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MANUAL OF BEST PRACTICES IN FISHERIES THAT USE MOORED FISH AGGREGATING DEVICES (FADs)

A joint activity of the CRFM Pelagic Fisheries Working Group and the CRFM/WECAFC/JICA/Ifremer Working Group on Fisheries that use Fish Aggregating Devices

VOLUME I

FAD DESIGN, CONSTRUCTION AND DEPLOYMENT

December 2015

CRFM Secretariat

Belize

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FAD DESIGN, CONSTRUCTION AND DEPLOYMENT

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VOLUME I – FAD DESIGN, CONSTRUCTION AND DEPLOYMENT

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FOREWORD

It has been more than three decades since initial experimentation with the use of moored fish aggregating devices (FADs) in the Caribbean region. The main driver for development of FAD fisheries has been the need to reduce fishing costs, increase fishing efficiency, to improve fishers' livelihoods as well as national food security and to reduce fishing pressure on over-exploited coastal resources. However, the development of these fisheries in the region has been influenced by the socio-economic and bio-physical conditions of the respective countries.

This manual on Best Practices in FAD Fisheries Management is being developed as a collaborative effort among the CRFM, the Caribbean Fisheries Co-management Project (funded by the Japan International Cooperation Agency - JICA), the French Institute for Exploitation of the Sea (Ifremer) and the Western Central Atlantic Fishery Commission (WECAFC). These institutions are partners of a regional working group on FAD fisheries that was established at the 15th Session of the WECAFC and during the period 2014 to 2016 is being led by the CRFM. The impetus for development of the manual originated from the recommendations of a joint meeting of the respective institutions in December 2013, in St Vincent and the Grenadines, which were put forward to the 15th Session of the WECAFC. This task was explicitly included in the Terms of Reference of the Working Group and in June 2015 the CRFM convened a Write-Shop on FAD Fisheries Management to advance development of the manual. The manual is being published in five separate volumes addressing interests related to FAD design, construction and deployment, maintaining the quality of FAD-caught fish, fishing and business strategies for sustainable anchored FAD fisheries, safety and working conditions of FAD fishers and governance of FAD fisheries. It represents the combined technical efforts of the Working Group partners and targets a wide range of stakeholders, from FAD fishers, to other industry persons, fisheries scientists and managers. To facilitate wider distribution it is also published online (see www.crfm.int).

The experiences that inform the best practices in FAD fisheries management are drawn from a number of regional initiatives, beginning with establishment of the WECAFC Ad Hoc Working Group on the Development of Sustainable Moored Fish Aggregating Device Fishing in the Lesser Antilles in 2001, followed by the JICA-funded study on Formulation of a Master Plan on Sustainable Use of Fisheries Resources for Coastal Community Development in the Caribbean from 2009 to 2012, the project on the Moored Fish Aggregating Devices in the Lesser Antilles (MAGDELESA Project) from 2011 to 2014 (see http://en.magdelesa.eu) and more recently the JICA-funded Caribbean Fisheries Co-management Project being implemented from 2013 to 2018. As well, these best practices are also informed by collaborative research with the Texas A&M University and the University of Florida, Florida Sea Grant. Both the Ad Hoc Working Group and the MAGDELESA Project were led by the Ifremer and focused primarily on examining the scientific information for development of sustainable FAD fisheries, promoting sub-regional cooperation in the sustainable development and management of FAD fishing and the sharing of related information and experiences. The MAGDELESA project also focused on improving the design and construction of FADs and examining fishing strategies, gear selectivity, fish quality, safety and work conditions of FAD fishers and governance of FAD fisheries. The Master Plan Study, through one of its four pilot projects, further improved FAD fishing technology, initiated FAD data collection programmes and explored aspects of co-management of the fishery in Dominica and Saint Lucia. The pilot project also developed a draft FAD fishery Management Plan for Dominica. The current CARIFICO Project is providing additional support to Antigua and Barbuda, St Kitts and Nevis, Dominica, Saint Lucia, St Vincent and the Grenadines and Grenada to develop FAD fisheries and to address issues of governance.

ACKNOWLEDGEMENT

The production of this volume of the Manual of Best Practices in Fisheries that use Fish Aggregating Devices would not have been possible without the kind assistance and support of various agencies and experts, both regionally and internationally. We would like to thank the French Institute for Exploitation of the Sea, the Caribbean Fisheries Co-management (CARIFICO) Project and the Caribbean Regional Fisheries Mechanism (CRFM) for funding our participation at a Write-Shop on FAD Fisheries Management, which was convened in June 2015 in St Vincent and the Grenadines, to discuss and advance preparation of the Manual. We are also grateful to CRFM Secretariat for organizing this Write-Shop and for facilitating the review, editing, finalization and publication of the respective outputs. We are especially grateful to Ms Pamela Gibson for assisting with technical editing and proof reading of the final document and to Ms Kemara Brackin for the design and layout of the covers of this volume of the Manual. We also wish to express our appreciation to Mr Kazuo Udagawa and Mr Motoki Fujii for their constructive review of the document and suggestions for its improvement. This document has also benefitted from the review of the following fishers from St Vincent and the Grenadines: Mr Roderick Telemaque, Mr Donelee Providence, Mr Esworth Edwards, Mr Calvin Lampkin and Mr Winston Hazellwood, to whom we are deeply grateful. We are also grateful to the CARIFICO Project for funding the publication and dissemination of the Manual in two languages, English and French.

LIST OF ACRONYMS AND ABBREVIATIONS

CARIFICO	Caribbean Fisheries Co-management Project
CRFM	Caribbean Regional Fisheries Mechanism
FAD	Fish Aggregating Device
GPS	Global Positioning System
Ifremer	French Institute for Exploitation of the Sea (L'Institut Français de Recherche pour l'Exploitation de la Mer)
JICA	Japan International Cooperation Agency
MAGDELESA	Moored fish AGgregating DEvice in the LESser Antilles
PA	Polyamide
PE	Polyethylene
PES	Polyester
PP	Polypropylene
WECAFC	Western Central Atlantic Fishery Commission

TABLE OF CONTENTS

A. FAD DESIGN AND CONSTRUCTION

1. INTRODUCTION

FADs are structures that are used to aggregate fish to make them easier to catch while at the same time reducing the cost of fishing and making fishing more efficient. Designing and constructing FADs requires some technical knowledge of the ocean environment, such as the current strength and direction and how this varies over the years, the force of water at varying depths, the steepness of the ocean floor, the conductive nature of sea water, the wind speed and direction as well as knowledge of various types of construction material to ensure that the structure is able to withstand the environmental stresses of the ocean. Knowledge of the causes of FAD loss as well as the criteria for selecting the best location for setting FADs are critical towards maximizing the "life span" of a FAD. Here we provide the necessary details for designing and constructing five different types of FADs – each having the basic structure of a flotation system, a mooring line, an aggregation component and an anchoring system.

1.1 FADs

Anchored FADs, intended for artisanal fishing, are used in numerous countries, often islands of the inter-tropical belt. They are introduced to improve the livelihoods of fishers in rural communities and to contribute to national food security. As a consequence, they should not be mistaken with drifting FADs used by large tuna purse seiners practicing industrial fishing.

The depth of set up distinguishes deep FADs from coastal FADs. Coastal FADs, which are seldom used in the Caribbean area, are deployed under 100 m (300 ft.) and are intended for fishing small pelagic fish. As for deep FADs, they are deployed at depths ranging from 300 to 3000 m (1000 to 10 000 ft.) and are used for large pelagic fish such as tuna, marlins and dolphinfish. They are largely used in numerous Caribbean countries.

FADs are made of one or several floats connected to an anchoring system with a mooring line (Figure 1). Aggregators, such as trawl net pieces or tarpaulins, are distributed on the mooring line between the surface and a depth of approximately 30 m (100 ft.).

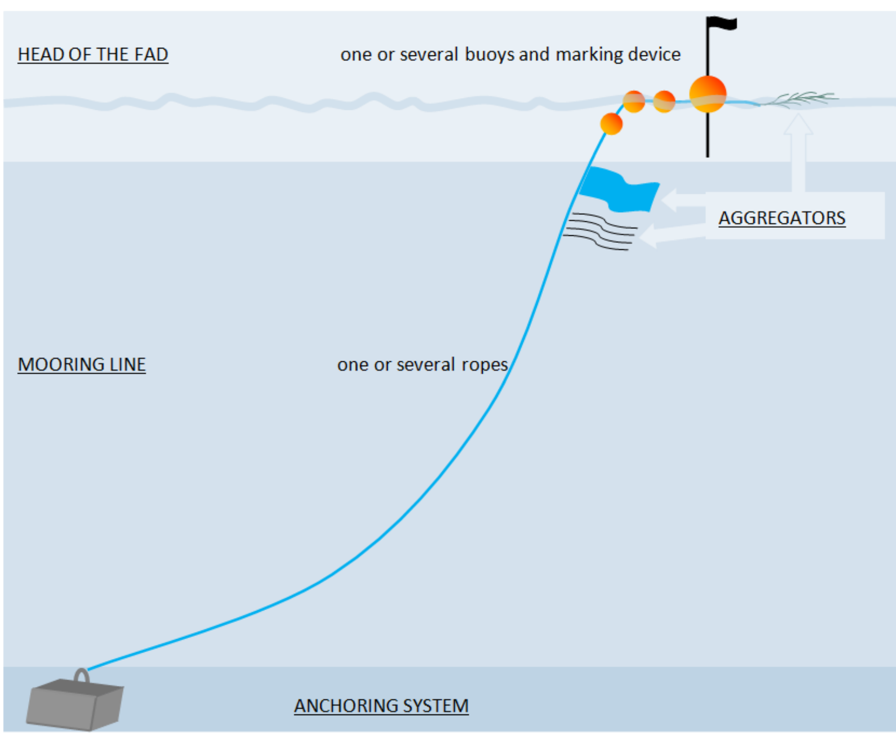


Figure 1: Diagram of a FAD.

FADs are divided in two groups based on their float system: monobuoy FADs, and string FADs with several floats.

FADs can further be divided into groups characterized by the financing influencing their manufacturing. Private FADs, made and financed by the fishermen themselves, are often light FADs, as cost-related issues limit their design and material selection (part of the components used to build them can be recycled materials). Public FADs benefit from more important financing schemes and can feature better-fitted and resistant materials. However, the cost constraint still stands, as they must remain affordable and consistent with the earnings stemming from their exploitation.

Sinkable FADs are FADs that will be submersed whenever the current is strong. They must withstand that submersion and come back to the surface as soon as the current decreases.

Unsinkable FADs are calculated to remain on the surface when the current is the strongest in the area where they are deployed.

There are also subsurface FADs conceived so that the float constantly remains 10-20m (30-60 ft.) from the surface. They can only be set at low depths, less than 200 m (650 ft.); they are thus coastal FADs.

Deep submerged FADs exist (Okinawa, Japan) but these are high technology and expensive FADs, very difficult to set up. They are not covered in this manual.

Two-headed FADs have a mooring line that is divided at 200 to 300 m (650 to 1000 ft.) under the surface, and two surface floats several hundred meters away from each other. They are not often used even though they have proved to be efficient.

1.2 FAD conception

We will look at the concept of deep FADs because only these require accurate designs regarding FAD elements: floats, ropes and anchoring system. Indeed, the current generates forces on each point of the mooring line. If it is long, the sum of these forces becomes significant and can lead to the total immersion of the floats. It is thus necessary to design and calculate the FAD so that it withstands submersion at best, while remaining affordable, as its price depends on its size.

Calculating the features of the ropes used for the mooring line must also ensure that a rope is never present either on the surface (risk when a ship approaches) or bottom (risk of premature wear).

The development process also takes into account the selection and efficiency of the materials used, as well as the assembly of the FAD. It deals with the making of the connections between the different FAD components and their protection against all sorts of damage, especially the elements located at the surface and along the upper part of the mooring line. The design process also aims at selecting the right metal pieces and preserving them from electrolysis (chemical corrosion that may occur when metal pieces are immersed in a conducting liquid such as sea water).

Observation and analysis of the causes of FAD loss are important for their design.

1.3 FAD loss

1.3.1 Three ways of losing a FAD

1. The upper part of the FAD goes adrift: After rupture of the mooring line, the lower part sinks or keeps floating in mid-water.

2. The whole FAD sinks or floats in mid-water: After implosion or destruction of floats or water filling of buoys.

3. The whole FAD goes adrift: Due to an improper balance between buoyancy and anchor weight or an excessive slope of the ocean bed.

1.3.2 Causes of loss

It is near the surface that the FAD undergoes the most potentially harmful damages, and most of the causes of loss concern the upper part of the mooring line or the flotation system.

The identified causes of loss are:

- Movement of the swell and waves
- Passage of a vessel on the FAD
- Implosion or destruction of the floats
- Damage caused by fishing gears
- Tangling
- Fish bites
- Wrong design
- Incorrect assembly
- Incorrect implementation
- Malicious acts
- Insufficient maintenance

<u>Movement of the swell and waves</u>

The movement of the swell and waves spread to the whole mooring line but the elasticity of the rope reduces it all along its length. The effects are more important at the surface; it is therefore at the surface that fatigue and wear are the strongest.

Passage of a vessel on the FAD

The passage of a vessel on the FAD causes the total destruction of the head of the FAD if it is a large vessel. When tangling with the propellers of small sailing boats occurs, the mooring line is most of the time cut to free the boat.

Photo 1: Passage of a vessel.

When the FAD is near a busy ship lane you must ensure good maintenance of the markings, lights, and radar reflector, and make them as visible as possible (color, flag).

Photo 2: Rupture after excessive tension.

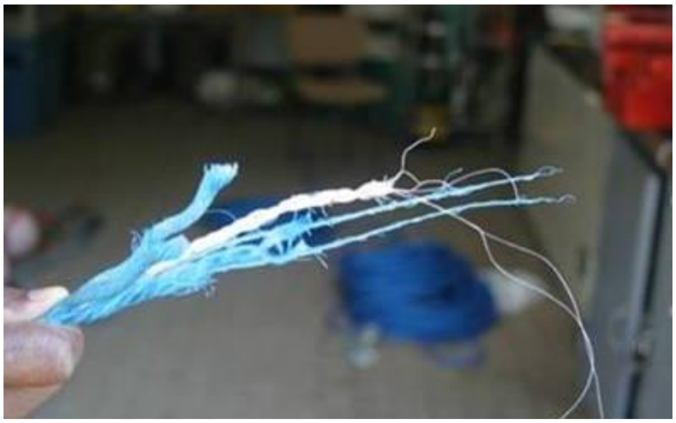
The aspect of the rope where the rupture occurred following excessive tension (collision) is typical: the 3 strands are broken at different levels and the threads of each strand untwist and take on a brushed aspect.

Damage caused by fishing gears

The tension of the mooring line of a few hundred kilograms when there is current, makes the line sensitive to cuts and various abrasions. Fishermen's lines do not represent a danger as long as they move along the mooring line, but whenever they find a breach on the rope (a knot or a preexisting damage) they can get stuck on it. Friction then always occurs on the same spot of the mooring line. If tensions are great and the fishing line is long, the anchoring line may break completely.

Fish can get round the anchoring line while the fishermen lift their line or tangling may happen between the float of the vertical long-line (can) and the mooring line at the beginning of the catching operations.

The most frequent cause of loss for FADs occurs when the upper part of the anchoring line is not reinforced.



Typical aspect of a cut made by a fishing line: 2 strands were cut by the line. The core and a few remaining threads from the 3rd strand finally gave in as a result of the tension of the rope.

Photo 3: Cut by a fishing line.

Implosion or destruction of the floats

When the current is strong, the buoyancy of the floats may be insufficient to keep them afloat; this causes immersion of the floats and eventually leads to their implosion due to the water pressure. The immersion may be worsened if the mooring line is too short or there are too many aggregators on the FAD.

Floats can implode or crack and fill up with water. Action must be taken if the loss of buoyancy reaches 10% of the total buoyancy. Short 5-float strings may, for example be inserted before the flag buoy.

Photo 4: Broken float on a MAGDELESA FAD.

Tangling

Tangling with drifting items, in particular the ropes of other FADs may result in loss of FADs. A lot of FADs were lost that way in Guadeloupe where the anchoring system of artisanal FADs is not heavy enough to withstand the strongest currents. Numerous cut fishing lines and hooks also tangle with the FADs and can weaken them. The succession of periods without current when tangling gets more serious because the mooring line is slack and shaken by the waves and periods of strong currents when the device re-tightens greatly worsens damages to the mooring line.

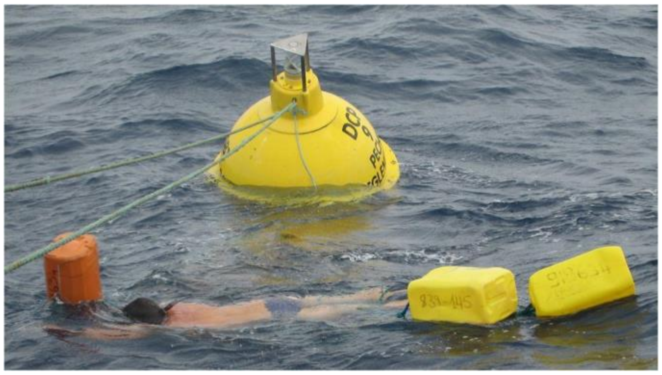


Photo 5: Tangling of an artisanal FAD with a public FAD.

Photo 6: Tangling on FAD.

In rare cases, if tangling occurs at the surface, untangling is possible. Most of the time, the tangled section is inaccessible and the anchoring line ends up breaking.

Fish bites

Losses may occur when bait or a small catch gets tangled around the FAD with the fishing line. A bigger fish can then cut the mooring line to get the catch. The king mackerel is especially feared for that behavior. Even though they seem quite unusual, cuts by shark bites have been reported.

Wrong design

For example:

- Line without sinking rope (a common occurrence with artisanal FADs).
  When there is no current, rope from the mooring line tends to rise to the surface.
- Line with too much sinking rope (rare and rather theoretical).
  When there is no current, rope from the mooring line rest on the ocean floor.
- Line too long for the slope (or too much slope). There is a danger of damage of the rope (as shown in Figure 2).
- The anchoring system is too light and the FAD moves and eventually gets lost as it gets out of the reach of fishermen, or it sinks if the mooring line gets too short.
- The buoyancy is too low, the mooring line is too short, or the floats are not resistant enough and cause the FAD to lose after the floats implode during immersion due to strong currents.

When the setup site is steep, the length of the anchoring line must be adapted to the slope of the ground and the length to depth ratios used must not be too high. In practice, sites where the average slope is greater than 30% are avoided (Figure 2).

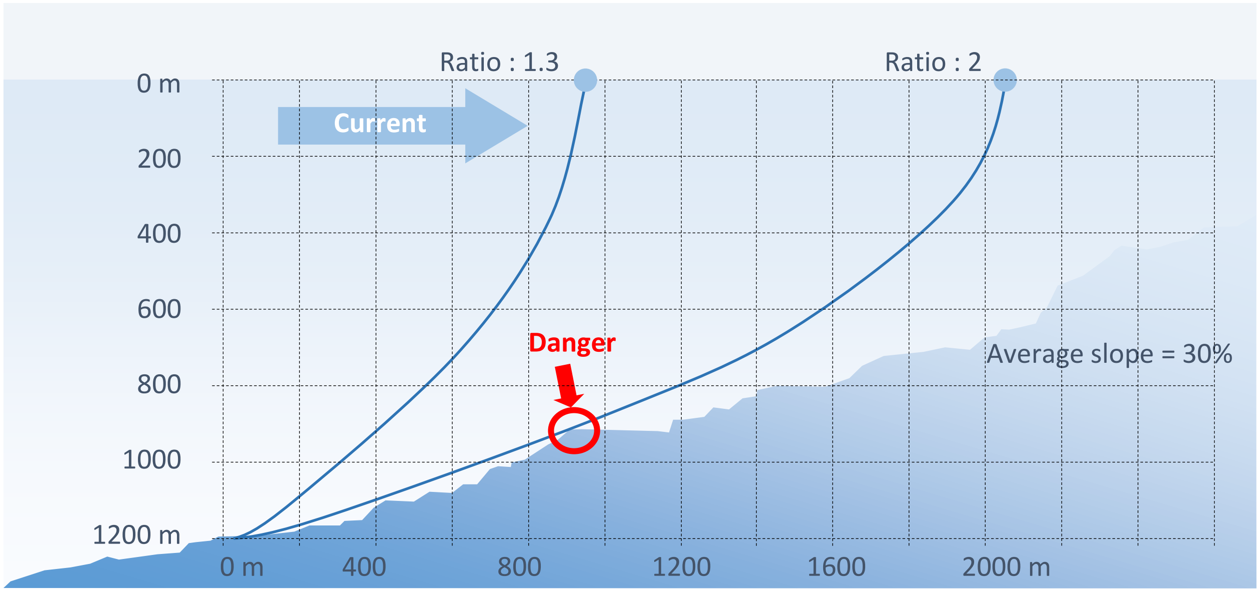


Figure 2: Limit slope 30%.

<u>Incorrect assembly</u>

- Poor rope quality:

Each meter of the mooring line must be checked. A rope of an acceptable quality for a mooring line presents a uniform and regular aspect on its whole length. If you have bought long lengths, make sure there are no suspect connections in the coils (approximate splice or even gluing).

- Connections between the different items done incorrectly:

Use of knots instead of splices, use of stainless steel items, use of metal elements without protection by anodes, problems with the thimbles or fillings.

Photo 7: Electrolysis on a stainless steel shackle.

Impressive (but not rare) electrolysis of a stainless steel shackle pin. Stainless steel items must be banned from FAD making; they are expensive and sensitive to electrolysis.

Photo 8: Comparison between metal pieces after 2 years in the sea protected and unprotected by anodes.

Items made of hoist quality galvanized steel resist electrolysis much better. They are recognizable from the marks indicating their diameter and MWL (maximum working load) (top right photo). «Galva » rigging steel available at ship chandlers' for boat mooring and common uses must be excluded because they are often of very poor quality. Nut and pin clevises are preferable to screw-on pins.

The photos show metal items that spent 2 years at sea, without (left photos) and with (right photos) a protection against electrolysis. Despite a superficial oxidation, unprotected shackles resisted rather well but the thimble greatly deteriorated, which is typical of electrolysis. The piece made of the weakest alloy is used as an anode and deteriorates greatly. As for the protected pieces, they are in like-new condition, only the trace of wear on the shackle attests to the time spent underwater.

Photo 9: Anode on a combination cable.

Photo 10: Anode on a 600 liters float.

Incorrect implementation

Deployment rules are not respected (e.g. direct shooting from the coils of ropes). Figures 3 and 4 show how to handle the coils of rope correctly.

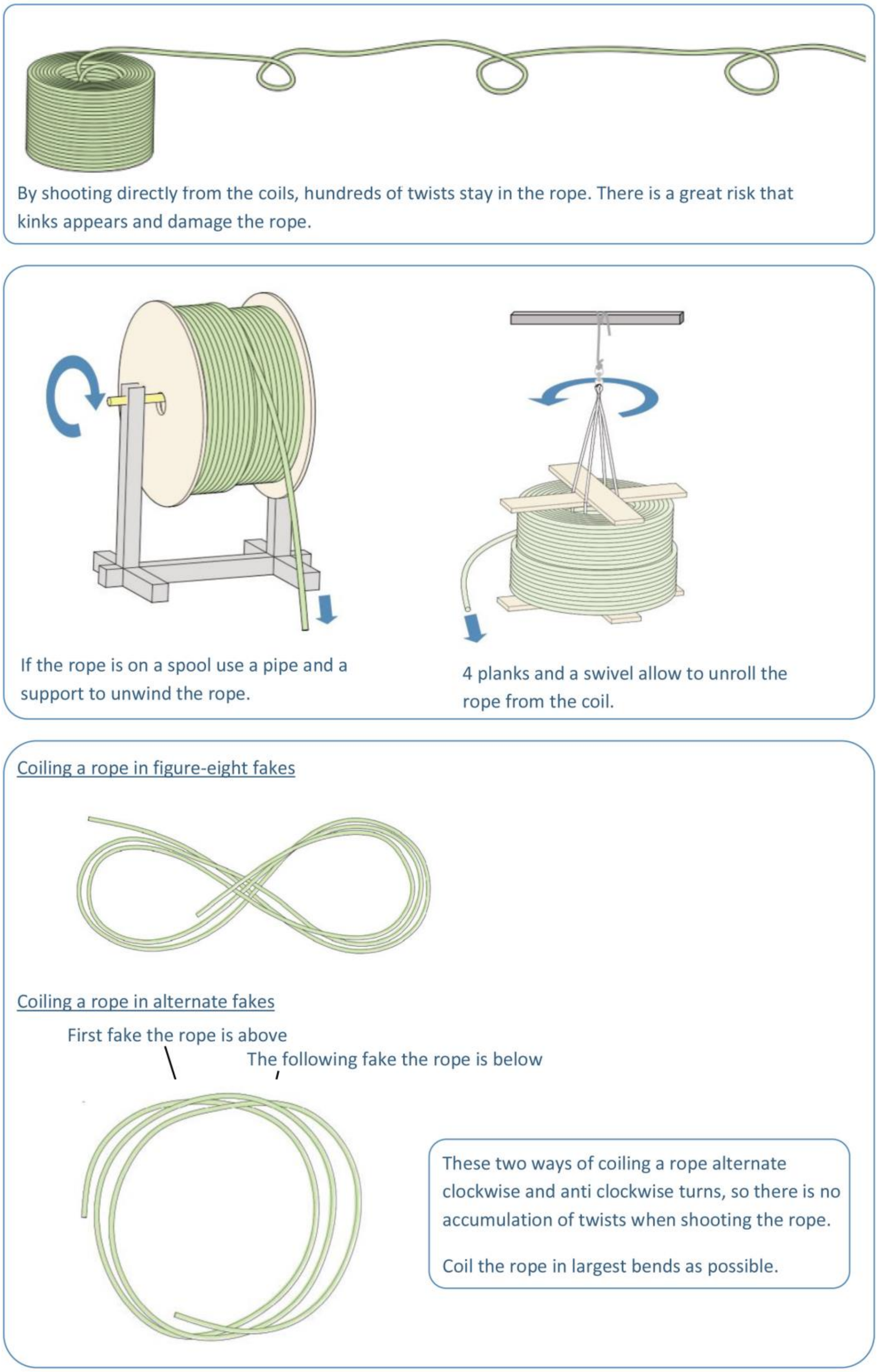
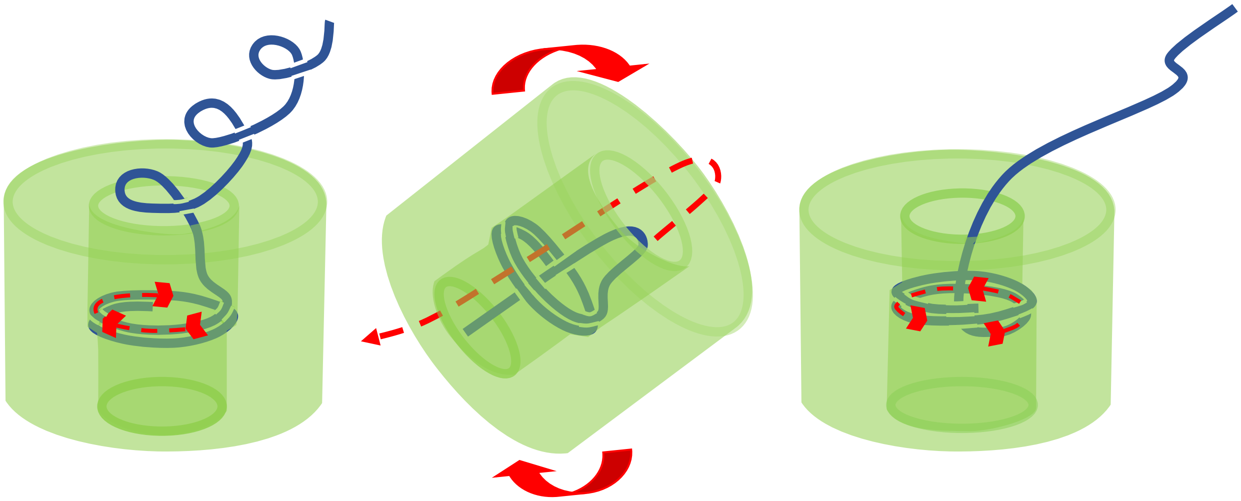


Figure 3: How to unwind the coils of rope.

If you uncoil the coils of ropes from the center (not recommended):



If the rope unwinds in clockwise direction many twits will stay in the rope.

You must upturn the coil and grab the rope through the center.

Now, the rope unwinds in counter clockwise direction. There will be much less twists in the rope

There still remain more twists than using the recommended method (see Figure 3).

Figure 4: Uncoil a coil of rope from the center.

Rupture near a kink has a chewed aspect on a short distance without any cut being noticeable.

Photo 11: Kink in a rope.

Photo 12: Aspect of a rupture near a kink.

Malicious acts

The incidences of malicious acts have considerably decreased since FAD fishing has become well known; however, conflicts persist and the danger of intentional acts of destruction remains a possibility.

Insufficient maintenance

Regular maintenance of the components of FADs (flag mast, flashing light, radar reflector, surface floats) can significantly increase their durability.

2. SITE SELECTION

2.1 Site selection criteria

The site selection will depend on:

- The opinion of local fishermen and their knowledge of the productivity in the area
- The distance from the fishing harbor(s) and fish landing sites
- The location of the busiest commercial harbors and shipping lanes
- The nature and profile of the sea bottom
- The presence of other FADs in the area
- The depth of water
- The presence of undersea cables

Opinion of local fishermen

The knowledge and experience of fishers in identifying appropriate FAD mooring sites in relation to productivity is an important reference. Notwithstanding that it is sometimes difficult to reach consensus among groups of fishers. However, to promote co-management of the FAD fishery, between fishers and fisheries authorities, it is very important that they are engaged in the decision making process which should incorporate both science and local knowledge.

Distance from the fishing harbor(s)

The distance from the fishing harbor or fish landing sites depends on the type of fleet that will use the device.

It may be of about 5 nautical miles (1 nautical mile = 1.151 mile) for fleets of small, lightly motorized boats. Some fishermen can share their time between more traditional coastal exploitation and occasional passages on the FAD.

Up to 20 or 30 nautical miles, the FAD is intended for a fleet of larger and more motorized boats, often specialized in fishing around FADs.

Beyond that distance, as far as 100 or 200 nautical miles from the coast, the FAD will be reserved to deck boats going at sea for several days.

The appropriate choice of a setup site is part of a global project including a good analysis of the activity of the different fleets exploiting the area. The distance from the fishing harbor also depends on the FADs already existing in the area. Most of the time, the first FADs deployed in an area are coastal ones. Over time, one notices that they are set farther from the coast, either to respect a sufficient distance between the FADs or for reasons of productivity or overload of those closest to the coast.

Location of the commercial harbors

You must go as far as possible from the shipping lanes serving the most important commercial harbors. Port authorities could transmit information regarding FAD location to ships cruising in the area on a regular basis. But although informing the users of the sea of their presence in the area is important, the large watch circle of the FADs and high variations of location stemming from it limit the efficiency of that type of measure. Ideally, FADs located in busy areas should be equipped with AIS (Automatic Identification System)-system giving large commercial vessels instant and accurate information on the nature and position of the device. Otherwise, you must ensure the presence and good maintenance of the FAD's regulatory equipment: monobuoy FAD floats are yellow; they will be equipped with a radar reflector set as high as possible on the flagstaff. The light will be yellow and will have a flashing pace different from that of normalized paces used for regulatory marking.

The period of lights on public FADs deployed in Guadeloupe and Martinique and on MAGDELESA FADs is 8 seconds. The pace is: occultation 3 seconds, extinction 2 seconds, sparkle 1 second, extinction 2 seconds.

Nature and profile of the sea bottom

The nature and profile of the sea bottom are two important criteria when choosing a site. Even and regular sea bottoms are better suited than sloping and hilly ones. Slopes over 30% must be avoided. If the area only has sloping sites, compatible options will have to be chosen during the conception of the FAD, as decreasing the length of the anchor line.

Presence of other FADs in the area

There are interactions among FADs related to fish behavior. They are complex and describing and assessing their effects is difficult. It was evidenced that when in the presence of two FADs set very close to each other, at dawn, fish tend to gather around one of them; two FADs when set close together thus seem to equal a single one in terms of their effect on the aggregation of fish.

The distance between two FADs is empirically set to 5 nautical miles. It was noticed that, within areas where there are a lot of FADs, fishermen spend a lot of time traveling from one FAD to another one, searching for the most active one. Part of the benefit from installing a FAD, the decrease in the searching time and prospection, is thus lost. But the use of double FADs ensures that the area is never deprived from FAD when one of them is lost; and it is a common practice by fishermen who own FADs to set 3 or 4 of them one nautical mile apart from one another.

In the case of public FADs, "twin" FADs may ensure that one has enough time to replace a FAD when one is lost. The continued presence of a FAD in a sector being one of the keys to the success of a deployment plan, it could be a solution to the lack of reactivity always noticed when it comes to replacing lost FADs. Setting up a two-headed FAD serves the same objective.

Depth of water

Although strongly influencing the design and behavior of the FAD, the depth of the setup depends on the site selected. The criteria related to the exploitation of the device are most of the time dominating. However, if two sites seem to be equivalent, the least deep will be chosen: the FAD will be less costly, less sensitive to submersion and its smaller watch circle will make spotting easier. (The watch circle is the area into which the FAD moves when the currents change). Once the site is selected based on different elements, you need to look at the depths in the area on a marine map. A reasonable shift of position compatible with the other criteria makes it sometimes possible to diminish the setup depth significantly.

The watch circle defines the area within which you will be able to look for the FAD. It commonly ranges from a few hundred meters, for the least deep FADs, to 3000 m (10 000 ft.) for the deepest ones. The range of vision of a FAD, very variable according to the FAD and weather conditions, is often about 500 m (1600 ft.), and time loss as well as fuel consumption can be considerable when looking for a deep FAD.

Presence of undersea cables

Even if undersea cables are sturdy enough to withstand the contact with the anchoring system of a FAD, incidents caused by tangling with FADs during cable lifting operations were reported. It is thus necessary to enquire about the position of those cables in the region concerned by the FAD setup projects.

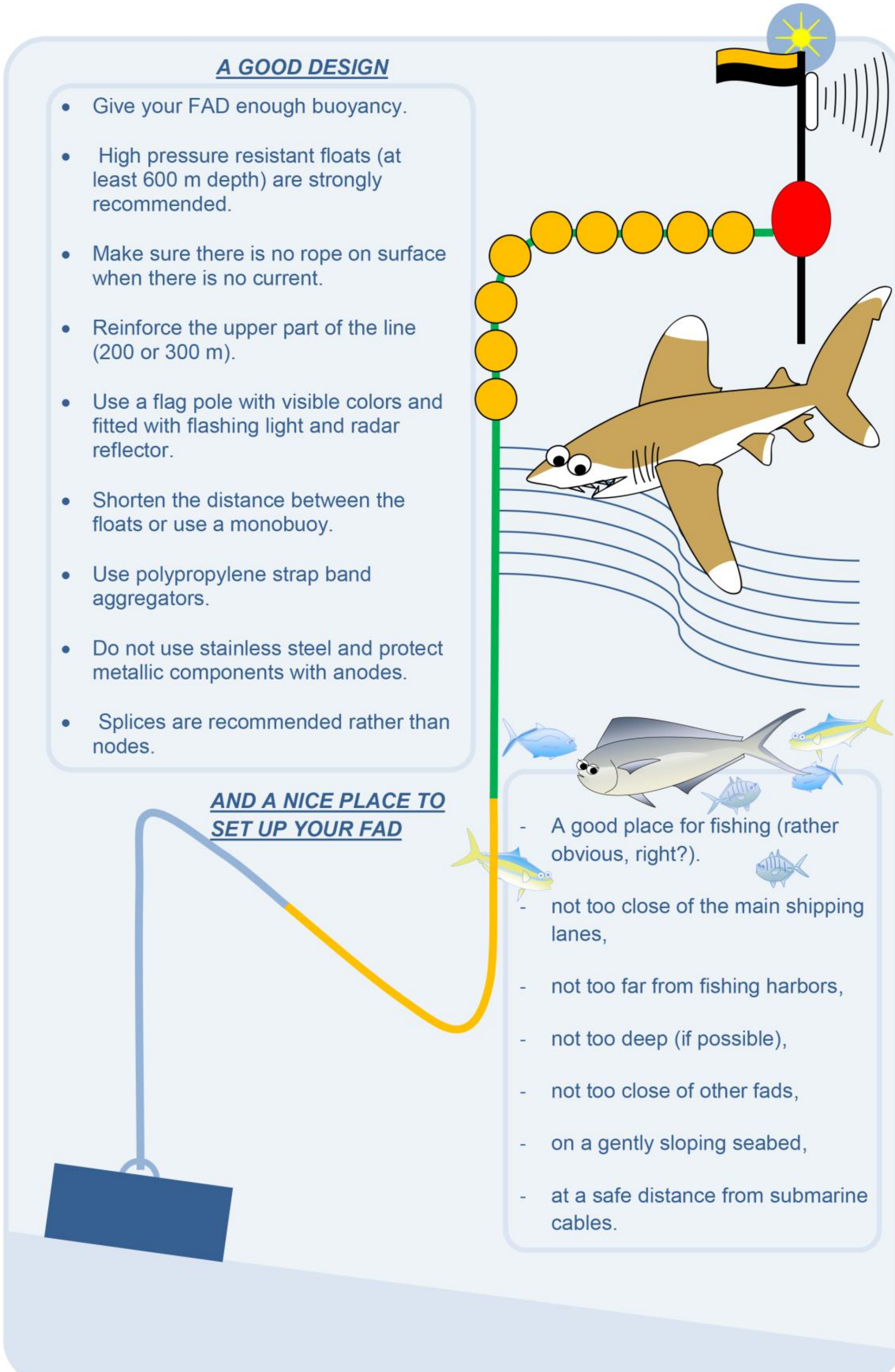


Figure 5: A Good FAD Design.

2.2 Ocean Currents in the Lesser Antilles

Knowing the current pattern ensures a better knowledge of the behavior of FADs with maximum currents existing in the area and to thus assess or correct the selected options for their design and construction.

The local current system is dominated by the influence of the Caribbean current, itself strengthened by the equatorial northerly current and the Guyana current. On the whole, it bears to the west-northwest at a speed of approximately 0.7 m/s close to Venezuela, and affects the entire southern part of the Greater Antilles. Close to the Antilles and in the Caribbean Sea, it is swirling on a strong complex in which the size and displacement of the swirls are very variable. Such complexity goes along with the presence of coasts and channels considerably pressuring the whole system, as well as with the effect of surface currents due to trade winds or hurricanes and deeper tidal streams that superimpose.

Consequently, FADs set in the area are exposed to currents with very variable directions. The currents' speeds will, on average, be greater when setting West and North than when setting East and South. The currents will be much more stable in areas where they are more influenced by the coast, but where inversions still happen. The swirling character of the main current is even stronger downwind.

When designing FADs, you must know the maximum currents for each depth. These current peaks are not necessarily consistent on one given point. You will consider the case of a profile with an unfavorable current whose all noted values at the different depths occur at the same time. It is the theoretical maximum current adopted for that particular place.

In the southern part of the Antilles, from Grenada to Guadeloupe, the maximum speeds noted all along the year 2013, in 6 different points vary:

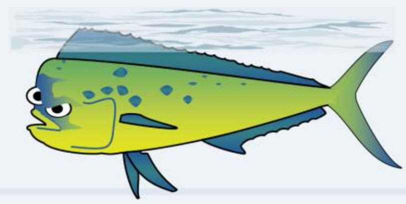
- At the surface, from 0.7 to 1.75 m/s,
- At 100 m (330 ft.), from 0.3 to 1.25 m/s,
- At 300 m (660 ft.), from 0.2 to 0.75 m/s,
- At 1000 m (3300 ft.), from 0.1 to 0.5 m/s,
- At 2000 m (6600 ft.), from 0.05 to 0.45 m/s.

The high variability noted shows that checking the status of the currents of the area selected for setup is important. The data are available on "Global Ocean Physics Analysis and Forecast Updated Daily", on the Myocean website of Mercator Ocean.

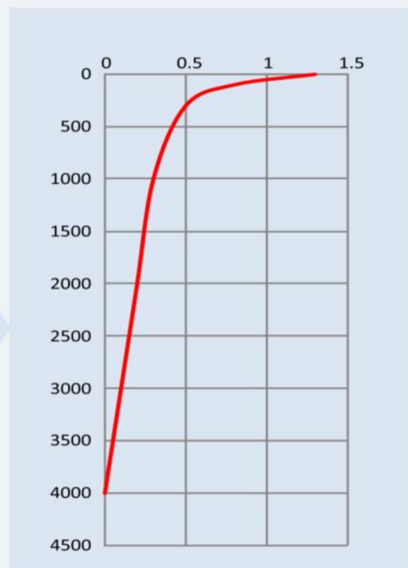
Furthermore, the analysis of those currents evidence a crucial point for FAD conception: in the entire area, maximum currents are approximately two-times stronger than average ones and are only valid for a short period of the year, sometimes barely more than a week. As a result, a FAD that appears to be well conceived because it was set several months before and works fine, may be undersized to withstand the maximum currents of the area.

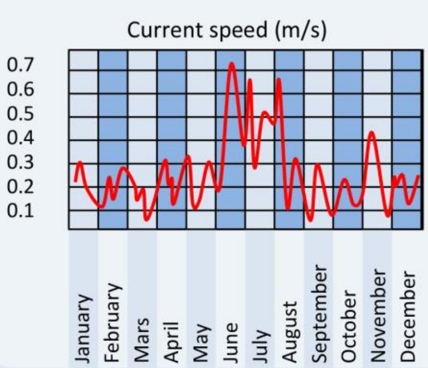
WHAT IS THE CURRENT YOUR FAD HAS TO WITHSTAND?

- All current directions are possible.
- Currents bearing North and West are stronger.



- There is some current throughout the water column, from the surface to the bottom, which you must consider when designing the FAD.
- In the Caribbean area, your FAD should withstand these maximum currents.
- Currents are stronger in the south of the area.





- The maximum speed of the current is more than twice its average speed (more than 4 times more effect on the FAD).
- You must consider the changes in current during the year when designing the FAD-Your FAD deployed in September seems a perfect design, but the next year it may not be able to resist the strong currents at mid-year.

Figure 6: What is the current your FAD has to withstand?

3. FLOAT SELECTION

3.1 Buoyancy

We have two meanings for buoyancy:

1. Buoyancy is the upward force exerted by water on a partially or completely immersed object. Its intensity is equal to the weight of the displaced volume of water.
   The buoyancy unit is the Newton (N). "Upthrust" is another term used for "buoyancy".

2. Buoyancy is the ability of an object to float.
   In fresh water, the buoyancy is positive if the volume of the object, in liters, is greater than its weight, in kilograms, the object floats.
   The buoyancy is negative if the volume of the object, in liters, is smaller than its weight, in kilograms, the object sinks.
   The buoyancy is neutral if the volume of the object, in liters, is equal to its weight in kilograms

For a float, the buoyancy is always positive and equivalent to the reserve of buoyancy of the float.

With the float freely floating on the water:
Reserve of buoyancy (liters) = emerged volume (liters)
Reserve of buoyancy = total volume (liters) – immersed volume (liters)

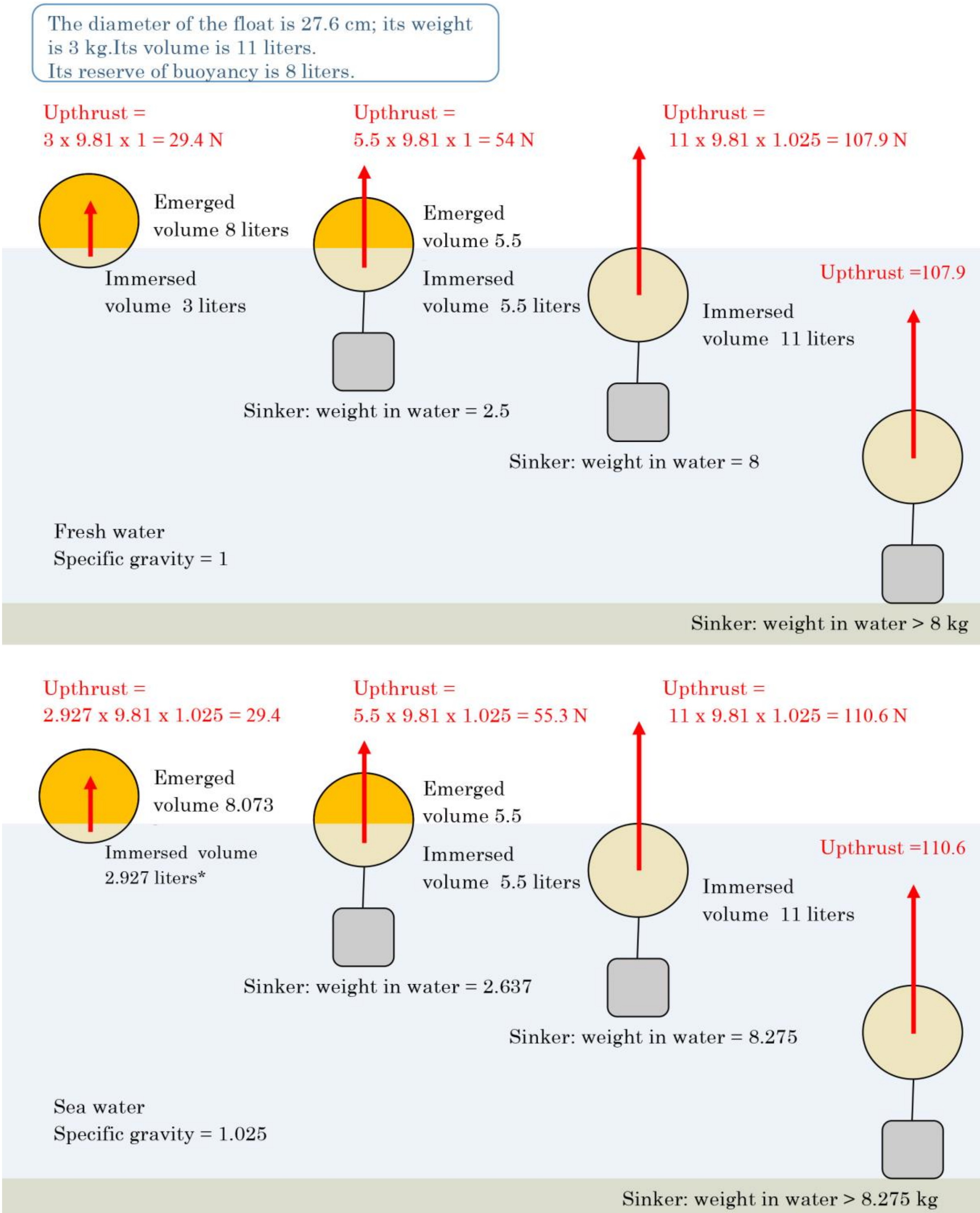
The Archimedes principle gives that the immersed volume (liters) of the float freely floating on (fresh) water equals its weight (kg):
Immersed volume (liters) = mass (kg)
Reserve of buoyancy (liters) = total volume (liters) – weight (kg)

In this manual we will use buoyancy (in liters) with the meaning of reserve of buoyancy of a float to characterize the size of the float, and precisely the effective part of its volume.
With these conventions, we get:
Buoyancy (liters) = volume (liters) – mass (kg)

Keep in mind:
- A 1-liter buoyancy (reserve of buoyancy) float can withstand a charge of one kilogram (weight in water) without sinking.
- An 11-liter float, weighing 3 kg, has an 8-liter buoyancy (reserve of buoyancy) - (Figure 7).

The other essential points are:
- The load to be withstood by the FAD float equals the weight in water and the tension of the mooring line.
- The tension of the mooring line is the result of the effect of the forces exercised by the current on each point of the line.

As a consequence, the greater the buoyancy of a FAD float, the greater the load (thus tension) it stands, and the better its resistance to the effects of the currents.



* The weight of the displaced volume of water (float immersed volume) equals the weight of the float:
Immersed volume = (weight of the float) / (sea water specific gravity) = 3 / 1.025

** (emerged volume of the float freely floating on water) x (sea water specific gravity) = 8.073 x 1.025

Figure 7: The upthrust on an 11 -liter buoyancy float in fresh and sea water.

3.2 Selecting buoyancy

We have seen that the greater the buoyancy of the FAD, the better it withstands the currents. It is the major factor, even if the diameter and length of the mooring rope also matter. However, the buoyancy will affect all aspects of the FAD design, especially the weight of the anchor and the conditions of its deployment.

In the Caribbean, the biggest FADs set to date have approximately a 600 liter buoyancy. Setting up FADs of that size is possible with decked ships of 10 to 12 m (33 to 40 ft.); their cost remains reasonable, although too high for the poorest countries. The smallest devices have approximately 150-liter buoyancy and are often set by fishermen (mostly in Guadeloupe, Martinique and Dominica).

The selection of the buoyancy is mainly based on the depth of the setup site. Although current speeds decreases quite fast with the depth, the data show that there is current at all the depths of the water column. The tension of the mooring line resulting from the accumulation of forces exercised on the ropes will thus increase with its length and the depth of the site will influence the selection of suitable buoyancy.

In a purely indicative way, a 200 liter FAD may suit depths lower than 500 m (1600 ft.). At 2000 m (7000 ft.) the buoyancy should not be less than 400 liters. Beyond, only a minimum 600 liter buoyancy enables the FAD to remain at the surface most of the time.

Two types of FADs result from these observations: Unsinkable FADs which are meant to always remain at the surface and withstand maximum currents in the area, and sinkable FADs known to immerse under the effects of such currents and to return to the surface when the current decreases.

3.3 FAD types

You then need to select one of the two types of FADs: either the string FAD, which has a buoyancy that is distributed between several floats, or the monobuoy FAD, in which the buoyancy is concentrated on a single float.

The string FAD is the most widely used type. In its most artisanal form, it is often made of recycled floats: long liner floats and various cans or containers, often completed with inflatable buoys. More elaborate FADs of that type are made with floats from trawling nets with a center hole. The string ends is a classic flag buoy made with an inflatable buoy meant for that purpose. The FADs used in the course of the MAGDELESA program are of that type; they are made with a specific flag buoy for increased longevity.

The string FAD is less expensive than the monobuoy FAD; its light and easily available components make set-up easy and it forms a shock absorber at the surface for the jolts caused by swells on the mooring line. The line suffers less but the string itself is subjected to wear caused by the continuous agitation occurring on the surface and therefore requires regular maintenance. A string FAD is also less visible and extends 20 m (70 ft.) or more on the sea surface, which significantly increases the risk of collision with vessels. In addition, equipping it with marking material is more difficult since each period of total immersion being more frequent because of its lower buoyancy; the marking light needs to be frequently replaced.

A monobuoy FAD's reduced exposure at the surface limits the risks and consequences of a collision. It is also more visible and can be correctly signaled. It needs less maintenance but is more expensive than a string FAD. Handling and setting it up is more difficult. The float can be equipped with a GPS and reused over and over each time the mooring line breaks.

But fishermen like the surface laying of the string FAD indicating the current direction at all times and helping them place their drifting vertical lines accurately. They are used to adding a few floats to monobuoy FADs so that they play that role of indicator. However, these additional strings make the device bigger thus entailing the loss of one of the advantages of a single float. If fishermen care for such configuration, they should at least use a small diameter rope (< 6 mm, that will break before dragging the buoy down the propeller). Such practice is nevertheless in contradiction with the very principle of that type of float.

3.4 Float types

String FAD floats

When the current is strong, low or medium buoyancy FADs immerse at several hundred meters, their floats have to withstand the pressure of those depths. Several spherical models of hard plastic floats come in different sizes, levels of resistance and fixing modes. 11 liter trawl floats with a center hole that withstand a depth of 600 m (2000 ft.) are well suited. The floats made for longliners are meant for surface use, they do not resist submersion (especially the old/used floats) and quickly implode. Eared-floats are more difficult to set than those with a center hole.

Monobuoy FAD floats

Despite greater buoyancy, monobuoy floats must also withstand potential submersion. The spherical shape offers the best resistance to compression and a thicker skin ensures better resistance.

Indicatively, an 800 liter polyester float with a 2.5 cm thick skin weighs 200 kg and resists compression at a depth of 400 m (1300 ft.).

Metal buoys

Metal buoys can also be used; they are often cylindrical. They are solid and can often be made locally. Make sure that the welds are watertight and place enough anodes against electrolysis. Such floats will however require more regular maintenance than polyester ones.

Inflatable buoys

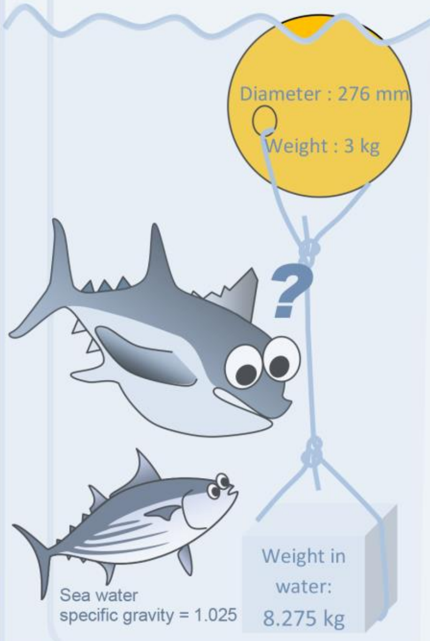
Inflatable buoys are frequently used as tracking buoys on smaller FADs. They are available in volumes of several hundred liters, the most common ones being of about sixty liters. Their advantage is that they are not subject to implosion when submerged, but as their volume decreases with pressure, their buoyancy decreases with depth, which leads to deeper submersion. They sometimes fill up with water and their limited lifespan calls for regular replacement.

Plastic drums and cans

20 or 30 liter cans are frequently used in artisanal FADs. They partially fill up with water when submerged but they are supple enough not to implode. 200 hundred plastic drums are sometimes used.

FLOAT OR FLOATS (HOW MANY?)

- The buoyancy (in fact reserve buoyancy) characterizes the size and the effectiveness of a float.

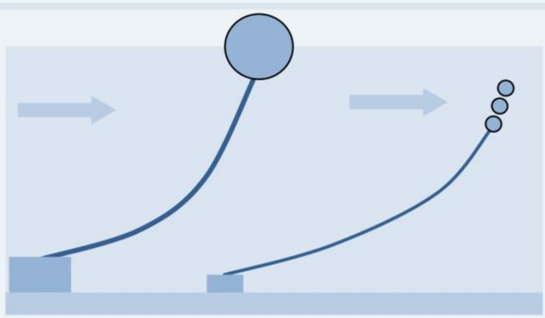


Float's reserve buoyancy = float's volume - float's weight,

volume = $\frac{4}{3}\pi r^3 = 11 dm^3$ = 11 liters,

reserve of buoyancy = 11 - 3 = 8 liters.

- If the weight in water of the sinker exceeds
$(11 - (3 / 1.025)) \times 1.025 = 8.275$ kg
the entire sinks, otherwise it floats.



- In the same current, the biggest FAD remains on the surface while the smallest sinks.
- But it requires a heavier anchorage and a stronger mooring line.
- It is right to increase the buoyancy with the depth.

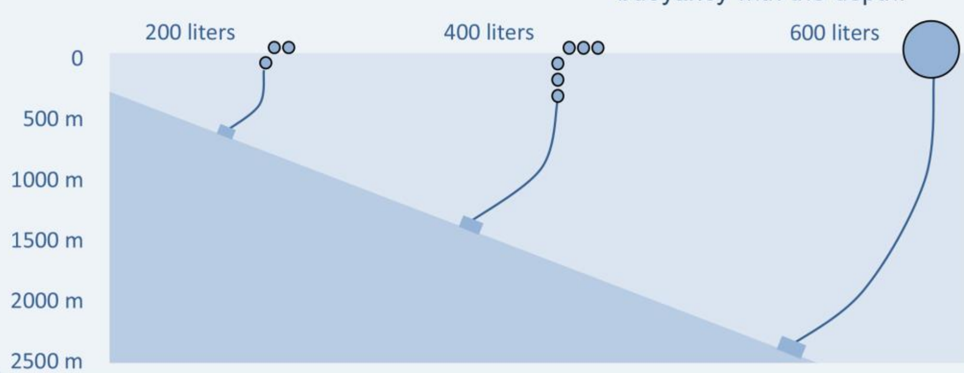


Figure 8: Float or floats (how many?).

4. ROPE SELECTION

4.1 General information on FAD mooring lines

Mooring lines are mainly composed of ropes made of synthetic material with sections in cable, combination cable or chain.

The mooring line must comprise two parts: the first one starting from the anchoring block is floating to avoid the rope touching the bottom of the sea; the second one, at the surface, is sinking in order not to float at the surface. If the length of the two sections is calculated correctly, without current and under the effect of its weight and application of Archimedes' principle, the line forms two loops, the lower loop not touching the bottom and the top one not reaching the surface. The shape taken by the mooring line is a catenary curve (the curve assumed by a cord that hangs freely from two fixed points) - (Figure 9).

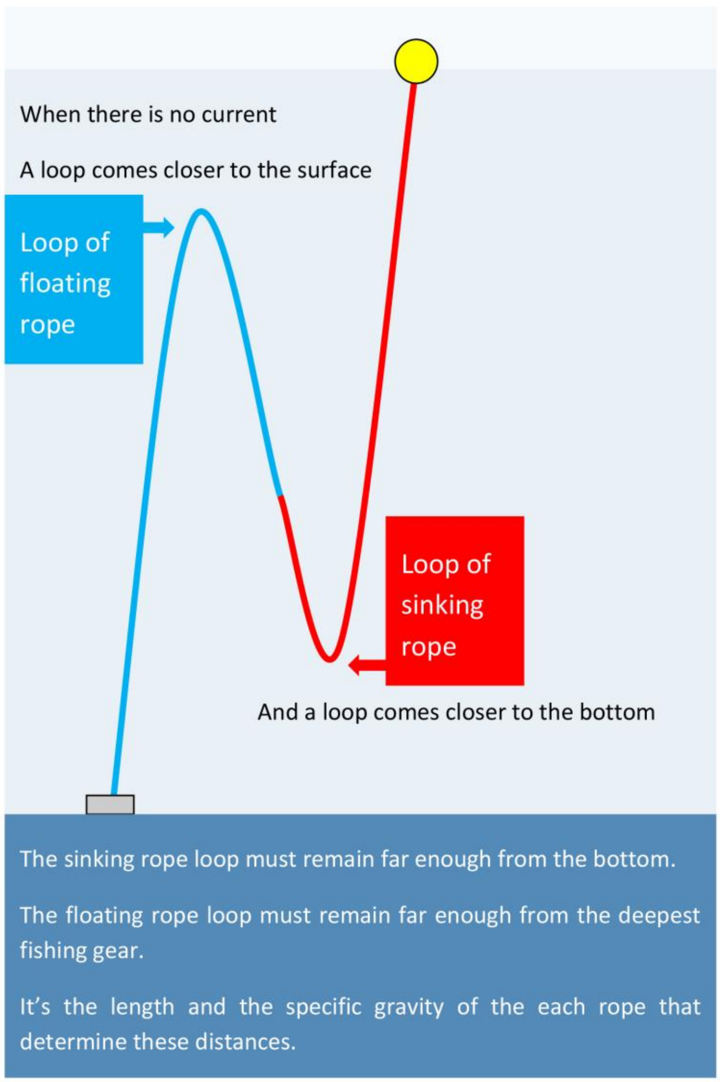


Figure 9: When there is no current, the two loops of the catenary curve.

Polyamide ropes, the most commonly used for the sinking part, are costly. Few devices thus respect that conception rule, and the whole mooring line is generally in polypropylene or polyethylene. Ballasts are placed in the upper part of the mooring line to sink it. Such solution, though more affordable, is not advised, as the ballasts are potential weak points on the mooring line. They tend to create wear, tangling and concentration of kinks on the mooring line.

To complete the mooring line, you can use a section of chain starting from the anchoring block. Its function is to make the anchoring system heavier, to reduce the angle between the line and the sea bottom and consequently improve the holding of the anchoring and cushion the jolts it is subjected to. But the price of the chains or the decision to limit the number of metal components sensitive to wear, and especially to electrolysis, limits the use of chains.

There can be a short chain section at the surface, right under the buoy. It acts as a ballast for the buoy and protects the upper part. More often there is, under the buoy, a cable or a combination rope to reinforce that part of the mooring line, the most sensitive one as it is exposed to the different causes of rupture. Its length varies between 100 and 400 m (300 and 1300 ft.) and it also acts as ballast under the float of monobuoy FADs. It must absolutely be protected from electrolysis with anodes.

4.2 The different types of ropes

There are two different types of ropes according to their method of manufacturing: stranded ropes and braided ropes (Figure 10). Here we describe the ropes that are commonly used to make FADs.

Stranded ropes are the cheapest and the most commonly used. They are made by twisting the strands composing the rope. Once the strands are gathered and the twists released, they naturally curl up into a rope. There are 3 or 4-strand ropes.

Stranded ropes look like triple helicoids. The lead of the helicoids corresponds to the length of rope for one “turn” of strand. The characteristics of the ropes change with the lead, when the lead increases, the solidity increases, the resiliency decreases, and the flexibility increases. If the lead is too great (soft twist), the strands separate easily; the rope becomes slack. If the lead is too small (hard twist), the rope is very tight and difficult to splice. Stranded ropes of appropriate quality for making FADs are 3-strand ones with a medium twist (they can be spliced without a marlinspike but not too easily).

Because of the way they are manufactured, their inconvenience is that they accumulate twists. Too many twists cause overturns of the strands called kinks, which weaken the rope considerably. When short lengths are used, that phenomenon remains unseen because the twists spread and easily disappear at the end of the rope that can freely spin on itself. The situation is quite different with longer lengths: as the twists cannot evacuate, they move along the rope and if they concentrate they are likely to form kinks and damage the rope. If you use stranded ropes, precautions must be taken and adapted techniques used to prepare the ropes before setting up the FAD (see Figures 3 and 4). If you take such precautions, you may use stranded ropes although they are advised against in many publications, which encourage instead the use of braided ropes.

Although less frequently used, braided ropes are better adapted to FADs. As their manufacturing does not include torsion, they do not have the same inconvenience as stranded ropes and tend to create less twists and kinks. They are anti-rotation because, contrary to stranded ropes, they do not turn on themselves when their tension varies.

Two main types of braided ropes are found: 8-strand braided rope and multi-strand braided rope. The latter are made of an outer braid around a thinner braid forming the core. Those are top of the range ropes, too expensive to be used to make FAD mooring lines and presenting the major defect of being difficult to splice. Slightly more expensive than multi-stranded ropes, 8-strand braided ropes are handier and can be spliced, even though splicing is a little more difficult and takes longer. The other modes of manufacturing are basically round braids and double braids. Those are more expensive ropes, with which splicing is more difficult. They are not used to make FADs.

Metal cables are often made of 6 strands and a core. It is difficult to use important lengths as they are very sensitive to the presence of twists, any kink damages them irreparably. They require the use of cable winding winches and are therefore ill-suited for making artisanal FADs.

As for combination cables, they are much more flexible. By using specific techniques to handle them (described in Figure 3), they can be used without winches on small ships. They are spliced easily and well adapted for the protection and strengthening of the upper part of the mooring line. They are used for lengths ranging from 200 to 400 m (650 to 1300 ft.).

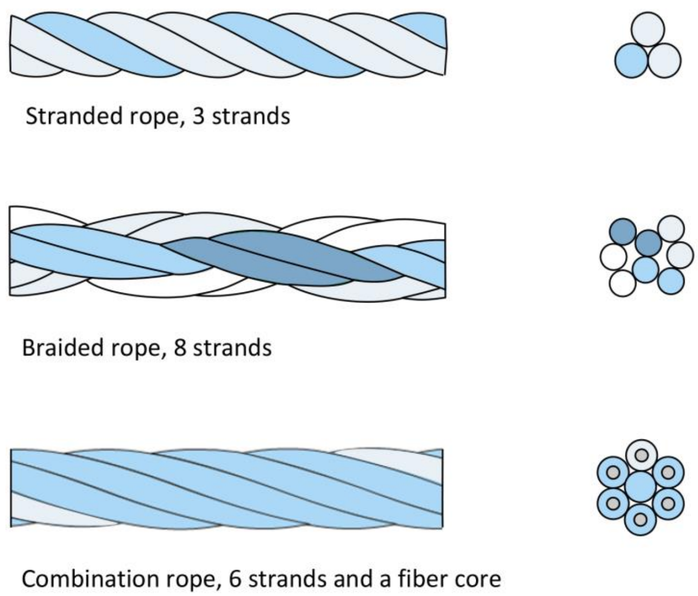


Figure 10: Types of ropes used in FAD mooring lines.

4.3 The materials of the fibers used to make the ropes

The materials used are:
Polypropylene (PP) or polyethylene (PE) for floating ropes
Polyamide (PA) or polyester (PES) for sinking rope

The other fibers are high performance fibers. Their high prices make them impractical for constructing FADs.
They are mainly:

- Aramides like Kevlar®
- HMPEs (High-Modulus Polyethylene) like Dyneema® and Spectra®
- LCAPs (Liquid Crystal Aromatic Polyester) like Vectran®
- PBOs (Poly-p-phenylenebenzobioxazole) like Zylon®

Polyolefines comprise polypropylenes, polyethylenes and combinations of these two components. These combinations are also called copolymer and have slightly better characteristics than polypropylene or polyethylene. Ropes made of copolymer are usable as floating ropes for FADs.

Each rope has its respective characteristics that make it more or less adapted to the intended use.

The use as FAD rope is little demanding. The main characteristic sought is the resistance to "fatigue" in the marine environment with rather strong tensions and continuous crushing due to swells and waves.

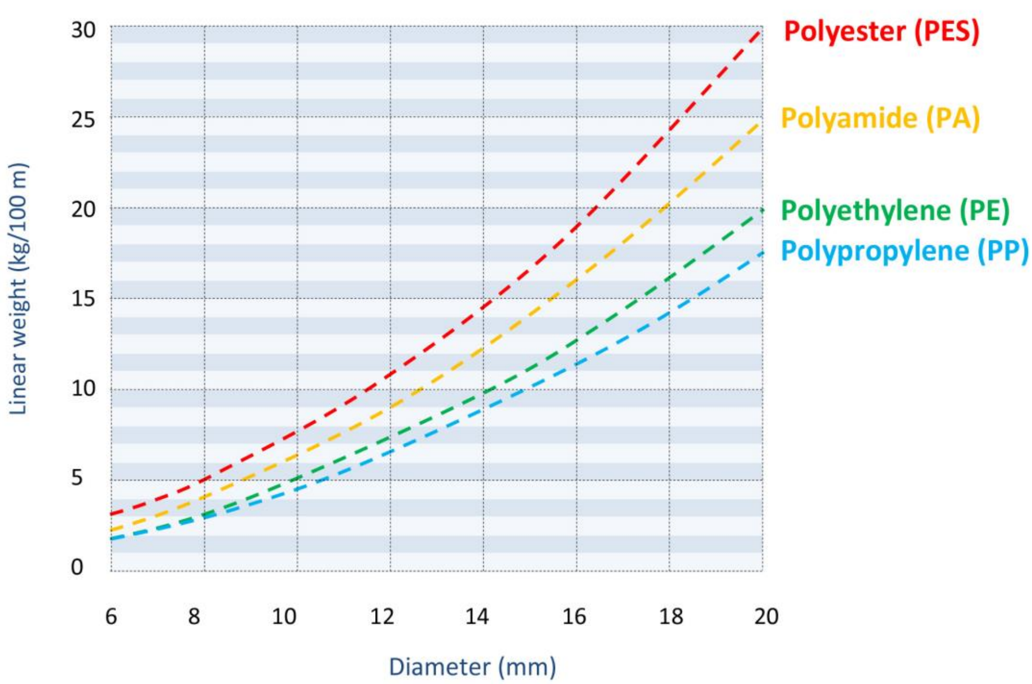
The information matching these criteria is:

- A greater elasticity of polyamide and polyethylene that could ensure a better absorption of the high tensions caused by the swell.
- A better resistance to the marine environment of polyester that keeps its characteristics when used in water whereas polyamide loses its.
- Polyethylene is less resistant but the residual resistance after a long period of use will depend on the number of damaged fibers, and thus on the resistance to abrasion. Polyethylene's resistance to abrasion is of good repute, but on this criterion, the comparison between fibers is indicative and difficult to assess.

There are thus few elements to accurately guide one's choice and you will often choose according to the price and availability of the ropes.

The ropes used for FAD mooring lines are standard ones. In the range of ropes available on the market, there are poor and very poor quality items (especially polyethylene and polypropylene) that you need to recognize and rule out.

The linear weight is an indicator of the quality of the rope (Figure 11). If it is smaller than the average weight for that type of rope, it is a bad sign; the manufacturer may compromise on the quantity of material, and therefore one can thus fear that they also compromise on the quality of the manufacturing process.



The diagram gives the average linear weight provided by 5 rope manufacturers for products that are roughly comparable.

Figure 11: The linear weight of a rope.

The aspect must be perfectly regular; no strand must seem to sink slightly more than the others into the rope. Very slack ropes whose strands can be parted from one another without effort must be excluded.

Be careful: the nominal diameters given by the manufacturer are purely indicative; the measure is very uncertain because the rope is deformable and is not cylindrical.

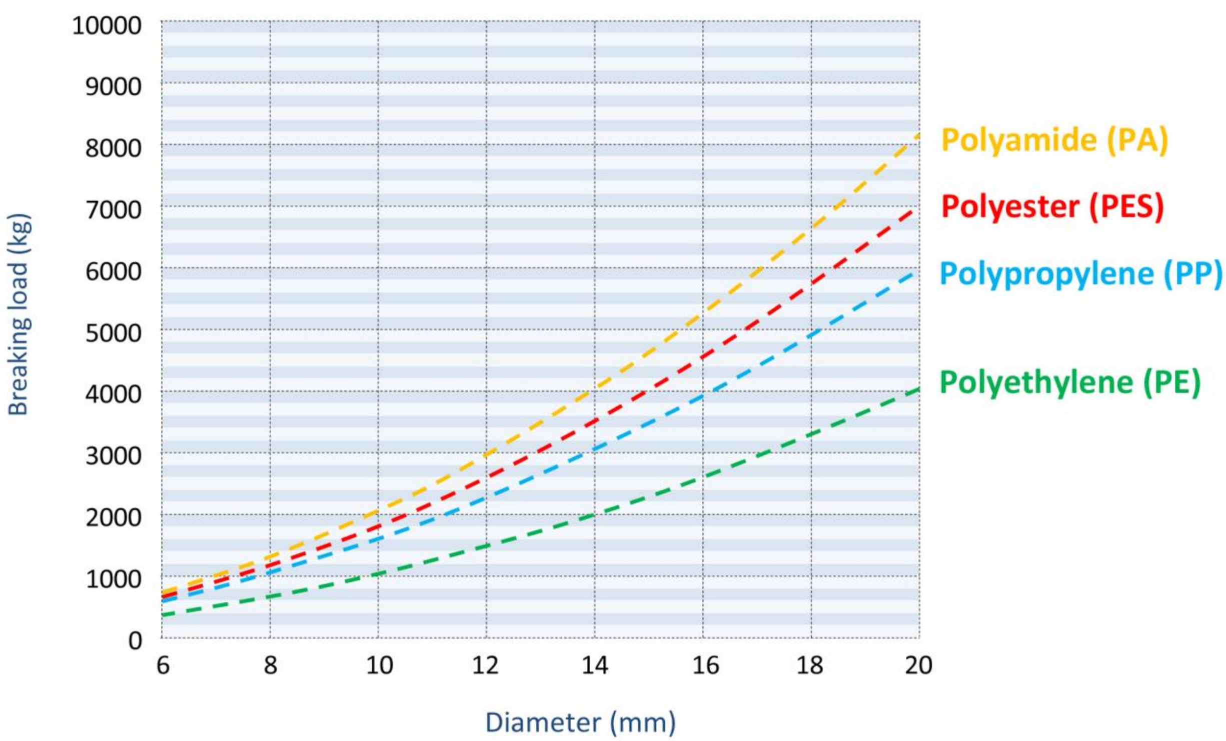
Prior to any price comparison between providers, you must absolutely recalculate the price by meter given by the providers to change it into a price per kilo.

*Price ($/kg) = Price ($/m) / linear weight (kg/100m) *100*

It is cautious to check the weight of the coils when the ropes are delivered.

4.4 Rope resistance

The resistance of the ropes depends on their diameter, material and manufacturing process. The breaking load of the rope expressed in kilograms or tons characterizes it (Figure 12).



The diagram gives the average breaking load provided by 5 rope manufacturers for products that are roughly comparable.

The resistance of polyamide ropes (PA) decreases by 10% when they are wet.
The resistance of spliced ropes decreases by 10%.
The resistance of knotted ropes decreases by 50%.

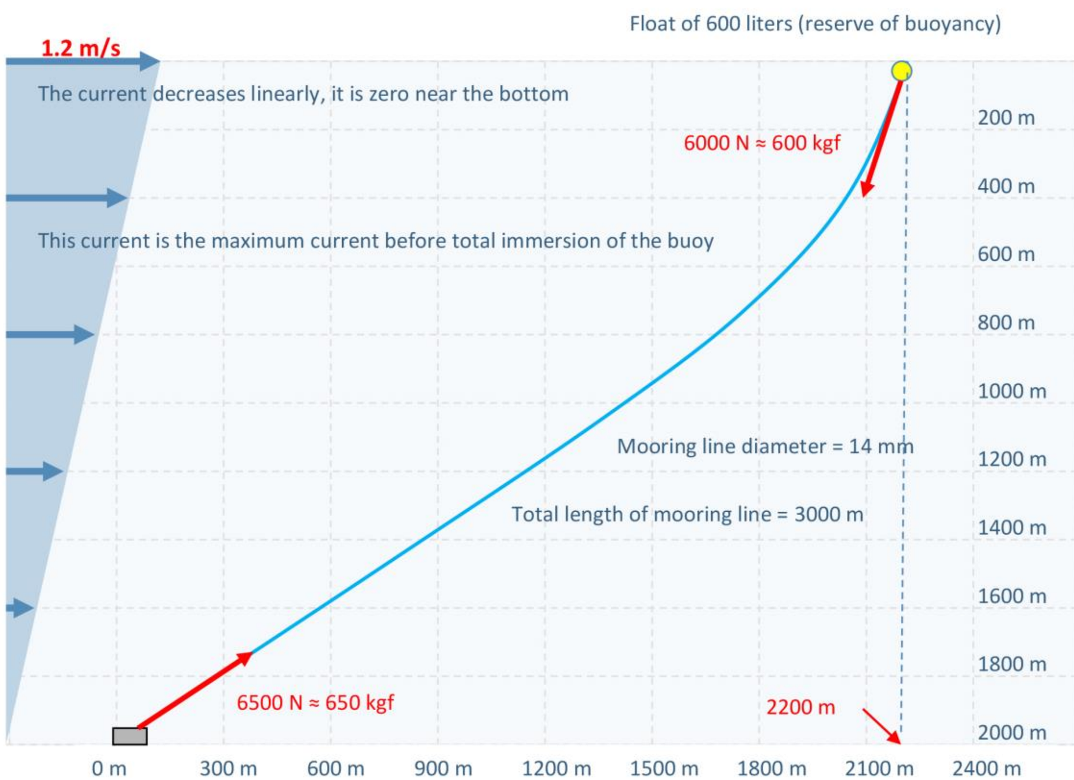
Figure 12: Breaking load of ropes.

The real resistance of the rope decreases greatly if it is tied and, to a lesser degree, if it is wet (for polyamide). The aging process, exposure to ultraviolet radiation, and fatigues due to sudden and repeated variations of tension strongly diminish the resistance to breaking of the ropes. It is thus necessary to adopt a safety coefficient between the breaking load and the operating load of a rope. The coefficient is at least 10 if the rope is used to lift loads; it can be reduced for FAD making, but must at least equal 3.

Operating load = breaking load / safety coefficient

It is the maximum currents in the area of the FAD that determine the maximum tension experienced by the mooring line. That tension will be considered as the operating load; it can be calculated with Ifremer's FAD modeling software (downloaded from the site http://carafad.eu) and by estimating the maximum currents present in the region (Figure 13).

As an example, let us take a 600-liter buoyancy FAD set on a site of depth 2000 m (6500 ft.) and with mooring line, of a total length of 3000 m (10 000 ft.) and made with ropes of 14 mm diameter. If the FAD is subject to strong currents leading to its total submersion, the tension on the mooring line is about 600 kg near the buoy, and 650 kg near the anchorage. If the current further increases so much that the FAD immerses at 400 m (1300 ft.), the maximum tension reaches 750 kg. The safety coefficient is then 4 in relation to the 14-mm PP rope used (breaking load 3000 kg, see Figure 12). The usual tension of the rope for moderate currents of about 0.35 m/s is approximately 120 kg.



By modeling the FAD we obtain the maximum supportable current, the shape of the rope, the tensions in the rope and the radius of the watch circle.

Figure 13: Modeling a FAD.

The safety coefficient will be such that the mooring line can resist aging long enough. The immersed rope is well protected from ultraviolet radiation, which is an important aging factor, but it undergoes continuous variations of tension due to swell provoking fatigues that are difficult to evaluate. The most important and sudden falls in the resistance of the rope of the mooring line are caused by everything that damages it: abrasion, partial cuts, tangling, kinks and knots. Resistance to abrasion and rubbing is particular to each type of rope; it is important when choosing a rope for the mooring line. You may choose ropes with a low breaking load but a better resistance to abrasion, as almost all breakages occur after events of accidental wear.

4.5 Selecting the diameter of the ropes

As a consequence, the selection of the diameter of the ropes must comply with resistance requirements and withstand aging and minor damages to their surface. But the diameter of the different sections of the mooring line determines the value of the drag forces caused by the effects of the current on the rope: the smaller the diameter of the line, the weaker those forces and the better the FAD will withstand currents. You will have to find the best compromise: the bigger the diameter, the more solid the FAD but the less its resistance to total submersion.

The compromise is even more sensitive near the surface because it is the area where the mooring line is most exposed to various damages and fatigue factors. It would thus be good to increase its diameter, but it is also at the surface that currents are the strongest and that the angle between the direction of the line –almost vertical- and that of the current is the most disadvantageous. These two factors would lead one to diminish the diameter of the rope.

The "hawser" FAD illustrates that difficulty very well: fishermen sometimes find long lengths of hawsers, with a diameter as important as 80 millimeters, floating on the surface. They use them to make FADs that are therefore solid, well protected where the hawser is, but easily submerged when the current heightens.

5. THE LENGTH OF THE ROPES

5.1 The total length of the mooring line

The total length of the mooring line is one of the main features of the FAD. It influences how it holds as well as its resistance to submersion when the current in strong. It also conditions the watch circle. The cost of the very long mooring line of deep FADs constitutes a large part of their total price.

The relation between the total length of rope and the depth; or length to depth ratio, determines the length of the rope (Figure 14). The ratio is necessarily superior to 1, except for subsurface FADs, as they are always immersed. For ratios close to 1, the FAD is easily completely immersed as soon as the current increases a little. Ratios close to 1.2 may be used in areas not exceeding 1000 m (3000 ft), where currents are not too strong. Ratios around 1.5 are more frequently used and represent a good compromise in numerous cases. The greatest ratios applied are 2; beyond, the watch circles become huge.

ratio < 1	only for very shallow water (subsurface FADs)
ratio =1.2	although sometimes recommended in the literature, modeling shows that this ratio is only suitable for areas not too deep where currents are not too strong
ratio = 1.5	a good compromise for deep set up
ratio = 2	This ratio is often used by fishermen for artisanal FAD, but very often without enough sinking rope or sinkers. A lot of rope may be at the surface when there is no current. For deep FADs the watch circle becomes huge.
ratio = 3	maximum theoretical ratio, beyond you have necessarily rope at the surface or on the bottom

Figure 14: The length to depth ratio.

5.2 Length of the floating rope, length of the sinking rope

When the current is low, the shape of the mooring line depends on the right calculation and distribution of the length between the floating and the sinking rope. The longer the floating rope, the closer the line gets to the surface. If there is too much rope, there will be rope at the surface. If the sinking rope is too long, there will be lengths of rope on the sea bottom. An accurate calculation of the length of both ropes avoids these two situations and places the loop at the right distance from the surface in order to avoid tangling with fishing gears. The calculation depends on the diameter and density of both ropes.

5.3 The ballast option for polypropylene (PP) or polyethylene (PE) mooring lines

Although it is an unadvisable practice, a lot of artisanal FADs' mooring lines are made with floating ropes only. Ballasts, often sand bags, are placed on the line to make it sink. The calculation provides the amount of ballast to be used and its position on the mooring line to obtain the desired layout. A good idea would be to divide the ballast and distribute it over a length of 100 or 200 m (300 to 700 ft.) around the position indicated by the calculation.

When currents are low, the mooring line forms two loops: one goes up to the surface and the other one dives towards the bottom if the current switches direction and sets in a direction opposite to that of the previous current. The two loops can meet because the current speeds differ according to the depth. It is therefore important that they can slide on one another and redeploy properly. During these phases of change in the current patterns, the presence of ballasts may create tangling that can very seriously harm the solidity of the mooring line. Hence the importance of using setup techniques for the ballasts taking these risks into account.

5.4 The length of the combination cable

When there is no current, some of the sinking ropes stand vertically from the float. Their weight affects the buoyancy of the FAD but does not influence the shape of the mooring line. Therefore, the length of the combination cable only depends on the distance over which you want to protect the mooring line, and in some instances, on the ballast weight of the buoy you want to reach. It varies between 200 and 400 m (700 and 1300 ft.).

5.5 The length of the inter-float ropes

For string FADs, the length of rope between the floats must be the shortest possible in order to limit the length of the device at the surface. On artisanal FADs, the length observed between the floats is sometimes important. Indeed, there is a widely spread belief that a deeper float pulls stronger upward: and so, by putting more length between the floats, the first sunk floats work better to help the other ones. Although Archimedes does not agree with such approach, it keeps prevailing and produces great quantities of rope at the surface as well as very vulnerable FADs e.g., the floats could also become entangled.

5.6 The watch circle

Once you know the depth and length of the mooring line, you get the watch circle of the device: it is the horizontal distance between the FAD float and its anchoring block when the current is such that the float is at the limit of being completely immersed. That distance fluctuates by a few dozen meters depending on the profile of the current according to the depth. It is greater for surface currents and lower for deeper currents. An approximate value is enough to look for the FAD.

5.7 The lengthening and resiliency of the rope

The total lengthening of a rope comprises two components:

- The permanent lengthening relates to new ropes. It increases until the rope has worked enough so that each fiber finds its place.
- The elastic lengthening that disappears when there is no tension anymore.

Although the lengthening of the ropes is not a decisive factor in the making of a FAD, it needs to be taken into account to precisely calculate the watch circle especially if polyamide (PA) is used (Figure 15).

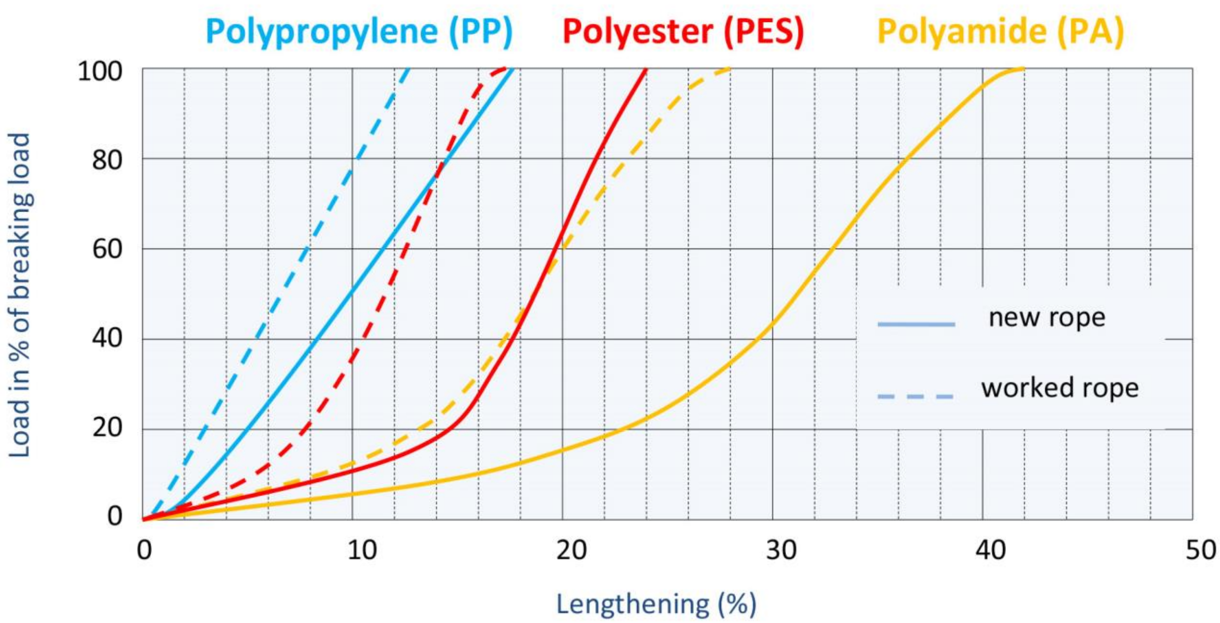
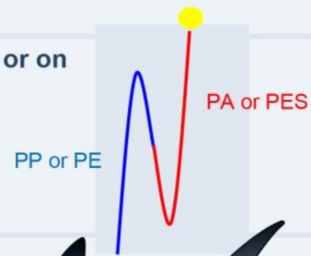


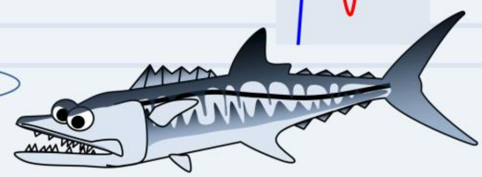
Figure 15: The lengthening of ropes.

CHOICE OF THE ROPES FOR THE FAD MOORING LINE

Take care not to have rope on the surface of the water or on the sea bed when there is no current.

- Use floating rope and sinking rope (recommended).
- Use sinkers if you don't use sinking rope.





Reinforce the upper part of the line.

For the first 200 or 300 m of the line:

- Use a combination cable.
- Use a larger diameter of polyamide (PA) or polyester (PES).

Choose the ratio length /depth.

Consider:

- The depth,
- The current in the area,
- The watch circle,
- The price of the FAD.

Choose the ropes and their diameters:

- Stranded 3 strands (the cheaper),
- Braided 8 strands (recommended),

- PP or PE for the floating rope,
- PA or PES for the sinking rope.

For example:

buoyancy of floats	diameter of rope
300 liters	10 /12 mm
400 liters	12 /14 mm
600 liters	14 /18 mm

Put the right length for each rope or the right weight for the sinkers.

For polypropylene (PP) and polyamide (PA):

PP	PA
3/5 of total length	2/5 of total length

For polypropylene (PP) and polyester (PES):

PP	PES
2/3 of total length	1/3 of total length

Examples for polypropylene (PP) line and sand bags sinkers:

depth	total length of line	diameter	weight of sand sinkers	position from the surface end of the rope
1000 m	1500 m	12 mm	10 kg	550 m
1500 m	2250 m	12 mm	13 kg	675 m
2000 m	3000 m	14 mm	22 kg	800 m
2500 m	3750 m	14 mm	27 kg	925 m

Figure 16: Choice of the ropes for the FAD mooring line.

6. ANCHORING SYSTEM SELECTION

6.1 The weight of the anchoring system

The anchoring system of the FAD can be a block of concrete, recycled metal pieces –banning the still common use of contaminated old engines- or sand bags. You must calculate the weight of the anchoring system so that the float can neither lift it nor make it slip on the bottom, as a result of the forces generated by the current on the anchoring line.

If the weight in water of the block is greater than the buoyancy of the FAD float, the latter will not be able to lift it. It is the theoretical minimum weight that is used as the base for the calculation of the weight of the anchoring system. But that weight is not enough, the anchoring block may also slip on the bottom as a result of the lateral component of the force exercised by the mooring line on the anchoring system. Calculating the weight of the anchoring system preventing such slip is more difficult. Indeed, it depends not only on the friction between the block and the bottom, therefore the nature of the sea bottom, but also on the slope of said bottom and the direction of the current in relation to that slope. If the bottom is sloping and the current goes in the direction of the slope, the FAD –for which the weight of the anchoring block is insufficient- will go adrift and risk being lost because the length of the mooring line will get too short for further depths. If the ocean bed is flat, the FAD will drag the block and stop when the strength of the current diminishes. It will thus become a moving FAD very difficult to track and running the risk of tangling with other FADs.

In the absence of accurate calculations, observation and experience lead to increase by at least 50% the theoretical minimum weight calculated while limiting to 100% because the weight of the anchoring system is often the main difficulty met in setup operations. As a consequence, the safety coefficient for the calculation of the anchoring weight varies from 1.5 to 2. The choice of the coefficient will thus depend on the depth: as deep as 1500 m (5000 ft.), a 1.5-coefficient is enough; a 1.6 to 17-coefficient for depths between 1500 and 2500 m (5000 and 12 000 ft.) seems to be right; a 2-coefficient is needed beyond 2500 m (12 000 ft.). The weight in water of the block depends on the density of the material of which it is composed, and on the relative density of the water.

6.2 Blocks of concrete

Blocks of concrete are the most common anchoring system. It is quite easy to make and not too costly. But the rather low relative density of concrete leads to quite high weights of blocks –about three times the buoyancy of the FAD. In the case of blocks of concrete, the load may be divided into several blocks gathered together. On the boat, you will have to prepare the setup very carefully so that there is no incident when the blocks can tip the vessel over. The presence of a chain cast in the concrete of the anchoring block at the beginning of the mooring line, frequent in the literature about FAD making, increases the weight of whole set, improves the angle of traction on the anchoring block, and cushions the jolts on the anchoring line. It is not necessary if the block is heavy enough, and that solution is little used.

6.3 Metal pieces

The anchoring weight needed depends on the relative density of the materials. A similar result will be reached with a slightly lighter weight by using metal pieces rather than concrete block.

For example, a 1500 kg block of concrete can be replaced by 840 kg of metal pieces. The use of recycled metal pieces is much spread for small artisanal FADs not needing more than 200 or 300 kg of ballast, but a block of concrete is generally used for public FADs because finding enough metal pieces of the right weight and shapes to make an anchoring block is not always easy.

6.4 Sand bags

The use of sand bags as anchors can be a cheap and practical solution on small boats because sand may be easily available locally, they are easy to carry by hand as each bag may weight 50-55 kg and they may remain steady even on a sloped bottom. The total anchor weight is easy to adjust by varying the number of bags. The bags have to be solid enough and the connection between them correctly made. The bags being numerous, you must make sure that they get into water at the same time. If they are suspended along the side of the boat, the operation is rather safe. As the load is distributed on each side of the boat, you must ensure that the dropping is perfectly synchronized. If you use sand, which has an unknown density, checking the weight in water of a bag by weighing it when it is totally immersed is advisable; you can then infer the density of the sand by comparing the value to the weight of the dry sand.

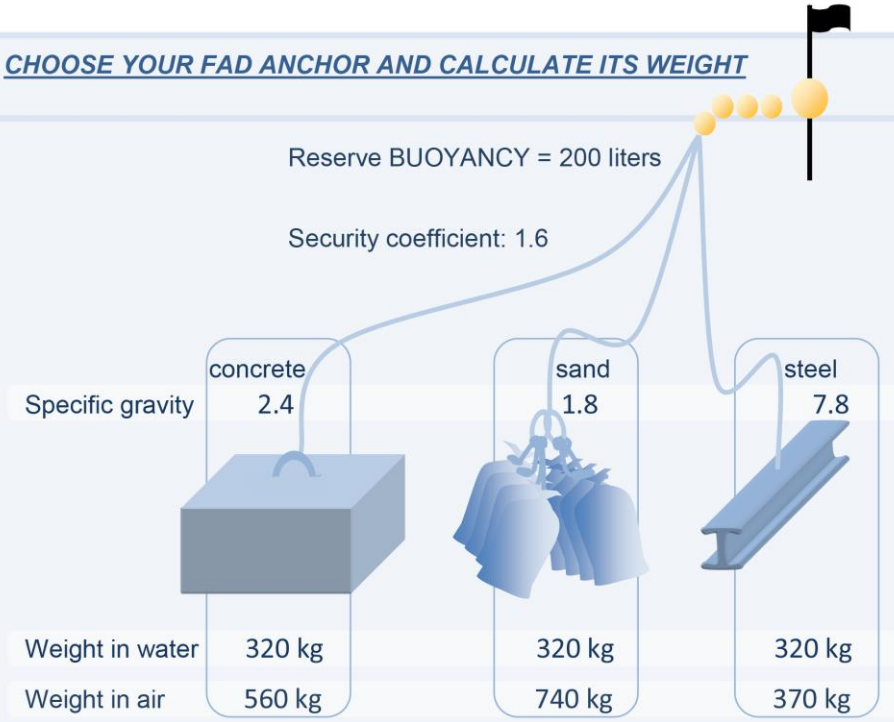
Material specific gravity = (weight in air / (weight in air – weight in water)) x sea water specific gravity

6.5 Anchors and chains

The weight of the anchoring system can be sensibly diminished by using anchors and chains. The shape of the anchors considerably increases their adherence; the chains make the lower part of the anchoring system heavier and further favors the holding of the whole device. Although attractive, this solution that sensibly reduces the weight of the elements to be handled during the setup is not used because of the cost of anchors and chains.

Examples of mixed systems were observed: a block of concrete is completed by a small quantity of chain and an anchor or a grapnel in order to avoid slipping. Then again these measurements are not useful if the block of concrete is heavy enough. They can be useful in helping to diminish the weight of the whole device if the ship meant for the setup has a limited load capacity.

CHOOSE YOUR FAD ANCHOR AND CALCULATE ITS WEIGHT

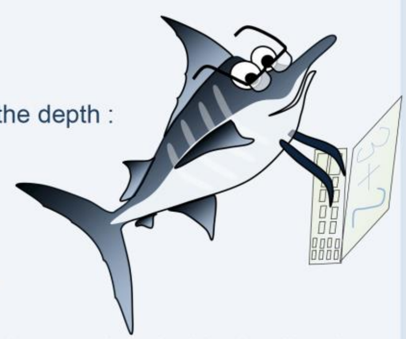


Weight in water = Weight in air (1-(sea water specific gravity /material specific gravity))

Weight in air = Weight in water/ (1-(sea water specific gravity /material specific gravity))

- Be sure that your anchorage is heavy enough :
  - for concrete and sand at least 3 times the buoyancy of the FAD,
  - for metal pieces around twice.
- Better : do the calculations !
- Increase the security coefficient with the depth :

depth	security coef.
1000 m	1.4
2000 m	1.7
3000 m	2



- Don't use not depolluted old engines.
- Be sure the boat you want use for deployment is suited for loading the anchorage.
- Think carefully about tilting system of the anchor.
- Check the correct lashing of the anchor before navigating.

Figure 17: Choose your FAD anchor and calculate its weight.

7. METAL COMPONENTS OF FAD MOORING LINES

Figure 18 and its nomenclature shows the various metal components of a FAD's mooring lines.

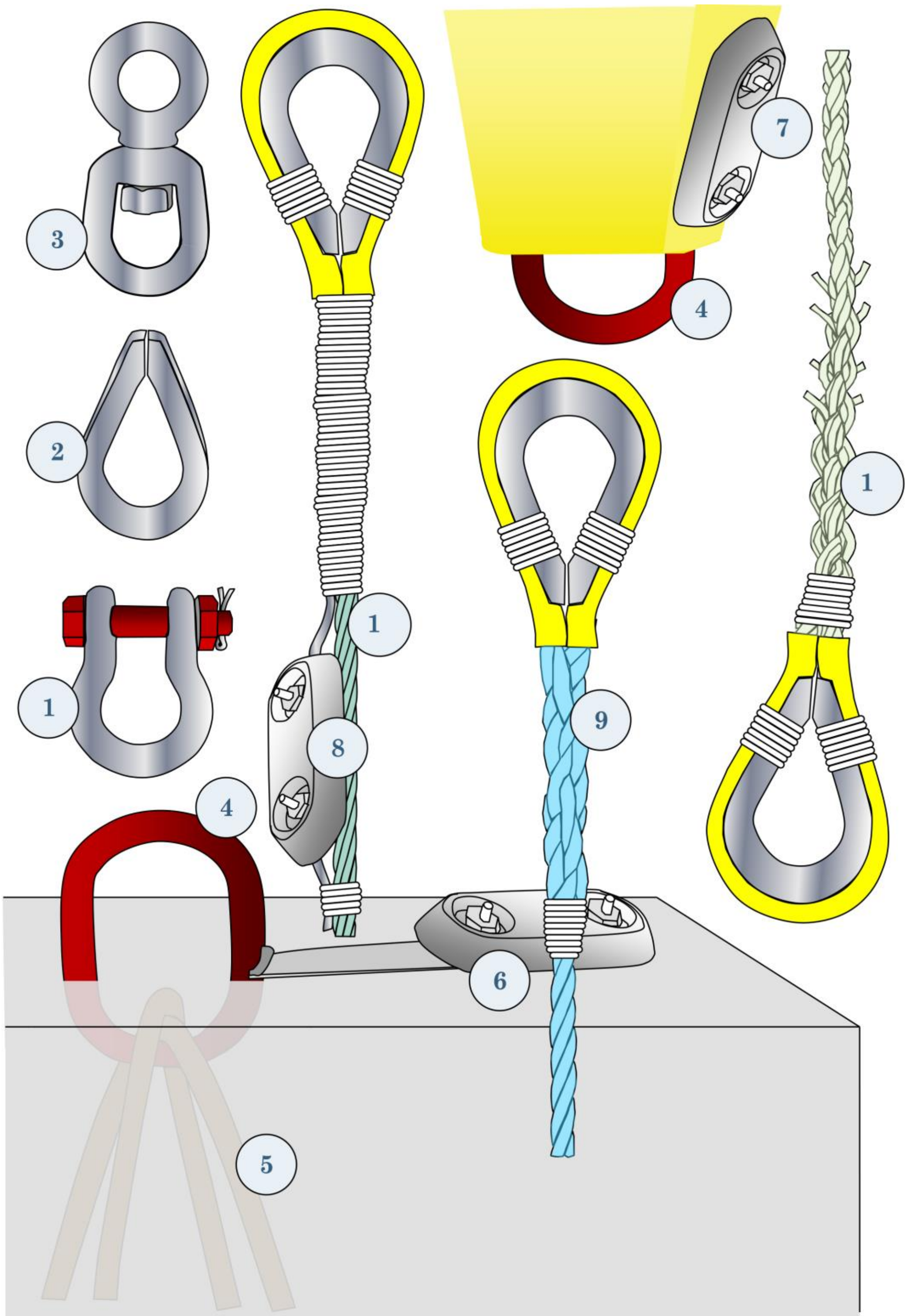


Figure 18: Metal components of a FAD.

Nomenclature of Figure 18:

(1) Shackles are in galvanized steel in the quality for lifting equipment. The working load limit (WLL) is always incised on shackles for lifting. The best is lyre shackles with screw and cotter pin.

(2) The thimbles are thimbles for cable whose section is much thicker than those for ropes, and of better quality. We use a thimble one or two size more than the diameter of the rope for example a 20 mm thimble is used for a 14 mm rope. The flexible hose protection suits the rope diameter to that of the thimble.

(3) The swivel is often described as an essential component of Fads' mooring lines.
But swivels are not very efficient:

- Swivels can rotate only if the load does not exceed a few tens of kilos which is almost always the case with FADs.
- Turns are not transmitted if the line is lack, usually the line twists on itself and kink.
- Very often swivels are blocked by corrosion and more often by trolling lines tangled.

Luckily swivels are also not very useful:

- The heads of FAD doesn't turn on itself
- The number of revolutions of a FAD around its turning circle is small and the long mooring line can tolerate a few turns. (DOM1 a MAGDELESA FAD was fitted with a GPS and we count less than 10 turns in height months, and not always in the same direction).
- If the preparing and shooting rules are respected the mooring line has few turns after deployment.

The main role of the swivel is trying to evacuate hundreds of turns in the rope when shooting directly from coils. (Not recommended).

The 7 and 8 Fads, without swivels, laid in Martinique in 2010 are still there (August 2015).

We see the same trend (elimination of swivels) in other regions of the world particularly in Polynesia.

If there is swivel they must be of the same quality as the shackle (for lifting quality).

(4) Lifting rings are used for anchorage and for monobuoy.

(5) Two rebars pass through the ring for consolidating.

(6) The anode is bolted on a flat iron and welded on the ring.

(7) During manufacture of the buoy an electrical connection is provided between the mounting bolts of the anode and the ring.

(8) The anode is fastened with cable clamps on the metal core of the combination cable

(9) Spliced eye in a 3 strands rope (see seamanship works for FAD http://carafad.eu).

(10) Spliced eye in an 8 strands rope (see seamanship works for FAD http://carafad.eu).

(11) Spliced eye in a combination cable (see seamanship works for FAD http://carafad.eu).

8. AGGREGATORS

8.1 Description

Aggregators simulate objects, wrecks and other floating debris around which fish are used to gathering. The most commonly found aggregators are tarpaulins, trawl blankets, sails and other similar items. They are fixed in a flag-like setting on the mooring line, from 2 or 3 m (10 ft.) up to 30 m (100 ft.) under the FAD. A surface aggregator floating behind the FAD is often added and is commonly made of coconut palms or trawl blankets.

The use of polypropylene strapping set in layers gives interesting results. Indeed, they trap much less hooks than other types of aggregators, are quite insensitive to fouling, do not grow too heavy and have a good aging resistance. They however, take longer to make.

Nothing indicates that one type of aggregator is more efficient than another one. Aggregators have almost no incidence on the position of the FAD when there is no current. They were thus neglected in the calculations. It is nevertheless important not to overload the FAD with aggregators as they increase the forces exercised by the current on the float. Indicatively, the common configuration is 3 tarps of a dozen m^2 (40 ft^2) and a 3-m (10-ft) trawl blanket on the surface.

8.2 The maintenance of the aggregators, aggregator kits

Fishermen are used to regularly and frequently maintaining the aggregators of the FAD. Such maintenance consists of replacing or cleaning the tarpaulins. This habit is meant to "reactivate" the FADs and increase their productivity. It seems empirically justified since fishermen have never stopped doing it, even though it is hard and sometimes dangerous work when performed with small boats. Originally, aggregators are well maintained because "new" FADs are productive.

With monobuoy FADs, as they are always equipped with combination ropes at the surface, that operation becomes impossible because of the very weight of the mooring line. Fishermen have thus started to add new aggregators without fixing them to the mooring line but simply suspending them to the buoy. It leads to a new concept of "aggregator line" completely separated from the mooring line. Such aggregator line must be weighted enough so that no part comes back at the surface because of the current and be light enough to be pulled up from a boat after having been separated from the FAD.

Photo 13: Aggregators in polypropylene strap bands.

9. DIAGRAMS OF 5 EXAMPLES OF FADs

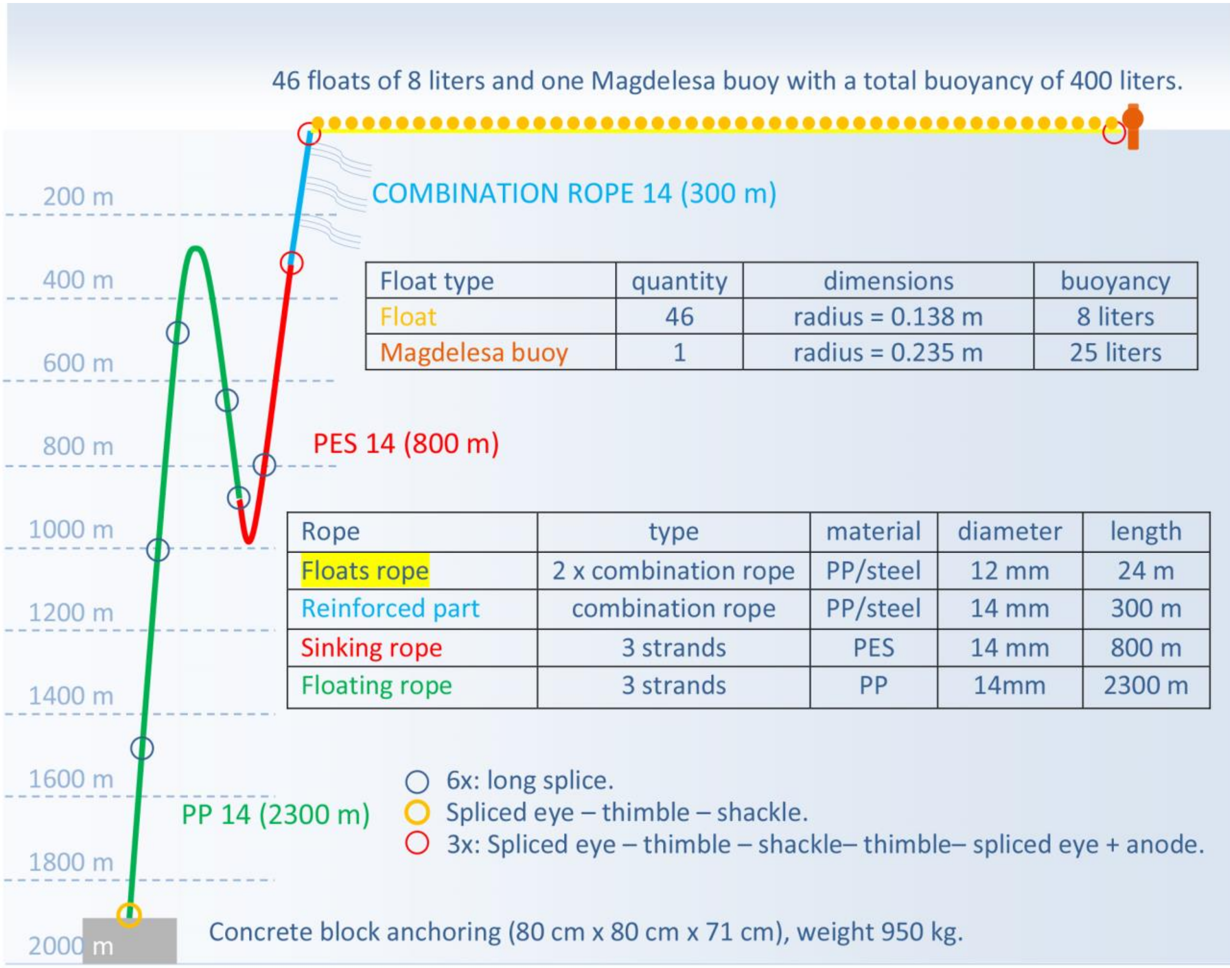
9.1 Artisanal FAD

Float type	quantity	dimensions	buoyancy
Float	3	radius = 0.138 m	8 liters
Can	4	L= 0.2 m l= 0.3 m h=0.4 m	23 liters
Inflatable buoy	1	radius = 0.25 m	59 liters

Rope	type	material	diameter	length
Floats rope	3 strands	PES	20 mm	20 m
Reinforced part	3 strands	PES	20 mm	180 m
Floating rope	3 strands	PP	10 mm	2800 m

Figure 19: Artisanal FAD.

9.2 MAGDELESA FAD



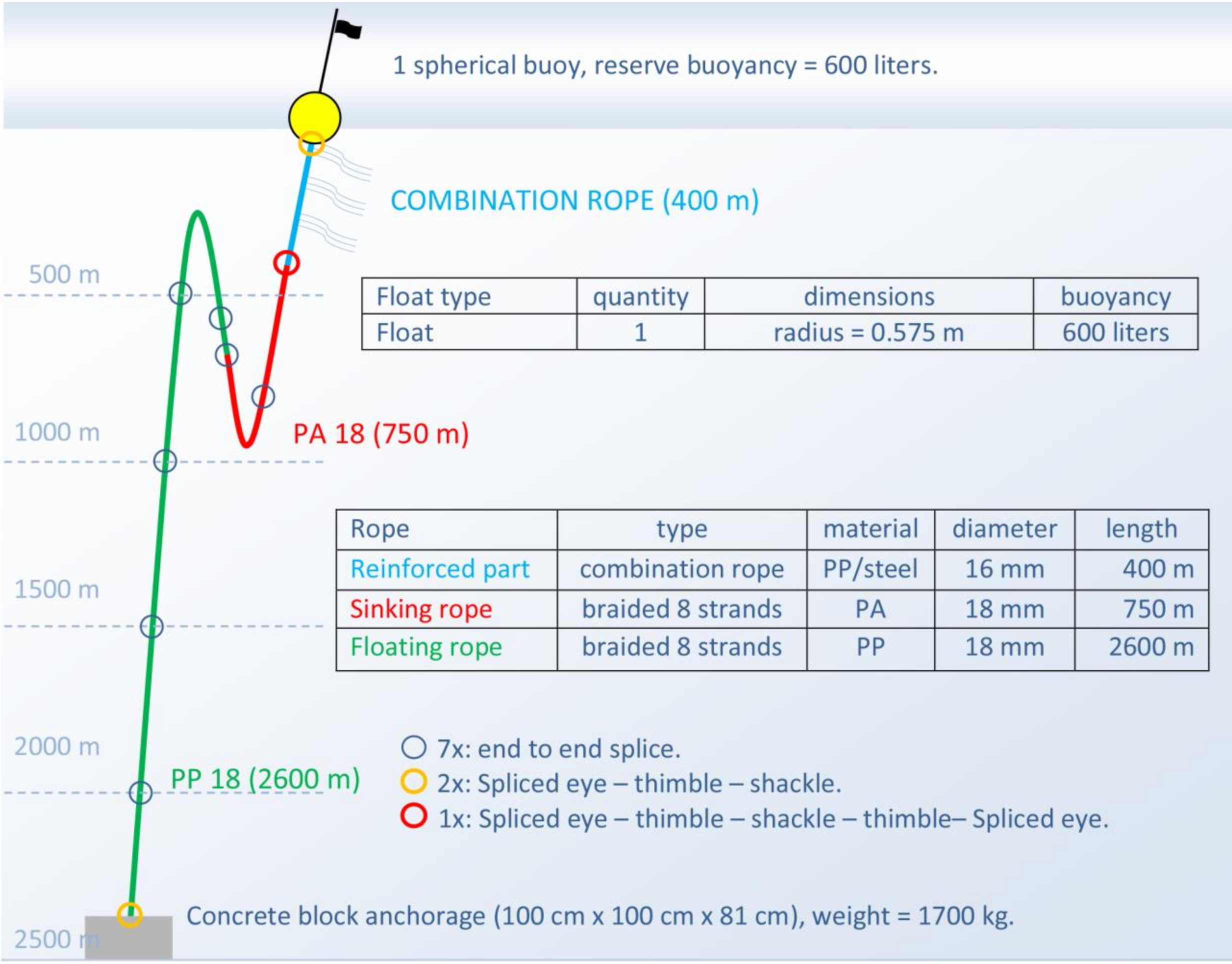
Float type	quantity	dimensions	buoyancy
Float	46	radius = 0.138 m	8 liters
Magdelesa buoy	1	radius = 0.235 m	25 liters

Rope	type	material	diameter	length
Floats rope	2 x combination rope	PP/steel	12 mm	24 m
Reinforced part	combination rope	PP/steel	14 mm	300 m
Sinking rope	3 strands	PES	14 mm	800 m
Floating rope	3 strands	PP	14mm	2300 m

Figure 20: MAGDELESA FAD.

Photo 14: MAGDELESA FADs.

9.3 PLK600 FAD



Float type	quantity	dimensions	buoyancy
Float	1	radius = 0.575 m	600 liters

Rope	type	material	diameter	length
Reinforced part	combination rope	PP/steel	16 mm	400 m
Sinking rope	braided 8 strands	PA	18 mm	750 m
Floating rope	braided 8 strands	PP	18 mm	2600 m

Figure 21: PLK600 FAD.

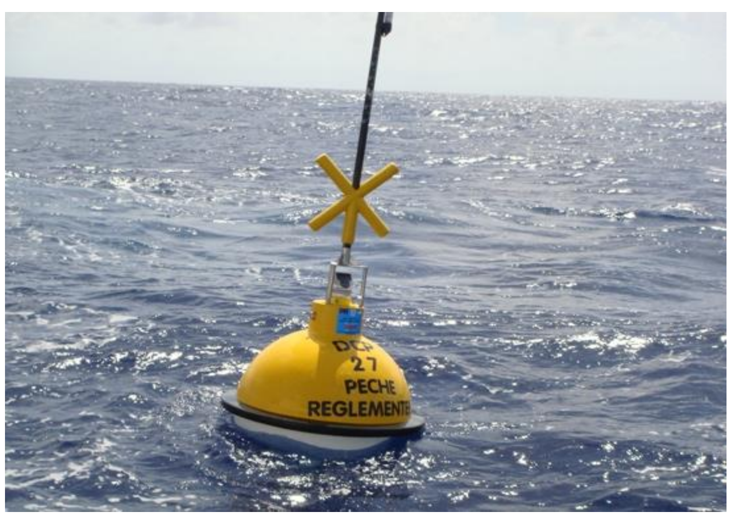


Photo 15: PLK600 FAD.

9.4 Two-Headed FAD

Float type	quantity	dimensions	buoyancy
Float	2	radius = 0.455 m	600 liters

Rope	type	material	diameter	length
Reinforced part	combination rope	PP/steel	12 mm	400 m
Sinking rope	3 strands	PA	14 mm	200 m
Sinking rope	3 strands	PA	14 mm	800 m
Floating rope	3 strands	PP	14 mm	1000 m

Figure 22: Two-Headed FAD.

350 m

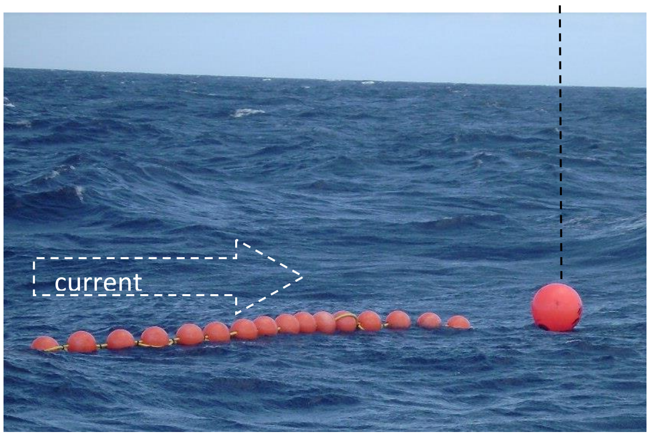


Photo 16: First head of a Two-Headed FAD.

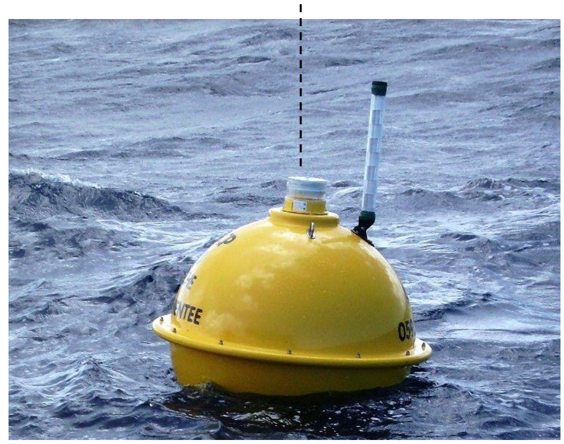
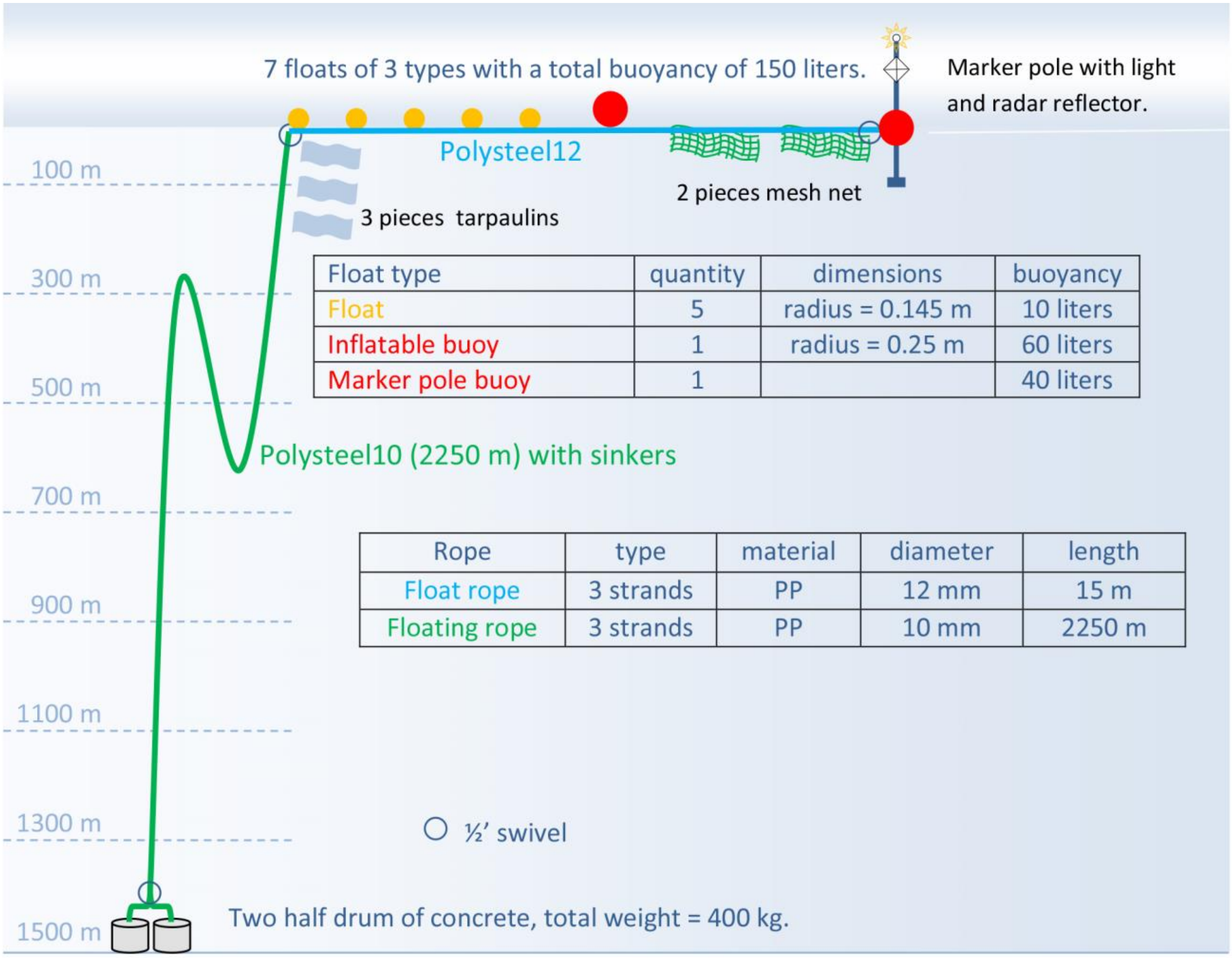


Photo 17: Second head of a Two-Headed FAD.

9.5 CARIFICO Project FAD



Float type	quantity	dimensions	buoyancy
Float	5	radius = 0.145 m	10 liters
Inflatable buoy	1	radius = 0.25 m	60 liters
Marker pole buoy	1		40 liters

Rope	type	material	diameter	length
Float rope	3 strands	PP	12 mm	15 m
Floating rope	3 strands	PP	10 mm	2250 m

Figure 23: CARIFICO Project FAD.

Photo 18: CARIFICO Project FAD.

B. FAD DEPLOYMENT

10. DEPLOYMENT, PREPARATIONS AND OPERATIONS

10.1 Introduction

The deployment of FADs has specific aspects that we will describe. The competencies required for navigation are those that every good captain must master. The crew must have the skill necessary for appropriately lashing load on deck and conducting usual maneuvers on a boat. If deployment of FADs is conducted occasionally it is important to take extra precautions for safety.

Though "anchor first" deployment is possible and significantly increases the accuracy of deployment position, it is, for obvious safety reasons, prohibited on small boats. And "anchor last" technique will only be recommended.

The boat must be a decked; at least 10 m (33 ft.) long, the ideal is that it has a door in the transom so that the anchor can be placed directly on deck. Otherwise strong tables are built to raise the anchor block above the transom.

The use of sandbags is well suited for small boats; they can be easily loaded with the weight distributed evenly on each side of the boat for safety. Once on site the bags are evenly suspended on both sides of the boat which are held together by a rope attached to two connecting rings. When all is clear the rope is cut to release the anchor.

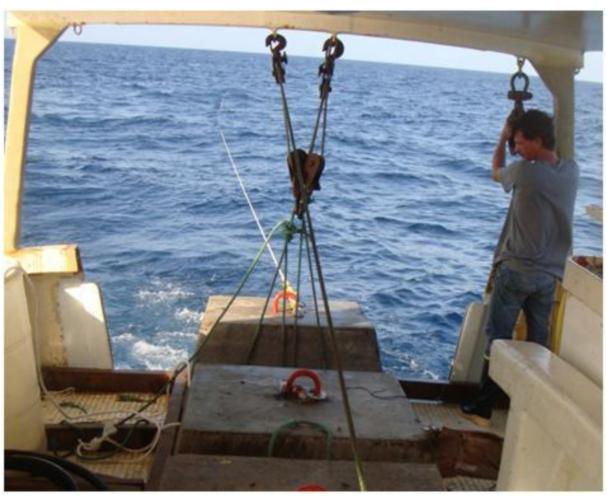


Photo 19: Large stern door in the transom, the concrete blocks are loaded directly on the deck.

Photo 20: A makeshift table raises the block slightly above the transom.

Photo 21: Rings for sandbags anchor.

Photo 22: Sandbags anchor alongside the boat.

10.2 The Choice of the Deployment Side and the Arrangement Aboard

Whatever its initial course, when a boat stops at sea, it evolves up to crosswind. It then remains in this stable heading, maintaining a drift speed directed in the same direction as the wind. In this situation one side is suitable for deploying the FAD: this is the side from which the wind is coming.

When deploying on this side the boat moves away from the material and shooting can continue without difficulty even when the boat stops or moves at very low speed. When deploying on the other side the rope may go under the boat and rub on the hull which poses serious risks of damages and entanglement in the propeller when the boat resumes its course.

So it is important to choose the correct side for FAD deployment. In this way a part of the shooting can be made while the boat is stopped, using the single drift speed of the wind, especially the deployment of floats and aggregators. In unforeseeable circumstances the crew may, at any time, stop the boat while still shooting the line. Always remaining under the right tack (the side from which the wind is coming) the rope shoots in open spaces without ever going above materials still on board, whatever the speed of the boat. It can stop if necessary without risk of drifting towards the rope already in the water.

The layout on board will have to be adapted to the boat's configuration (Figures 24 and 25). The coils of ropes will be unwound and the rope faked in wide folds preferably in rope crates (Figure 3).

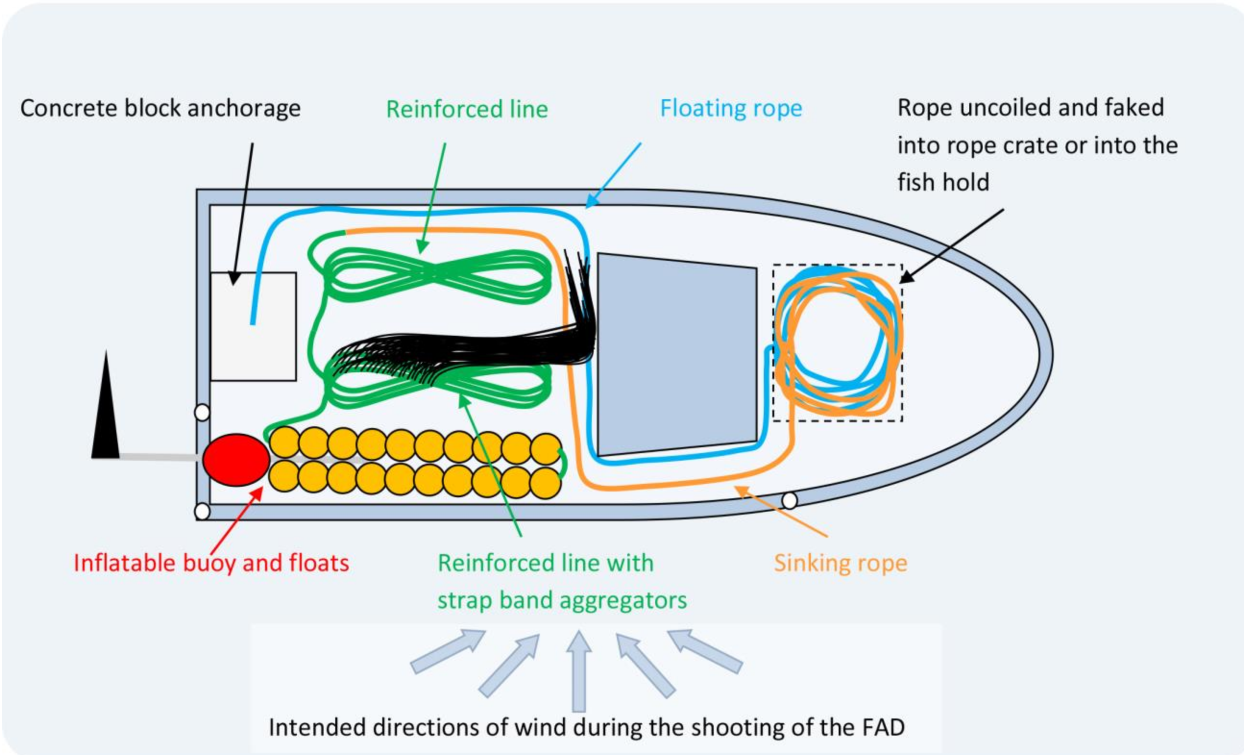


Figure 24: Correct layout on the deck of an 11 m (36 ft.) fishing boat for deployment on starboard side.

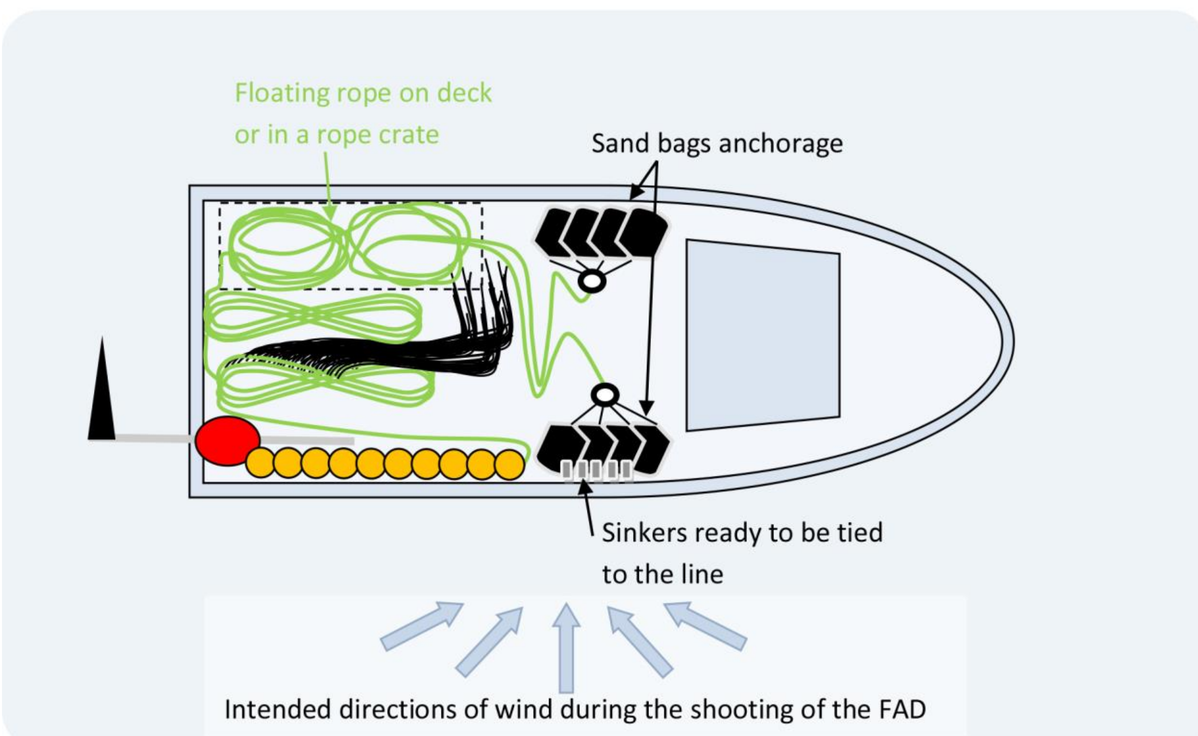


Figure 25: Correct layout on the deck of a 9 m (30 ft.) fishing boat for deployment on starboard side.

10.3 Deployment on a straight line course

The straight line deployment against the current, though often described in the FAD literature, is not advisable because it is the technique that engenders the maximum tension on the mooring line during the descent of the anchor. When the anchor approaches the bottom it reaches depths where there is no current, and then stops drifting with the same speed as the buoy. If the FAD is deployed against the current it creates tension on the buoy and line. On the contrary, if the FAD is deployed with the current this creates slack in the line and decreases the tension (Figure 26).

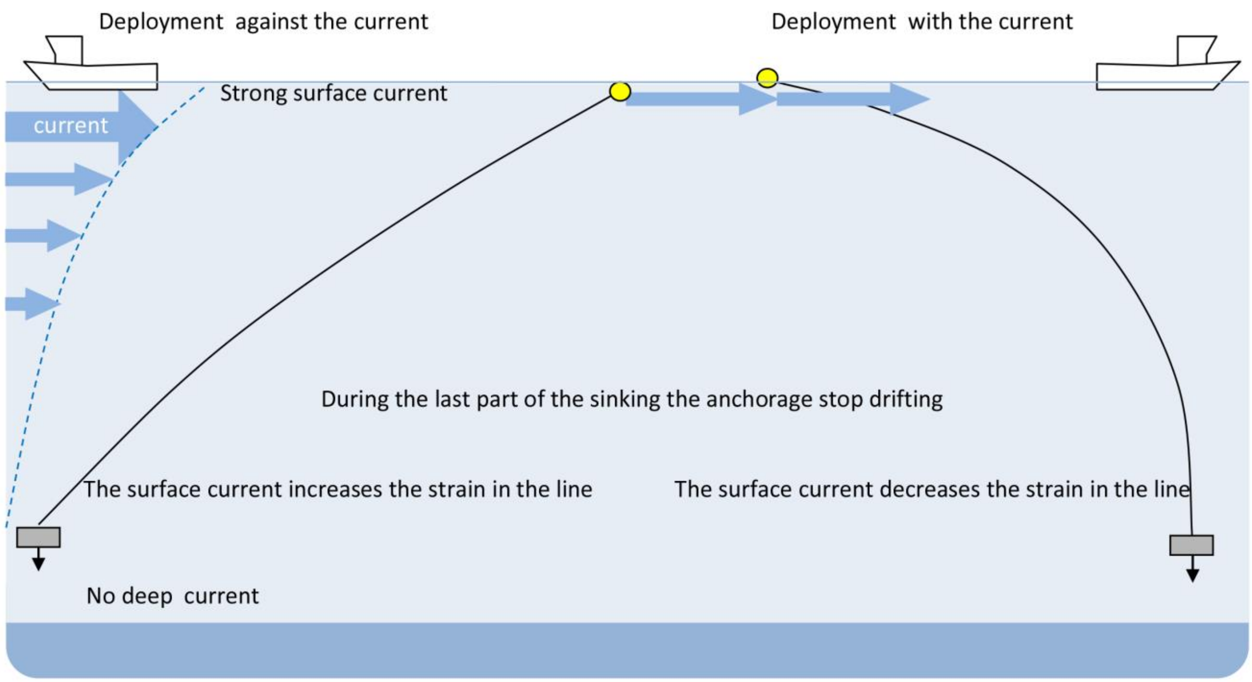


Figure 26: Avoid deploying straight against the current.

If the wind and current are heading in the same direction it is strongly discouraged to shoot against the current, because if the boat must stop then it will drift back onto the rope. Moreover, during its sinking, the anchor moves towards the buoy, this horizontal displacement is difficult to evaluate with accuracy which substantially reduces the precision of the deployment position. It is maximized with a straight deployment (Figure 27).

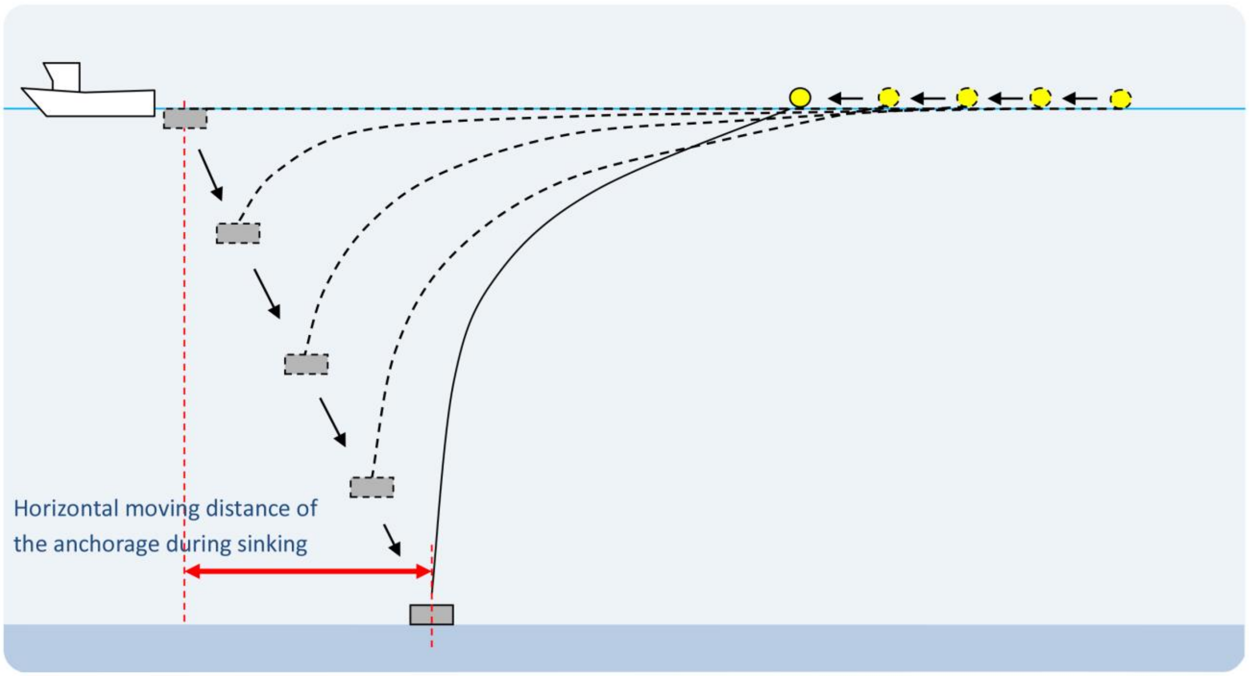


Figure 27: In a straight deployment the anchorage moves towards the buoy during the sinking.

Trajectories in circles, hairpins or zigzag are proposed to increase the accuracy of deployment position however, they are not recommended because they force the boat to change its tack during deployment, exposing risks.

10.4 Recommended courses for FAD deployment

The recommended deployment courses include a change of direction at half the shooting: in the first half the course will be at 20° or 160° from the wind and the second half crosswind. In this way the distance between the buoy and the anchor is significantly reduced and the anchor line is less tense. Very approximately, the block will move during its descent in the direction of the line (in the second part of deployment) with a distance equal to 1/4 of the depth (Figure 28).

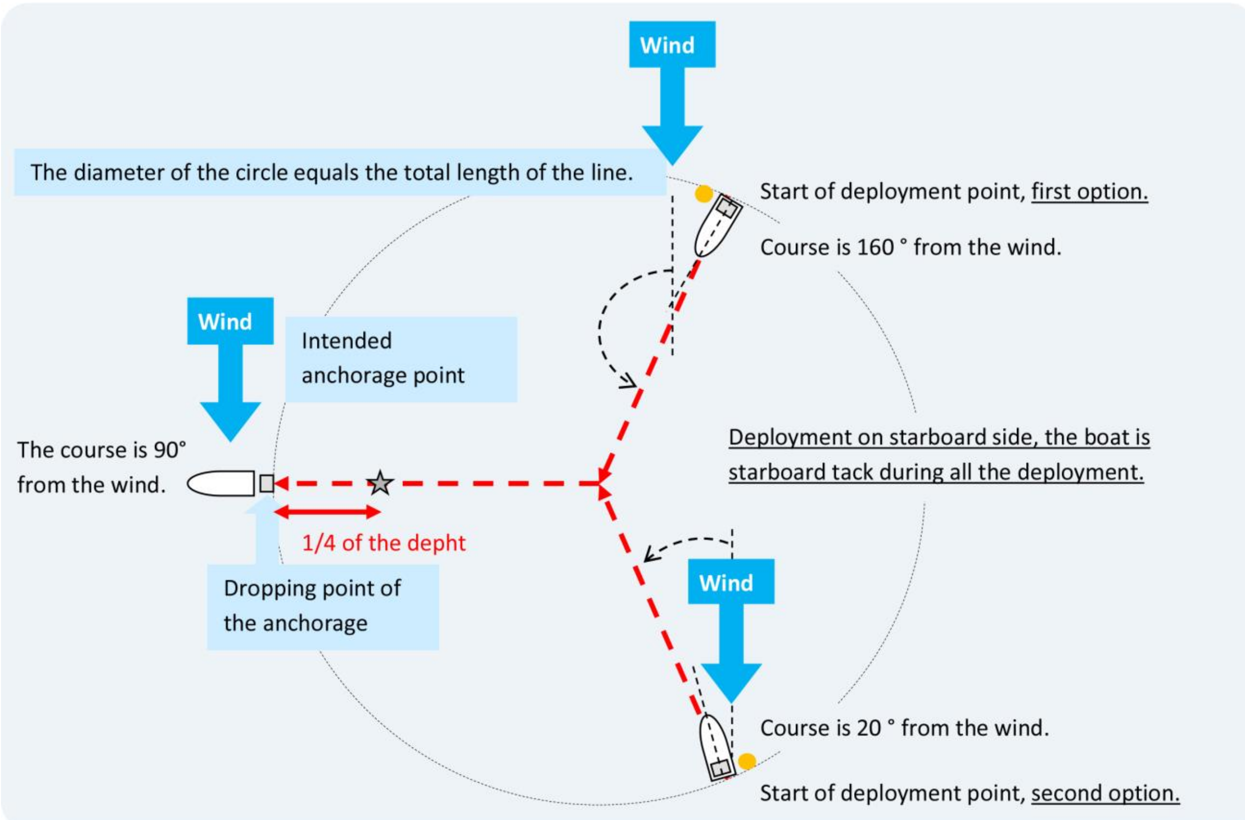


Figure 28: Courses during the deployment. Start points and dropping points when there is no current.

10.5 Start of deployment position

This position must anticipate the direction of the current during the deployment and during the sinking of the anchor as well as the anchor moves towards the line during its descent. Things to consider are:

- Speed and direction of the current - Upon arrival on the site, the current is measured; if the wind is weak the drift of the stop boat can be observed. If the wind is strong, and more accurate information is required on the current, then a float weighted with a drogue (a device outside the boat, but attached to the stern that is used to slow the boat down, particularly during a storm) can be launched. Comparing the release point and the recovery point (e.g. after 10 minutes) gives the direction and speed of the current.
- The duration of the deployment - it depends on length of line and shooting speed.
- The duration of the sinking of the anchor - it depends primarily on depth and density of the anchor system.
- Horizontal movement of the anchor towards the line - it depends on depth and trajectory of deployment.

10.6 Graphic construction to find the starting point of deployment

Preparatory calculations for graphic construction of the starting point:

Table 1: Preparatory Calculations

Data	Calculations
Deployment speed = 5 knots	*Deployment time*
Length of line = 4000 m	*=distance/speed [(4000/(1852*5))*60]*
	25 minutes
Depth= 2000 m	*Sinking time of the anchor*
	15 minutes (estimation)
Current speed = 1.5 knot	*Drifting distance during the deployment of the line*
	*= time x current speed [(25/60)*1.5]*
	0.625 nautical mile = 1157.5 meters
	Distance toward the line during the sinking of the anchor
	= depth/4 [2000/4]
	500 meters
	Drifting distance during the sinking of the anchorage
	= time x 1/2 current speed [(15/60)(1.5/2)]*
	0.1875 nautical mile = 347.25 meters
Drift due to the wind(for dual boats deployment)= 0.6 knots	*Estimation for medium wind and small fishing boat:*
	*= time x drift speed [(25/60)*0.6]*
	0.25 nautical mile = 463 meters

The rules of 'dead reckoning navigation' applied to calculated data allows one to place, on the map or on the plotter, the starting point of the deployment of FADs.

For memory: *Course through water = true heading + drift (from the wind)*

And vectorially: *Course over the ground = course through water + drift (from the current)*

Starting from the FAD intended anchorage point, we draw vectors 1 to 5, in numerical order, the end of vector 5 is the start of deployment point. (Vectors 1 to 4 in the case of a two-boat deployment).

Figures 29, 30 and 31 show three examples of graphical determination of start of deployment point.

10.7 The deployment

The boat starts at the calculated starting point with the wind on the right side. The crew deploys the head of FAD and aggregators, and then starts shooting the line with its first course. When half of the line is deployed the boat changes its course. The determined point of dropping the anchor must be reached when shooting the line is finished (Figure 29).

If there is a plotter, COG (Course Over the Ground) is drawn and the boat follows it. It is possible to compensate, partly, the inaccuracies with small changing of courses.

Vector	*Description*	*Direction (°)*	*Length(m)*
1	*current during the sinking*	270	350
2	*distance toward the line during the sinking*	135	500
3	*current during the deployment*	270	1150
4	*course through the sea (second part of deployment)*	315	2000
5	*course through the sea (first part of deployment)*	25	2000
6	*course over the ground*		
7	*course over the ground*		

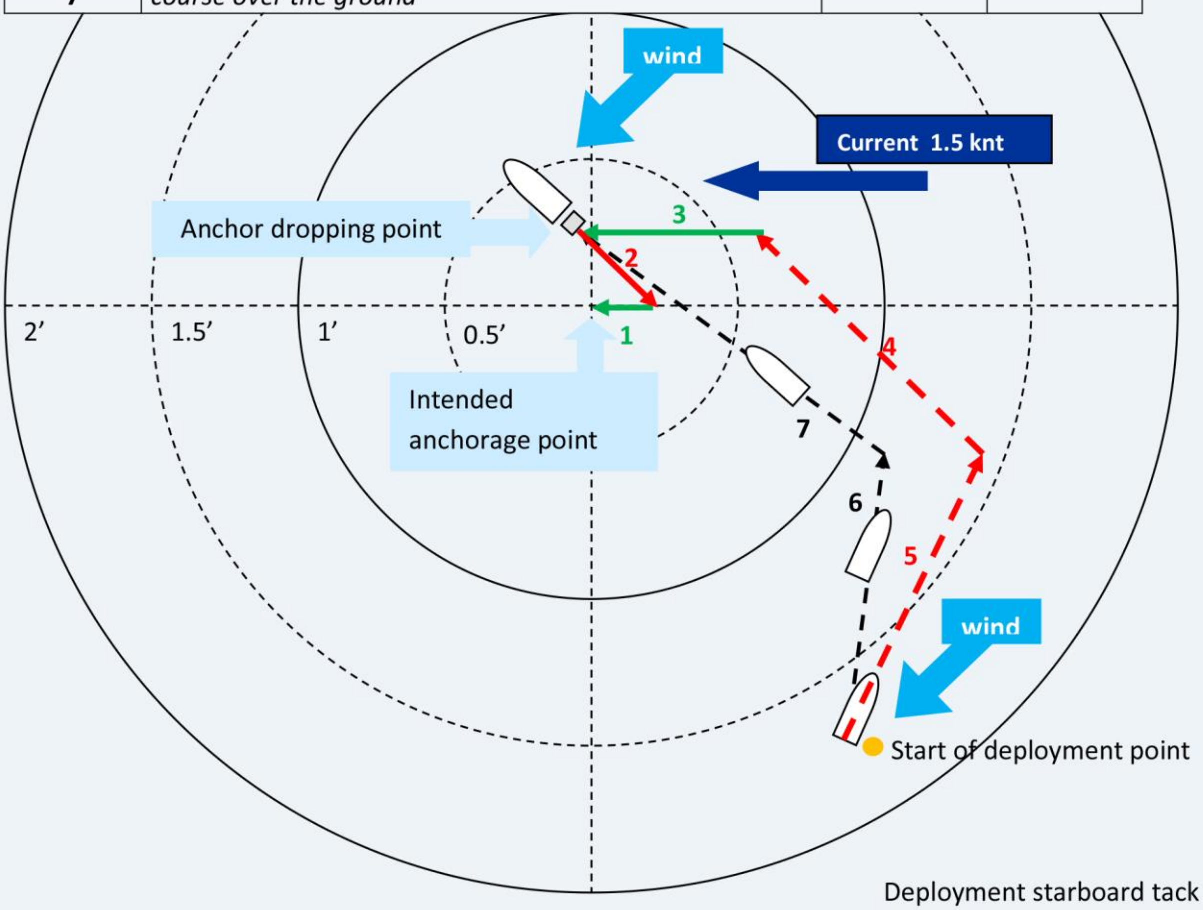


Figure 29: Courses during the deployment. Example with a NE wind and a W current (1.5knt).

Other trajectories are possible, provided you do not change the tack, the first part can be done at 160° from the wind and the second at 20°, it is a "V" path that reduces the distance between the buoy and the dropping point and increases the accuracy of deployment position (Figure 30).

Vector	*Description*	*Direction (°)*	*Length(m)*
1	*current during the sinking*	270	350
2	*distance toward the line during the sinking*	205	300
3	*current during the deployment*	270	1150
4	*course through the sea (second part of deployment)*	25	2000
5	*course through the sea (first part of deployment)*	245	2000
6	*course over the ground*		
7	*course over the ground*		

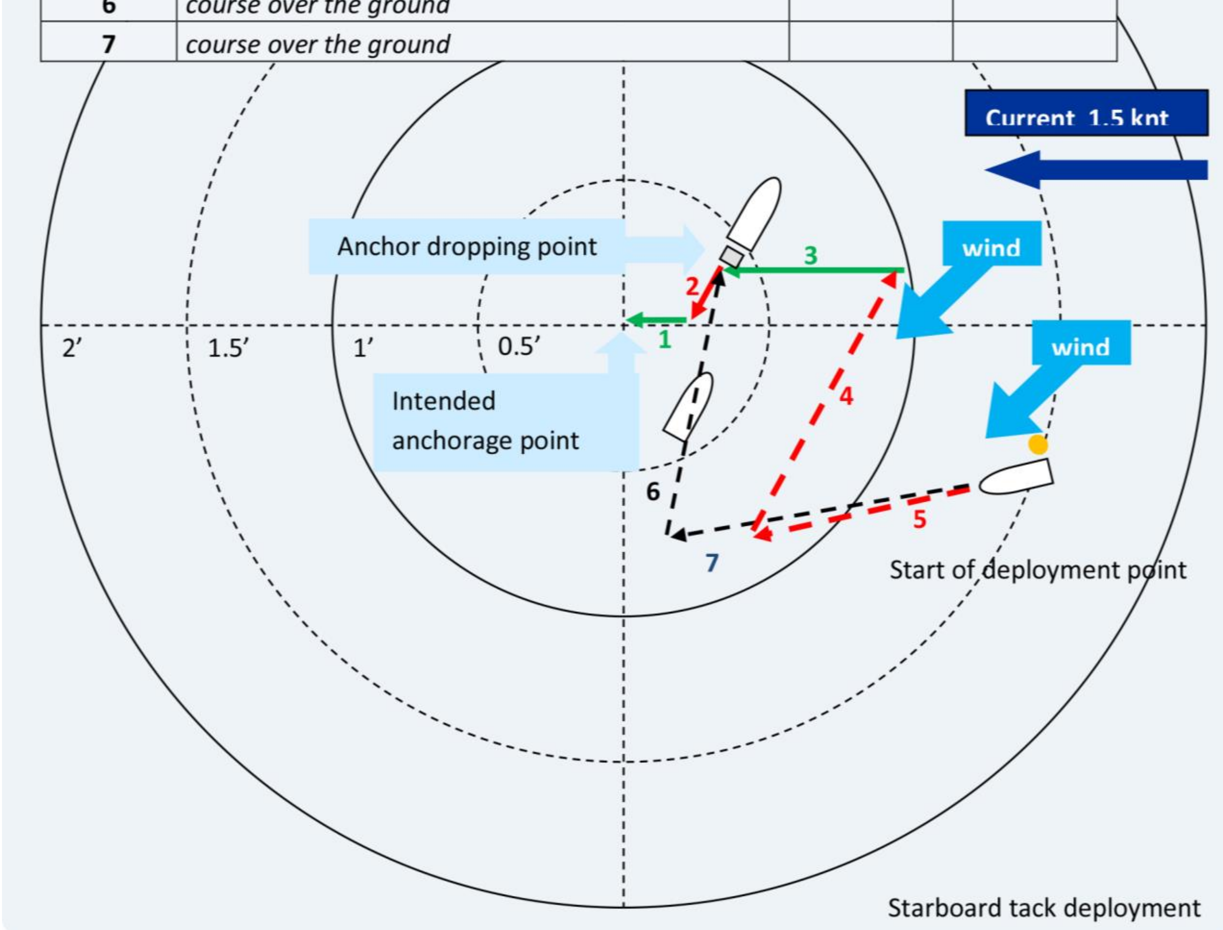


Figure 30: Courses during the deployment. 2nd Example with a NE wind and a W current (1.5knt).

10.8 Deployment with a combination cable

If the line includes a combination cable, the boat remains drifting while shooting, the weight of the cable pulls the line and the boat drives ahead only when the shooting speed becomes too low. The calculation to determine the starting point should be modified and adjusted.

10.9 Deployment with two small boats

If two small boats are used, the boat carrying the anchor is placed so as to drift and reach the dropping point when the deployment is complete by the other boat. The shooting starts when the end of the line is connected to the anchor, the layout on board should be done in the reverse order of what was described previously (Figure 31).

Vector	*Description*	*Direction (°)*	*Length (m)*
1	*current during the sinking*	270	350
2	*distance toward the line during the sinking*	25	400
3	*Drift due to the wind (boat with anchor)*	225	460
4	*current during the deployment*	270	1150
5	*course through the sea (first part of deployment)*	25	2000
6	*course through the sea (second part of deployment)*	245	2000
7	*course over the ground (deploying boat)*		
8	*course over the ground (deploying boat)*		
9	*course over the ground (boat with the anchorage)*	270	1150

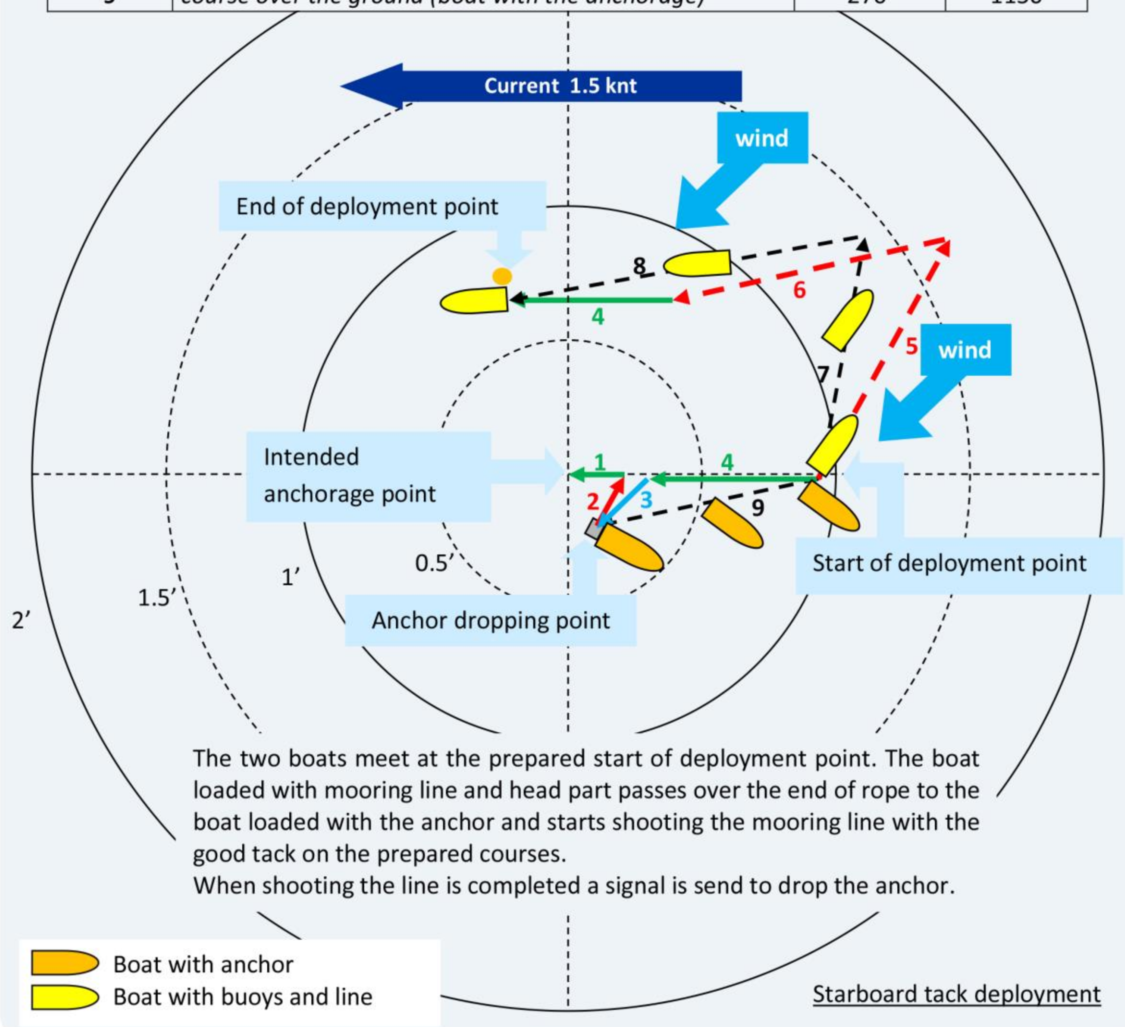


Figure 31: Dual boat deployment. Example with a NE wind and a W current (1.5knt).

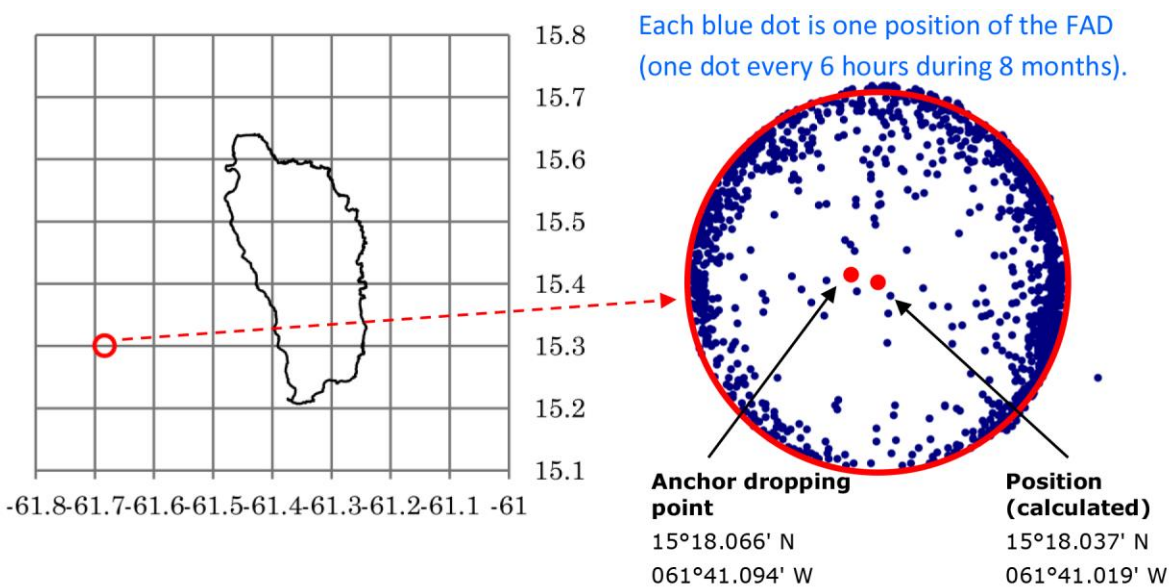
10.10 Deployment on steep site

Extreme caution should be taken when deploying a FAD on a steep site. If the rope to depth ratio is too low this may result in the loss of the FAD if the anchor drops in a deeper area due to inaccuracy. If the risk exists it is good to shift to shallower depths. Using a length to depth ratio of 1.5 and following proper deployment procedures will eliminate risk of loss.

10.11 The geographical coordinates of the setup site

The position is noted when dropping the mooring block, and an estimated position of the anchoring block is deduced by integrating the drift and pendulum effect during the descent of the anchorage (Vectors 1 and 2 of the pictures in Figure 31).

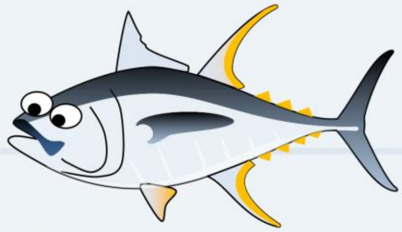
If the FAD is equipped with a GPS, the different positions of the FAD form a cloud of dots inside the watch circle; the real position of the mooring block can easily be inferred. If not, the positions noted by the fishermen may serve the same purpose. Besides the graphic solution, 3 points of the watch circle can be noted to obtain its center through a mathematical relation.



DOM1 position was recalculated with GPS positions transmitted every 6 hours by satellite. The measured watch circle radius (1800 m) is consistent with the depth to length ratio.

Figure 32: Geographical coordinates of DOM1 in Dominica.

DEPLOYMENT OF FAD

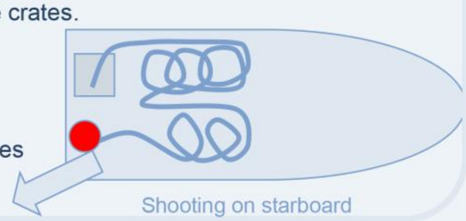


SAFETY FIRST!

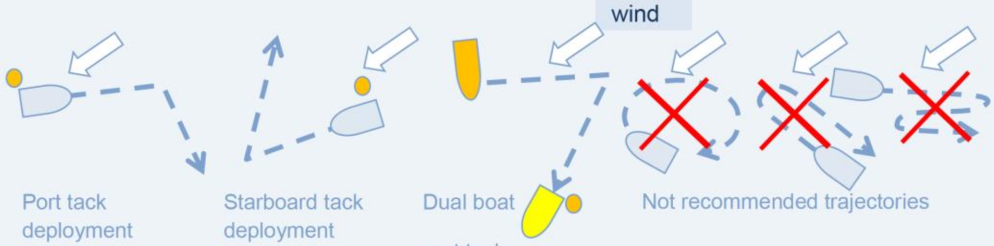
- Use at least a 10 m decked boat.
- Or two boats (be sure of the stability of the boat that loads the anchor).
- Use the "anchor last" deployment.
- Be sure that the crew as enough skill and experience for that operation.
- All the material (especially the anchor) must be secured by appropriate lashing.

Choose a side for deployment and arrange material:

- Arrange the material a logical way according to the selected shooting side.
- Ropes should be uncoiled and faked into rope crates.
- Reverse the arrangement for a dual boat deployment.
- A thorough and thoughtful arrangement ensures a safe running of the laying.



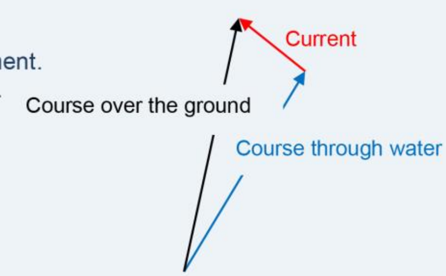
Deploy without changing the tack (the side from which you receive the wind).



Straight line deployment decreases the accuracy and increases tension in the line during the sinking of the anchor.

Anticipate:

- The drift due to the current during deployment.
- The moving of the anchor towards the line.



Train yourself to make graphic calculation of start deployment position.

Keep watch the depth on steep site.

Figure 33: Deployment of FAD.

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