rope to move with the current without twisting, while the chain prevents the rope getting tangled and rubbing against the anchor block. When attaching the main line to the swivel, ensure that the main line rope is protected from chafing by: whipping the main line rope along the section that goes through the swivel (Figure 29, left); encasing the rope in plastic tubing (Figure 29, centre); or using a thimble (Figure 29, right). The connection between the main line rope and swivel should be tight to restrict movement and chafing.

The swivel is then attached to the galvanised chain with a shackle. FAD technicians have experienced corrosion of the stainless-steel shackle locking pins, which can come loose. The locking pin should be secured by tying galvanised wire or thin rope through the eyelet of the locking pin and attaching that to the shackle, or spoiling the thread so that the locking pin does not come out.

The anchor chain is then connected to the anchor attachment point using a shackle. In the case of a cement block anchor, ensure that the steel rod used for the attachment point in the anchor is small enough for the chain and shackle to attach.

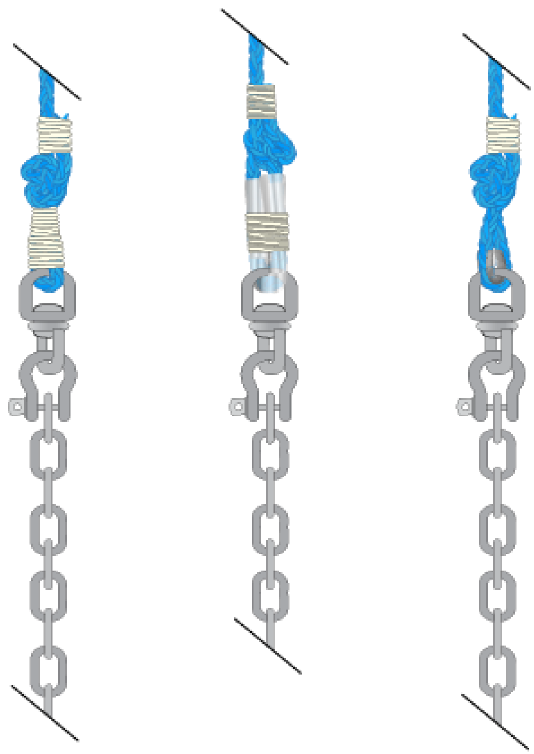


Figure 29. Anchor to main line rope connection.

4.3.5 Anchor weights for standard FAD designs

As described above, careful calculations are required to ensure that the anchor weight is sufficient to hold the total buoyancy of the FAD. The anchor weight (in water) should be at least three times the total buoyancy. However, due to safety concerns with lifting heavy anchors and the need to deploy FADs from small boats, when possible it is recommended to use supplementary techniques that mean the main anchor weight can be reduced.

Supplementary danforth anchors can be used for nearshore environments to enable a reduction in anchor weight. Danforth anchors have a holding power to weight ratio of 20:1 in sand and it is assumed that most of the substrates where FADs are deployed are sandy. In such circumstances, a 25 kg danforth anchor has an equivalent holding power of ~500 kg.

Table 10 provides the buoyancy, minimum anchor weight requirements, with and without using supplementary danforth anchors.

Table 10. Upper floatation buoyancy and anchor weights required for standard FAD designs (as per designs in this manual) with and without the use of a 25 kg supplementary danforth anchor.

		Bamboo (advanced)	Indo-Pacific (nearshore < 500 m)	Indo-Pacific (offshore)	Sub-surface	Lizard	NSW DPI (deep)
Buoyancy	Purse seine	-	5 x 7 kg	14 x 7 kg	-	4 x 7 kg	-
	ABS floats	1 x 24 kg, 1 x 11 kg	6 x 20 kg	15 x 20 kg	5 x 20 kg	8 x 20 kg	-
	Bamboo	3 x 3 m lengths (15 cm dia) or 50 kg buoyancy per 3 m length	-	-	-	-	-
	Special Mark (800 mm)	-	-	-	-	-	100 kg
Total buoyancy		155 kg	155 kg	398 kg	100 kg	188 kg	100 kg
Anchor weight without supplementary Danforth							
Minimum (in water) anchor weight (3 x buoyancy)		**465 kg**	**465 kg**	**1,194 kg**	**300 kg**	**564 kg**	**300 kg**
Anchor options (weight in air)	Cement	830 kg	830 kg	2,132 kg	535 kg	1,007 kg	535 kg
	Steel	530 kg	530 kg	1,372 kg	345 kg	648 kg	345 kg
	Sand	1,290 kg	1,290 kg	3,316 kg	833 kg	1,567 kg	833 kg
Anchor weight with supplementary 25kg Danforth							
Minimum (in water) anchor weight		**155kg (plus Danforth)**	**155kg (plus Danforth)**	Anchor weights can be reduced with these FAD designs when using a supplementary danforth anchor. The reduction in anchor weight is, however, dependent on deployment depth and sea conditions (current, swell, etc.). FAD technicians need to take this into consideration and use their best judgement when reducing anchor weight for these FAD designs.			
Anchor options (weight in air)	Cement	280 kg (plus danforth)	280 kg (plus danforth)				
	Steel	180 kg (plus danforth)	180 kg (plus danforth)				
	Sand	430 kg (plus danforth)	430 kg (plus danforth)				

5 Safe FAD deployments

5.1 FAD deployment location and bathymetric surveys

The location of a FAD deployment can ultimately influence the effectiveness of the FAD to attract and maintain an assemblage of pelagic fish. PICTs across the region will use different strategies and priorities to select the general area in their countries where FADs are deployed. This manual focuses on providing recommendations on selecting the actual FAD deployment location. While it is recognised that FADs deployed further offshore are more likely to aggregate large pelagic fish, well-placed nearshore FADs can also aggregate pelagic species, although smaller fish, such as skipjack tuna and bonito are usually aggregated. One of the most common, often overlooked, mechanisms in the FAD deployment location selection process is the involvement of local fishers or fisher associations. Discussions with fishers and communities prior to the selection of FAD deployment location can increase fisher and community ownership and enhance the identification of a more productive location (and thus effective FAD) through their local knowledge of ecological conditions favourable for pelagic fish.

A suitable FAD deployment location is one that is;

- physically suitable: favourable bathymetry such as flat or slight slope, with moderate currents;
- ecologically suitable: known presence of pelagic fish, or pelagic fish movement near the location; and
- accessible: fishers have suitable vessels and skills available to safely access and fish the FAD.

Nearshore FAD deployments should avoid deploying close to a river mouth, as the low salinity environment around rivers adversely affects tuna aggregations.

Bathymetric surveys using an echo sounder and the production of a bottom contour map are essential for the identification of a suitable physical location for a FAD. The detailed method for conducting bathymetric surveys and producing a contour map to guide FAD site selection can be found in the SPC 2005 FAD manual (Chapman et al. 2005). FAD sites that are less than 1,000 m can use a 1 kw echo sounder, while a 3 kw/28 khz sounder is required for deeper depths.

In general, it is recommended that FADs be deployed where the bottom contour is flat or slopes gently, far away from pinnacles or steep drop-offs. Some PICTs, however, have an unavoidable issue with slope and have limited options.

In such situations, the following can provide further guidance:

- try to retain slope to less than 30°;
- a small shelf can sometime be identified through bathymetric surveys of the seafloor that can be targeted for the anchor deployment site;
- ensure that extensive bathymetric surveys are undertaken and GPS locations of the best

possible location are accurately recorded;
- undertake bathymetric surveys and deployment on slack tide (peak of high or low tide) for more accurate deployments;
- use a grapnel or danforth anchor in addition to a block-type anchor to provide additional holding power;
- ensure the best possible weather and current conditions for deploying the FAD; and
- deploy the FAD at the same slack tide when the bathymetric survey was undertaken (high or low).

5.2 Small boat deployments

FAD deployments from small boats are becoming more common across the region due to limited availability / high cost of large vessels and the deployment of FADs in remote locations. Deployment from large vessels can also reduce deployment accuracy. While the trend to small boat deployments contributes to more widespread fisher access to FADs across the region, it is essential to ensure that deployments are conducted as safely and efficiently as possible. Safe FAD deployments from small boats (recommended to be larger than 23 ft) are possible, but some precautions should be undertaken to enhance safety using small boats.

1. Restrict anchor weight to 500 kg (deployment depths to 500 m).
2. Ensure the boat is stable and equipped with a GPS and echo sounder.
3. Position the anchor, anchor chain, main line rope and upper floatation appropriately in the boat to prevent entanglement (see 5.2.1 Pre-deployment layout arrangements and Chapman et al. (2005) for guidance).
4. Limit the number of personnel in the deployment boat to only those who are trained and essential for the deployment. (An additional vessel can be used to transport other people interested in watching the FAD deployment but they must be given clear instructions on where the vessel can be located once at the deployment site).
5. Prepare a pre-deployment plan and conduct a pre-deployment briefing to ensure that all crew are aware of the deployment plan and their role.
6. Use safe heavy lifting techniques for moving the anchor to the boat (e.g. lifting posture and using lift-bars). Image 6 above shows the use of steel pipe lifting bars on an engine block, enabling more people to share the weight of the anchor.
7. Deploy the FAD during calm seas on a slack tide.

5.2.1 Pre-deployment layout arrangements

The boat must have the anchor system in a position where it can be easily deployed while maintaining stability of the boat. The floatation and ropes should be loaded on board in a location that makes it easy and safe to deploy and avoid rope entanglement. On small boats, where space is limited, ropes can be either be flaked on the deck of the boat (when two boat deployments are used – see 5.2.3), or into a drum (Image 8). Ensure that flaking of ropes starts with the bottom of the mooring line, and begin with large loops (or figures of eight) at the base of the deck, becoming consistently smaller as the rope is flaked onto the deck. This prevents rope entanglement during deployment.

Image 8. Pre-deployment layout of ropes when using small boat deployments.

5.2.2 Onboard anchor platform

Onboard anchor platforms can be used to ease the deployment of anchors from small boats. The platform spreads the weight of the anchor across the boat to enhance stability of the boat during transport to the deployment location. The platform needs to be secure in the boat; this can be achieved by ensuring it is wider than the boat and timber blocks are attached under the platform, running down the outside of the boat gunnel. Ensure that the platform is also supported in the centre, by constructing a simple timber structure that fits within the boat. During deployment, one side of the platform is lifted with lift-bars and the anchor slips off the platform. Onboard anchor platforms can be used for different anchor types, e.g. single large blocks or multiple small blocks (Image 9).


Image 9. An onboard anchor platform showing two different designs.

5.2.3 Two-boat deployments

Small boat FAD deployments often use two boats due to the limited deck space. In this situation, one boat contains the anchor system, while the other contains the upper floatation and main line rope. During two-boat deployments, ensure that the upper floatation is deployed first, prior to connecting and deploying the anchor.

5.2.4 Anchor-first deployments

Anchor-first deployments are generally not recommended for deploying FADs, as they are higher risk and require trained FAD technicians. Anchor-first deployments may, however, be required when anchoring on a slope to enhance deployment accuracy. The deployment technique for anchor-first deployments should follow sub-surface FAD deployment techniques as outlined below in 5.4.2 Sub-surface and lizard FAD deployment sequence.

5.3 Small barge deployments

Deploying FADs using a small barge originated in French Polynesia as a mechanism for safe deployment of FADs in remote islands and is rapidly gaining traction across the region (Image 10 Figure 30 Diagram of the French Polynesia small barge). While the initial upfront construction costs for the barge are high, small barge deployments in remote locations can be a viable option for deploying FADs, including FADs that require a heavy anchor system, such as offshore FADs. The barge has been specifically designed with a sloped platform where the anchor is secured prior to deployment. Care must be taken to ensure that the anchor is secured well during transport, to ensure it does not prematurely slip into the ocean.

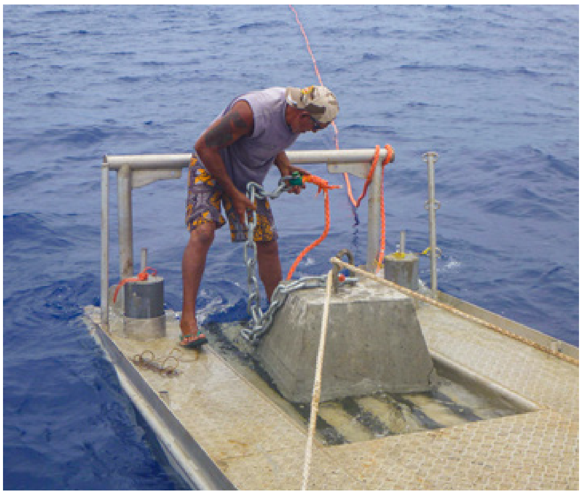


Image 10. Using the French Polynesia small barge for anchor deployment.

The barge, containing the anchor system, is towed by a smaller vessel to the FAD deployment site, while the upper floatation and main line rope are positioned in the vessel towing the barge. At the deployment location, the upper floatation and mooring system are deployed first, prior to connecting the main line with the anchor system. Once in position, the anchor is then deployed by simply releasing the ropes securing it in the barge.

For further details and the specifications for the small barge design, contact the FAD Program Manager, French Polynesia, Department of Fisheries and Marine Resources.

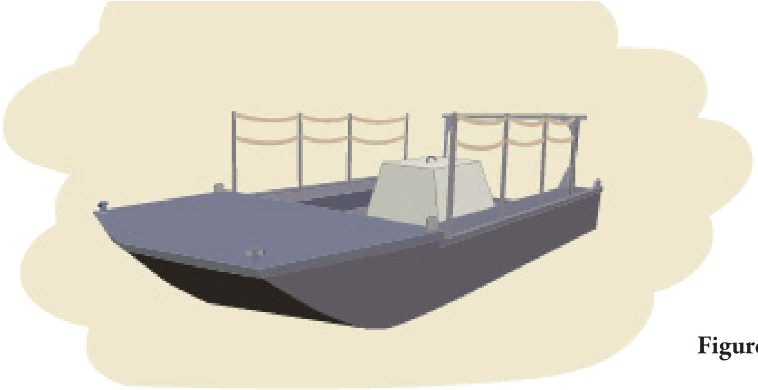


Figure 30. Diagram of the French Polynesia small barge.

5.4 Deployment techniques

All FADs should be deployed during optimum conditions when seas are calm and there is no wind (usually early morning). Websites and apps such as windy (www.windy.com) provide wind and wave forecasts that can aid in deployment planning. Unfortunately, even with the best planning, weather can change, and it may be safer to deploy the FAD rather than return to shore. Under these circumstances, ensure that the boat is side on with the waves and use a hairpin deployment method (see 5.4.1 Surface FAD deployment sequence). Another common issue sometimes faced is that, while planned for daylight hours, due to unforeseen circumstances, deployments end up as night deployments. While it is not recommended to deploy FADs at night due to safety issues, light sticks can be placed on the polypropylene rope to enable you to see the rope during deployment.

5.4.1 Surface FAD deployment sequence

Surface FAD deployments should follow the sequence described below.

1. Motor to the deployment GPS location, keeping an eye on the echo sounder to ensure you are within the planned deployment depth, and place the upper floatation into the water.
2. Motor the vessel in either a circle or hair-pin bend (Figure 31) until the boat is back to the deployment location, while feeding out the main line. This will help ensure that the boat does not become entangled with the ropes.
3. Once back at the deployment location, confirm that the GPS location and depth are correct and drop the anchor.

Circle and hair-pin deployments should always be conducted to ensure that the boat is headed in the direction of shallower waters/land. This will ensure that the anchor, which takes time to reach the bottom, does not end up in deeper waters, resulting in submersion of the upper floatation.

Surface FADs can also be deployed by straight line techniques, following the same approach of first deploying the upper floatation section, feeding out the main line and finally the anchor. Straight-line deployments are usually done in one of two ways.

1. Heading the boat into the current (and along the contour line if required) – the upper floatation is placed in the water when the boat is about two-thirds of the main line distance away from the deployment location. The main line rope is then fed into the water while heading towards (and past) the deployment location. Once the boat is one-third of the main line distance past the deployment location, the anchor is dropped.
2. Running the boat from shallow to deep water – the upper floatation is placed in the water when the boat is about four-fifths (80%) of the main line distance away from the deployment location. The main line rope is then fed into the water while heading towards (and past) the deployment location. Once the boat is one-fifth (20%) of the main line distance past the deployment location, the anchor is dropped.

The disadvantage of straight-line deployments over hair-pin or circle deployments is that the main line rope is pulled through the water during anchor deployment and the upper floatation system is often pulled to deep depths, prior to resettling on the water surface.

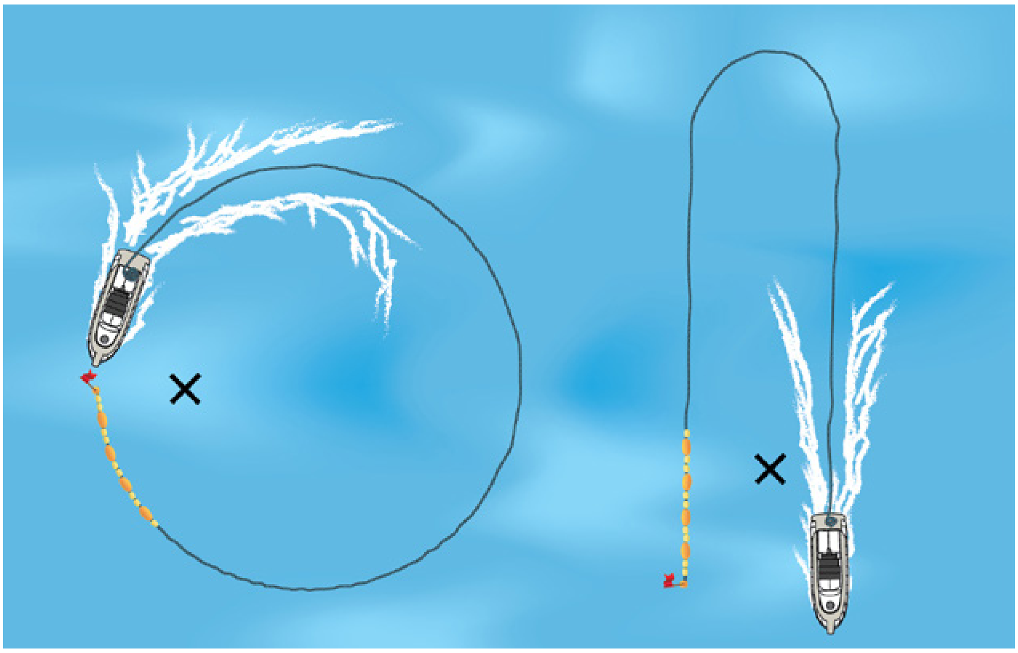


Figure 31. Circle and hair-pin deployment techniques. The cross (X) represents the intended final anchor location.

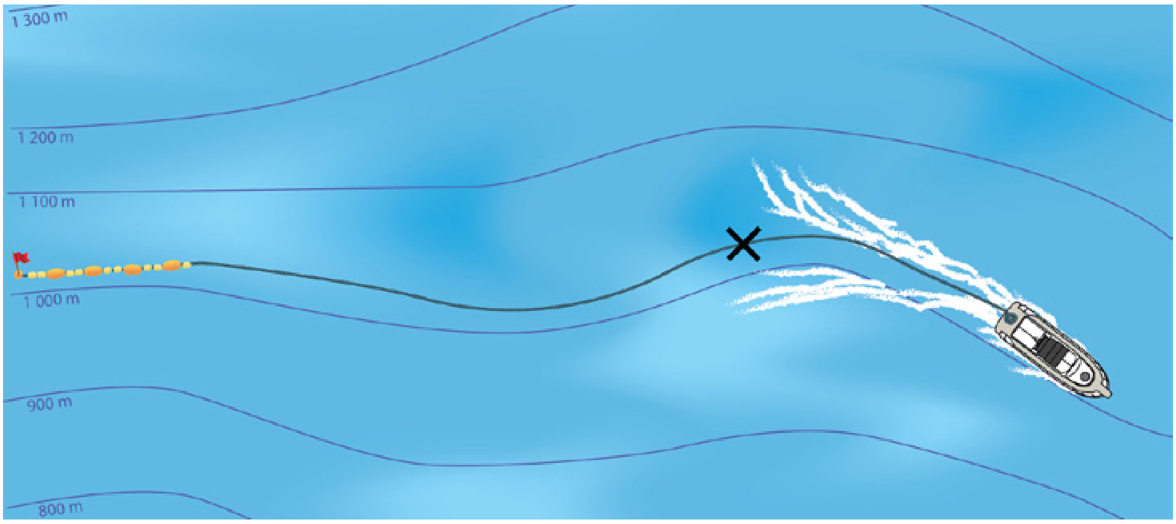


Figure 32. Straight line/contour deployment technique. The cross (X) represents the intended final anchor location.

5.4.2 Sub-surface and lizard FAD deployment sequence

Sub-surface and lizard FAD deployments follow a slightly different deployment sequence to ensure that the top of the upper floatation ends up at the correct depth (i.e. 20 to 40 m below the surface). The sequence is described below.

1. Motor the boat towards the deployment location and follow the deployment depth contour line, using the echo sounder.
2. When the boat is two times the depth away from the deployment site, release the main line (attach the end of the float line on the boat bollard on the opposite side of the boat to the anchor).
3. Continue to follow the contour line and once you are ¼ depth distance beyond the deployment mark, drop the anchor. Once the anchor tugs a little, release the floats into the water.
4. If the subsurface FAD is going to have a marker float attached, retain the marker float and messenger line in a drum on board and allow the messenger line to pay out (retaining the end of the messenger line attached to the boat). Once the anchor and floatation have settled, motor the boat above the FAD and measure out about 5 m of additional rope, attach the float/flag and place it in the water.

The lizard FAD follows the same principle but the lizard tail, i.e. the surface floatation, remains on board and is connected after the messenger line (16 mm nylon rope) is paid out. Ensure that the messenger line remains attached to the boat prior to attaching the surface floatation.

Figure 33. Sub-surface and lizard FAD deployment technique. The cross (X) represents the intended final anchor location.

5.5 Safety considerations for FAD deployments

Responsibility for safety lies with the FAD deployment teams, which should always use trained FAD technicians. FAD deployments often involve community members and fishers and, while it is important to retain community and fisher interest and involvement in deployments, this can lead to difficult scenarios and safety challenges. Ensure that the untrained personnel are involved in the pre-deployment briefing so they are aware of the safety risks and where their boats should and should not be located during FAD deployment. Request all unnecessary personnel to remain in a separate vessel and try to minimise the number of additional vessels at the deployment location. It is particularly important to ensure that these personnel remain out of the way of the anchor and ropes and understand the risks involved.

5.5.1 Safety checklist for FAD deployments

Ensure a clear pre-deployment procedure briefing outlining the deployment plan, individual roles and safety for onlookers.

Ensure that a sturdy boat is used for deployment (wide hull, or outrigger floats) and the anchor is secured during transit to the deployment location.

Plan deployments for suitable weather and do not hesitate to postpone if seas are rough or conditions unstable.

Minimise the number of people in the deployment vessel to those essential for the deployment.

Equip each crew member with a knife (in case of entanglement in rope during deployment) and ensure that the boat is equipped with a safety kit.

Have an emergency response system in place, for 'just in case'.

Safety kit essentials

1. First aid kit
2. Safety clothing for all crew (leather gloves, knife, high visual shirt/vest, safety shoes)
3. Standard boat safety gear (lifejackets, EPIRB or PLB, spare fuel, engine tools/spares, sea anchor, signalling device, water, bailing device, etc.)
4. Light sticks (in case of late deployments)

6 FAD maintenance and monitoring

Ongoing FAD maintenance and monitoring is essential to the longevity of the device and national FAD programmes as a whole. Despite this importance and the prevalence of anchored FAD deployments across the region, FAD maintenance is often infrequent and there remains a large gap in data and information to identify the outcome of FADs in the context of their desired objective.

6.1 Maintaining FADs

One of the primary ways to retain fish aggregation at a FAD is by using aggregators (see 4.1.5 Aggregators). Aggregators help enhance a FAD's performance by providing additional structures and accumulating algae. This provides an artificial habitat and food source for small fish, which, in turn, attract larger fish. Aggregators, by design, are semi-permanent and require regular replacement.

Anchored FADs are subject to the forces of the ocean (currents, rough seas), salt-water corrosion, entanglement with fishing gear and fouling (i.e. the growth and accumulation of unwanted materials, such as corals and oysters). Ocean forces can cause floats to submerge and implode or split, allowing water into the float; fouling of surface floats and rope increases the weight and resistance on the upper floatation section; entanglement of fishing lines can cut and weaken the main rope line; and salt water can cause corrosion of hardware. Each of these scenarios results in weak points, which can result in the premature loss of the FAD. Problems arising from these weak points can be reduced through regular maintenance and replacement of damaged floats, rope and hardware.

Regular maintenance of a FAD ensures that it continues to aggregate fish and remain in the water for as long as possible. Regular maintenance programmes (recommended monthly) involve lifting the FAD's surface floatation and ropes out of the water and into a boat for inspection and repair. Alternatively, maintenance can be done in the water. FAD maintenance activities should be performed at low tide, when currents are slack, and the most main line is able to be pulled out of the water.

The following are the main aspects to consider during maintenance.

- Inspect surface floats for cracks (replace as required) and remove any fouling material from the floats and ropes.
- Remove fishing line entangled around the ropes.
- Inspect the ropes for any twists, kinks or hockles and cut and resplice ropes if required.
- Inspect surface hardware for corrosion and replace as required.
- Replace aggregators.

Unfortunately, only the upper portion of a FAD (~30 to 80 m) can be maintained, but regular maintenance on this section can increase the longevity of a FAD by many years. FAD maintenance can be performed by the implementing agency (e.g. national fisheries agencies) or by trained fishers / community members or interested groups (e.g. some countries have established partnerships with dive tourism companies). National fisheries agencies are likely to have the equipment to maintain FADs to a greater depth (e.g. using scuba gear and lift bags), but such maintenance techniques should be undertaken only by experienced personnel due to the risks involved.

6.2 Monitoring FADs

Monitoring is the systematic process of collecting, analysing and using data to track how a project (or programme) is progressing towards reaching its objective. FAD monitoring activities should be related to the specific objectives of PICTs' overarching national FAD programmes.

Unfortunately, monitoring activities are funding-dependant and PICTs often do not have or cannot secure the budgets required for extensive monitoring activities. Well-developed FAD catch and effort monitoring, such as that being undertaken in the region by SPC's Tails data entry app, provides a protocol to capture FAD use and frequency, volume, production, value and species harvested (by method). Such programmes require planning and dedicated staff to implement, analyse and report on. At the other end of the scale, simple perception-based monitoring activities (i.e. discussions with fishers to understand their use and fishing patterns) can also provide information for national agencies, but in a less quantitative way. A semi-quantitative guideline for nearshore FAD monitoring in the Pacific Island region has been recently developed and provides a protocol for countries to adapt (Albert et al. 2019).

At a minimum, PICTs need to maintain a FAD registry containing:

- FAD design and type;
- deployment date;
- deployment site, region/area name, latitude and longitude;
- site depth and scope;
- FAD identifiers, markers; and
- status of FAD (when it is lost).

This information is required for reporting to maritime safety authorities (and other authorities as relevant to the country.

References

Albert J.A., Beare D., Schwarz A., Albert S., Warren R., Teri J., Siota F. and Andrew N. 2015. The contribution of nearshore fish aggregating devices (FADs) to food security and livelihoods in Solomon Islands, PLoS One 1-19.

Albert J.A. and Sokimi W. 2016. Sharing Pacific nearshore FAD expertise. SPC Fisheries Newsletter #150.

SPC. 2012. Fish aggregating devices (FADs). SPC Policy Brief 19/2012. Noumea. New Caledonia: Secretariat of the Pacific Community.

Amos G. and Nimoho G. 2015. Vatuika FADs survive category 5 cyclone Pam in Vanuatu. SPC Fisheries Newsletter #147.

Chapman L., Pasisi B., Bertram I., Beverly S. and Sokimi W. 2005. Manual on fish aggregating devices (FADs): Lower-cost moorings and programme management. Noumea. New Caledonia: Secretariat of the Pacific Community.

Notes

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