DESIGN OF ECOLOGICAL FADS

Jose Franco, Laurent Dagorn, Igor Sancristobal, Gala Moreno

Summary

Purse seiners deploy thousands of Drifting Fish Aggregating Devices (DFADs) in all tropical oceans to catch tropical tunas. Although different designs of DFADs exist, fishers all over the world mainly use bamboo rafts with black netting hanging underneath. However, this type of FADs is responsible for incidental mortality of sea turtles and sharks through entanglement. It is now urgent that fishers use "Ecological FADs" that reduce such ghost fishing in order to move towards sustainable and responsible purse seine fisheries. In this study, we first identify the criteria for Ecological FADs and we propose various possible designs for Ecological FADs.

J. Franco. AZTI-Tecnalia / Txatxarramendi Ugartea z/g, 48395 Sukarrieta, (Bizkaia) Spain
L. Dagorn. IRD, P.O. Box 570, Victoria, Seychelles
I. Sancristobal. AZTI-Tecnalia/ Herrera Kaia. Portualdea, z/g, 20110 Pasaia (Gipuzkoa), Spain
G.Moreno.[1] AZTI-Tecnalia/ Herrera Kaia. Portualdea, z/g, 20110 Pasaia (Gipuzkoa), Spain

[1] Corresponding author (e.mail: gmoreno@azti.es)

1 Introduction

Purse seiners have always been looking for objects floating at the surface of the oceans (e.g. logs) to find and catch tropical tuna. In the last two decades, this fishing mode has been more and more important and fishers have increased the number of floating objects in the ocean by regularly deploying thousands of artificial FADs to increase their catch of tropical tuna (Fonteneau et al. 2000, Moreno et al. 2007*a*).

Very little information in the scientific literature exists about the design and construction of drifting FADs (DFADs) currently used by the fishers. Despite the intensive use of DFADs in the Atlantic, Pacific and Indian oceans (Fonteneau et al. 2000), from 407 references about FADs reviewed by Dempster & Taquet (2004), all studies (24) with FAD design or technology as a primary topic concerned moored FADs. Another review (Itano, 2004) on anchored and DFADs has also highlighted the scarcity of documented information on technical parameters of FADs that are used in the Western and Central Pacific Ocean (WCPO) fishery. More recently (Itano, 2007) has summarized the operational and technical information on FADs in the WCPO purse seine fishery. However, the small literature on the design of those drifting FADs could be explained by the fact that most of tuna purse seiners in the world use one common design, as this design seem to meet their requirements. Artificial FADs mainly consist in bamboo rafts of 4-6 m^2 with black netting on the top of the bamboo and underneath (from a few meters up to tens of meters).

If such artificial drifting FADs are suitable for fishers (easy and cheap to construct, efficient in aggregating fish and durable), the problem is that this type of FADs are responsible for incidental mortality basically of sea turtles and sharks through entanglement. Therefore, there is urgent need to include modifications in the design of drifting FADs to reduce ghost fishing.

This document (i) makes a review of the current drifting FADs from fisher's interviews in the Indian Ocean, (ii) makes a review of previous experiments to modify the common design of FADs, (iii) proposes some designs according to specific criteria for Ecological FADs.

2 FADs currently used by purse seiners and entanglement of turtles and sharks

To obtain information about the FADs presently used by fishers in the Western Indian Ocean, a survey was performed through personal interviews onboard purse seiners in the Seychelles islands (to 8 French fishers) or by personal interviews, phone and email (to 14 Spanish fishers). Interviews were conducted during 2008 and 2009. The objective was to collect data on the design of FADs: floating structure (material, shape, dimensions), netting (material, mesh size, colour, dimensions e.g. depth of the net) and ideas for future ecological FADs were recovered.

The criteria used by fishers for designing FADs are:

1. Efficiency to aggregate tunas. Three factors seem to be important to aggregate tuna from fishers empirical knowledge (ranked by importance):
   - Fouling organisms on the netting
   - Shadow, produced by the structure of the FAD
   - Length of the hanging panel of netting

2. Not detectable by other vessels
3. Availability and low cost of materials
4. Ease to construct onboard

2.1 FADs currently in use

Floating structure

Bamboo is mainly used nowadays as material to handcraft the floating structure. Bamboo is used due to its lightweight nature, strength, resistance to waterlogging, very cheap price and ease to get. A vast majority of fishers make rectangular rafts of about 4-6 m^2 (Fig.1), as it was the case some years ago (Fonteneau *et al.* 2000).

Fig. 1. Picture of bamboo rafts (© Fadio/IRD/AZTI/gmoreno).

A minority of fishers use bundles of bamboo instead of the most frequently used rafts. The advantage of such a design is that turtles can not climb on the surface structure to rest but the fact that rafts are more flat and hence, less detectable for other fishing boats, make them being more used than bundles.

Most of the skippers use several layers of black nets or a black plastic over the bamboo raft to provide shade and make the FAD less detectable. The black plastic reduces the likelihood of entanglement of turtles on top of the FAD but in case of strong wind, the raft has a sail effect and eventually gets damaged.

In order to assure the buoyancy and eventually enhance the life-time of the structure, floats used in the floatline of the purse seine nets are attached in the upper part of the DFAD. These floats are made from EVA (Ethylene Vinyl Acetate copolymer) and with time they suffer bites from large marine animals and get full of water, loosing buoyancy. Eventually, the whole FAD could sink and get lost. In order to prevent this, some fishers have started using trawl floats and PVC pipes, as in the case of Pacific Ocean where DFADs life-time needs to be longer.

Satellite linked buoys are attached to DFADs to monitor their positions (radio buoys were used in the past) (Moreno et al. 2007*b*). Satellite buoys have a great autonomy and are not easily detectable by other vessels. Some of the satellite buoys are equipped with sounders with a threshold biomass alarm. However, the biomass estimation made by those sounders is still not fully reliable and most skippers prefer to switch the alarm off.

Submerged structure

The importance of the hanging panel of netting in the efficiency of the FAD has been pointed out by skippers and scientists (Armstrong & Oliver, 1995). The hanging panel of netting is usually made from rejected purse seine netting, so the mesh size used varies from 200 mm to 90 mm (Fig.2). A segment of chain or cables is sometimes attached at the bottom of the net to keep the net in a vertical position, but some skippers do not use weight, because they think the weight of the encrusted animals in the netting is enough.

Length and number of hanging panels of netting is quite variable, mainly depending on the oceans. From the recorded data collected in the survey, length varies from 45 to 55 meters in the Atlantic and from 6 to 25 meters in the Indian Ocean. In the Pacific Ocean the length is also very variable: from 9 to12 meters used by Spanish, from 20 to 30 meters by Japanese (Itano, 2004), and up to 50 meters in the eastern Pacific (Bromhead, 2003).

Number of hanging panels varies from one, hanging from the middle of the structure to two hanging panels from two opposite sides of the rectangular raft.

From fishers' knowledge, Korean FADs used in the Atlantic entangle very few turtles. Submerged structure of Korean FADs is made of a single piece of net (~ 45m) with transversal bamboo canes every few meters till the bottom of the net spreading out the net as a submerged "sail"(Fig 3). Heavy cables are hanging from bamboo canes conferring tautness to the "sail". Pieces of netting are wind around these cables to prevent damaging the purse seine net during fishing operation.

The purpose of this Korean design is making the drift being very slow, to maintain the FAD within a small area. It seems that the use of a single piece of net and its tautness prevents the entanglement of marine turtles.

Fig.2. Submerged part of a traditional FADs.
(© Fadio/IRD/Ifremer/mtaquet).

Fig.3. Submerged part of Korean style FAD with a bundle of bamboo in surface
(© Fadio/IRD/ Ifremer/mtaquet).

Human and material costs to build traditional FADs

In the Indian Ocean, costs to build traditional FADs are due only to the purchase of bamboo canes. The pieces of net for the submerged part of the structure are recycled from purse seine nets, as fishers store the remaining pieces from purse seine net repairs. EVA buoys for FAD floatation are also recycled from the purse seine.

Building the raft can cost around 6-8 € as each bamboo cane of 2-3 meters, can cost around 12-15 SCR (Seychelles Rupees) and approximately 10 canes are needed to build a single raft. Since other materials are recycled, the total cost to build a traditional FAD in the Indian Ocean is 6-8 Euros.

We should not forget that to complete the FAD gear, a positioning buoy is attached to the raft. The cost of these buoys can vary from 600 to 1300 € so that, the cost of the "hardware" of the FAD represents a maximum of 1% of the total cost.

In the Pacific Ocean, due to the fact that a higher number of FADs are used, fishers do not have enough pieces of net to recycle from their purse seine net repairs, that is why second hand pieces of net are bought. In some cases, PVC pipes are also bought for floatation, as the life time for a FAD in the Pacific is needed to be longer, therefore the cost of the FAD is a bit more expensive for this ocean.

Fig. 4. Building a FAD (© AZTI/isancristobal).

Fishers take time to build FADs that need to "survive" and be productive for a long time at sea and pay attention to do it in a precise way. Tasks comprise cutting canes to the proper length and attaching them, then, cutting pieces of net for both, to cover the raft and to hang them from the raft tens of meters, and finally, tying ropes to attach the buoy and to handle it (Fig. 4). An estimate of the human effort and time needed to build a single FAD is approximately 6- 8 persons devoting 40 min. The work is usually done in chain: first all the material is cut, then raft skeletons are prepared, and finally the hanging peaces of net arrangement, so that the time needed to build one is an estimate, although is not the way they proceed.

2.2 How do FADs catch turtles and sharks?

Turtles have been found entangled by DFADs in two ways:

- Turtles climb on the surface structure to rest; this behaviour causes entanglement on the top of the DFADs by the nets covering the DFADs (Fig.5).
- They are entangled in the nets hanging underneath the surface structure.

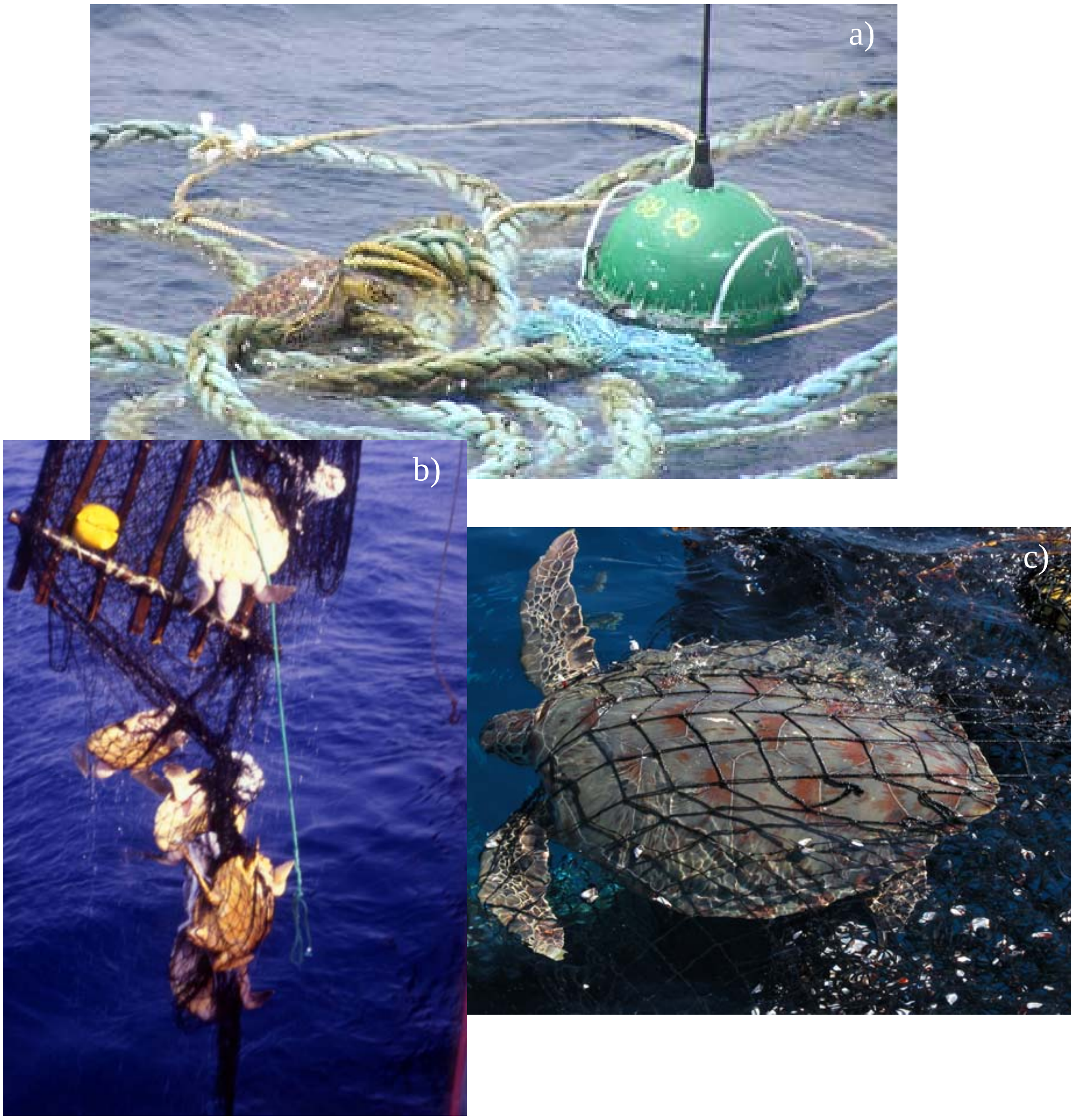

Fig. 5. a) Turttle climbing to rest on surface (© Fadio/IRD/AZTI/gmoreno);.b) and c)Turtle entanglement on the surface and underwater structures of FADs, (© AZTI/isancristobal) and (© Fadio/IRD/AZTI/gmoreno) respectively.

Sharks can also be entangled in the nets hanging underneath the surface structure (Fig.6). The entanglement may be due to the fact that sharks predate on fishes that tend to hide in the submerged pieces of net, eventually making sharks being entangled.

Fig. 6. Shark entanglement. (© Fadio/IRD/Ifremer/mtaquet)

3 Previous experiments with alternative FAD designs

Two Spanish ship-owners companies have worked with various types of DFADs in an attempt to avoid species entanglement.

One of the companies involved in a pilot project to find alternatives to the traditional DFADs (Delgado de Molina *et al.*, 2004; Delgado de Molina *et al.*, 2007), worked with various types of DFADs using two types of floating structures, cylinders made by polyethylene pipes, and bamboo rafts. The two floating structures were tested with different types of submerged structures, sailcloth, jute, semi-natural fabrics, ropes and palm leaves. Unfortunately drawing conclusions from this experiment was impossible as only 8 sets were performed on 5 different models.

Another Spanish company tested DFADs made by a polyethylene pipe cylinder in the upper part and agricultural netting material (shade clothes) as hanging netting (Fig. 7). Instead of being surface FADs, they were suspended 20 cm below surface to prevent being spotted by other vessels (Fig. 8).

Fishers have also tested on one's own initiative, different designs, as subsurface drums filled with bait (Fig. 9), in an attempt to attract more fishes. Some others have tried tagging empty salt sacks every 6-8 m along the hanging net from the DFAD, trying to produce brightness/shadow effects.

Fig. 7. Deployment of an experimental FAD tested by a Spanish company (© Inpesca)

Fig. 8. Surface view of the experimental FAD in the previous figure (© Inpesca).

Fig. 9. Subsurface FAD built with a drum (© Fadio/IRD/Ifremer/mtaquet).

Those new designs have not been adopted by the fleets and most of vessels still use bamboo rafts with black nets. Different reasons can be advanced to explain why those new FADs are not used:

- Most fishers strongly consider that rectangular rafts are the best FADs, and new shapes are usually not considered as good FADs.
- Fishers are used to manipulate bamboo and nets which are materials that are very cheap and easy to find.
- Most of times the experiments have not been done in a methodical way so lots of particular different reasons could have driven down the results even if the idea could have been good. So fishers tend to keep on with the usual known design.

4 Designs of Ecological FADs

4.1 Tuna attraction capability

It has been suggested that the attraction of fishes to FADs is due to mechanisms other than feeding on organisms encrusting the FADs (Ibrahim et al., 1996). There are different hypothesis to explain the association of fishes with floating objects (Freon and Dagorn 2000) and there is no reason to believe that all species, and all their different life stages, that associate with floating objects, do so for the same reason. Hall et al 1992, collected data on the characteristics of floating objects encountered at sea by observers assigned to tuna purse-seine vessels. Type of object (plant material, kelp, wooden man-made, …), shape of object, colour, epibiota and percentage submerged, were recorded not just for those floating objects that had tuna associated but for any floating object sighted. They explored the probability to find tuna under a floating object, using characteristics of floating objects, location, time of day, and environmental variables (temperature, clued cover, water clarity..). As a result, factors affecting catches on floating objects were, time of the day, the distance to the coast, and the percentage submerged. The only variable describing object characteristics that appeared to be of primary importance for catch per set was percentage submerged. This variable was thought to be correlated to the age of the object as well as the distance to the coast. These results suggest that the location of the floating object has a greater effect on catch per set than do the characteristics of the object. However, of all the types of floating objects considered, *discarded fishing gear* was the only one significantly better than others. Many of the objects in this rather heterogeneous class include tangled fragments of netting which, if incorporated into FADs, pose the undesiderable problem of entanglement of other animals in the FADs.Some categories of interest for the present study, as epibiota could not be included in the analyses because of sample size limitations. Although colour was considered a potentially important factor in attracting tunas, the color of object was not found to significantly affect catch per set.

In a study conducted by Moreno et al 2007*a*, half of the interviewed fishing masters considered natural floating objects (mainly logs) as the best platforms to aggregate fish. Natural logs do not have hanging panels of netting. It is difficult to know if the perceived higher efficiency of natural DFADs is due to their morphological characteristics, or their time at sea and movements related to oceanographic features. In anchored FADs´ (AFADs) studies, structure size and vertical profile were found as the most significant factors for attracting non-tuna species abundance, but no major characteristic of AFADs has explained the attraction of tuna species (Rountree 1989, Hall et al. 1992, Nelson 2003). Natural DFADs´ history may be a more relevant factor explaining their possible higher efficiency. They originate in forested coastal zones and usually spend several months at sea before arriving in the fishing grounds while fishers typically deploy artificial FADs in or near the fishing grounds only a few weeks before starting their fishing operation.

Fishers give a great importance to the hanging panels, which maybe due not only to the encrusting of the netting by sessile organisms (Fig.10) but also to the fact that hanging panels make the drift (speed and trajectory) being more appropriate for the FAD to be productive. There is no enough scientific knowledge on the role of hanging panels and DFAD trajectories on the attraction of tunas.

.

Fig. 10. Sessile organisms in the submerged part of a traditional FAD.
(© Fadio/IRD/Ifremer/mtaquet).

4.2 Criteria for ecological FADs

First of all, it is obvious that hanging nets are responsible for ghost fishing by FADs, and that flat surface structures favour turtles resting and therefore the entanglements in the nets covering the structure.

Considering the results of previous experiments and fishers knowledge or believes, several criteria must be taken into account.

Ecological considerations:

- FADs should not have hanging panels of nets with large mesh size that can cause entanglements of animals.
- FADs should not be covered by several layers of nets where turtles can be trapped, or should have surface structures on which turtles cannot climb on.
- FADs should be made of biodegradable materials as much as possible (to prevent that the elements of the FAD eventually end in natural habitats such as coral reefs, beaches…).

Fishers considerations:

- Ecological FADs should be as efficient as traditional ones to aggregate tuna. From our knowledge, any shape would work, as the unique characteristic concerning object type that had importance for catch per set was percentage of submerged part (Hall et al 1992). However, as fishers believe that rectangular rafts are efficient, it seems to be appropriate to adopt similar shapes (other shapes have never really been accepted by fishers) so that new Ecological FADs can easily be adopted by fishers.
- The surface structure should be dark to generate shadow.
- Underwater structures should allow fouling organisms to settle in. Length of underwater structures should correspond more or less (when possible) to length of current hanging panels, although there is no scientific knowledge about the role of such length.
- Ecological FADs should last as long as traditional ones (e.g. several months).
- Ecological FADs should be made in such a way that they do not put on risk the crew in the deployment or the recovery of the FADs.
- Ecological DFADs should not put on risk purse seiner net during fishing operation.
- The structure should allow the attachment of satellite buoys.
- Materials should be easy to find, and if possible, as cheap as possible (although this criteria is not technical).

4.3 Materials

The present section will first review the possible materials that can be used to fabricate ecological FADs.

Surface structure:

- The raft: As bamboo is a biodegradable material and well accepted by fishers, there is no major reason for not using this material for ecological FADs.
- Float line: EVA buoys are not biodegradable, but could still be used as very few of them are attached to DFADs. Real cork which is biodegradable loose buoyancy with time and suffer bites from large marine animals.
- Cover of DFAD:

  Not biodegradable:

    - *Shade clothes*: shade clothes are lightweight knitted polyethylene fabrics that are used in agriculture to provide plants with protection from the sun (Fig. 11). It avoids turtle entanglement but is not biodegradable, alternative solutions will be preferable.

Fig. 11. Shade clothes used to provide plants with protection from the sun

Biodegradable:

- *Palm leaves*
- *Fence structures* made by:

  Bambooslats: Each roll of screening is made of individual vertical bamboo slats cut from a large cane (each vertical is a complete slat - there are no breaks). The average width of each slat is 15mm, varying from approx 5mm to 20mm. The slats are tied together with horizontal galvanised wires (Fig 12a).

  Thin bamboo: Each roll is made of individual vertical bamboo canes. The average width of each cane is 9mm, varying from approx 5mm to 15mm. The canes are tied together with horizontal galvanised wire (Fig 12b).

Fig 12.a) Bamboo slats; b) thin bamboo

Underwater structure.

Different options can be adopted:

Not biodegradable:

- *Purse seiner nets* can still be used, but since the mesh size can vary from 90 to 200 mm they should be rolled and tied (forming some kind of "sausage") so that animals cannot be entangled.
- *Mussel Ropes*: polyester ropes used for mussel aquaculture, could be a good substrate for fouling organisms that, from fisher's point of view, are essential for the productivity of FADs (Fig. 13). Each rope has aproximately 45 mm diameter. Ropes hanging from the raft prevent turtles and sharks from being entangled.
- *Second hand ropes*: Although not biodegradable, ropes are easy to find and to store. They mitigate entanglement of turtles and sharks. Second hand ropes can be easily found for lower prices than the previous option.

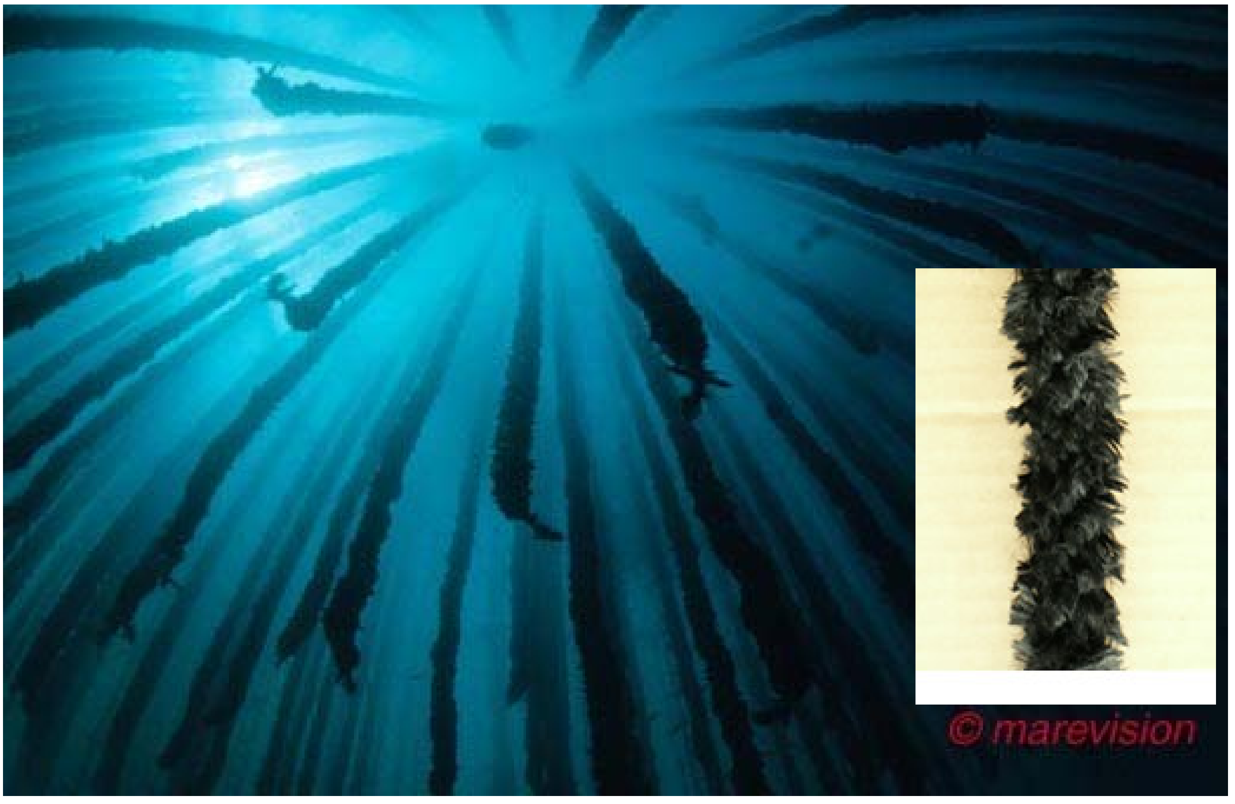

Fig 13.Underwater view of mussel ropes.

Biodegradable:

- *Biodegradable nets* made of vegetal fibre as sisal (*Agave sisalana*). These nets of 4,5 mm wire width and less than 80mm mesh size could be used rolled and tied forming some kind of "sausage" of 45 mm of diameter, so that animals cannot be entangled.
- *Jute* (genus *Corchorus*) fabric.
- *Palm leaves*: Those palm leaves are the material used by some artisanal fisheries on anchored FADs (Malta, Philippines, etc.) (Itano et al. 2004). They are biodegradable and can last several months. Palm leaves can be easily found for the same prices as bamboo canes in tropical areas and can be used to increase the volume of underwater structure of FADs.
- Ropes: There are various types of biodegradables ropes (sisal and raffia) and half-biodegradable ropes of various diameters that could be used hanging from the raft.

4.4 Costs

As stated before, nowadays material costs for FAD handcraft represents, in Indian Ocean, a maximum of 1% of the total cost of the FAD gear (including the instrumented buoy). Changing FAD structure to be biodegradable and to mitigate turtles and sharks entanglement may entail more economic effort devoted to this part.

In this section, costs of materials are estimated by unit. It should be taken into account that costs are for Europe and might vary for different countries and when buying in big amounts. Rope prices are not detailed as there are many possibilities. In general prices rise with rope diameter.

ITEM	PRICE (€)	UNIT	comments
SURFACE STRUCTURE			
Bamboo cane	0.75	2-3 m length cane	8-10 canes to built a raft
EVA buoys	0	-	Recycled from repairs
Shade cloth	12	1 X 5 m	
Bamboo fence	19	2 X 5 m	
UNDERWATER STR.			
Mussel ropes	1	1m length	
Purse seiner net	0	-	Recycled from repairs
Sisal net	7.6	12 m^2	Tied forming 8,5m length and 45 mm diameter "sausage"

4.5 Potential models of ecological FADs to test

All fishers agree that FADs should be made of a material that enhances the presence of fouling organisms and the encrusting of the netting. Mesh size is essential as big sizes make turtles and sharks being entangled, while too small mesh size (that should be good for preventing the entanglement of turtles) very soon becomes fully blocked and results unmanageable due to its heavy weight. Along the years fishers have tried several materials, and it seems that the most efficient netting in aggregating fish is the sack-cloth made from natural fibres (jute), but it lasts very little. This material becomes covered very soon by sessile organisms and eventually the submerged part of the FAD almost disappears because of the bites of predators.

The previous section provides information on the possible materials that fishers could use to make ecological FADs. Fishers could work from this list and design their own ecological FADs, or maybe find other materials that would fit the criteria for ecological FADs. We here propose two models of ecological FADs to be tested at sea. Other models have been rejected, as Korean style underwater structure (tied net), because it could be damaged with time, loosing tightness and eventually causing animal's entanglement. Bundles of bamboo instead of rafts were also rejected, due to fisher's strategy working with FADs. Bundles are more detectable than rafts for other fishing boats and most fishers believe that bundles do not provide enough shadow.

Figures 13 and 14 show drawings of the two FADs to be tested. EVA buoys are not shown as they would be as in the traditional FADs. Palm leaves can be easily attached to the proposed models to increase the underwater volume as well as to increase raft shadow in surface structure if needed.

Ecological DFAD 1

Only biodegradable materials: rack made of bamboo canes and shadow, which is optional, is provided with palm leaves. Submerged structure is made of sisal netting in sausages. As mentioned before, folding the net in sausages should reduce the entangling probability as the original mesh size of the recycled/waste pieces of nets used becomes much smaller.

Raft: 2 X 3 m

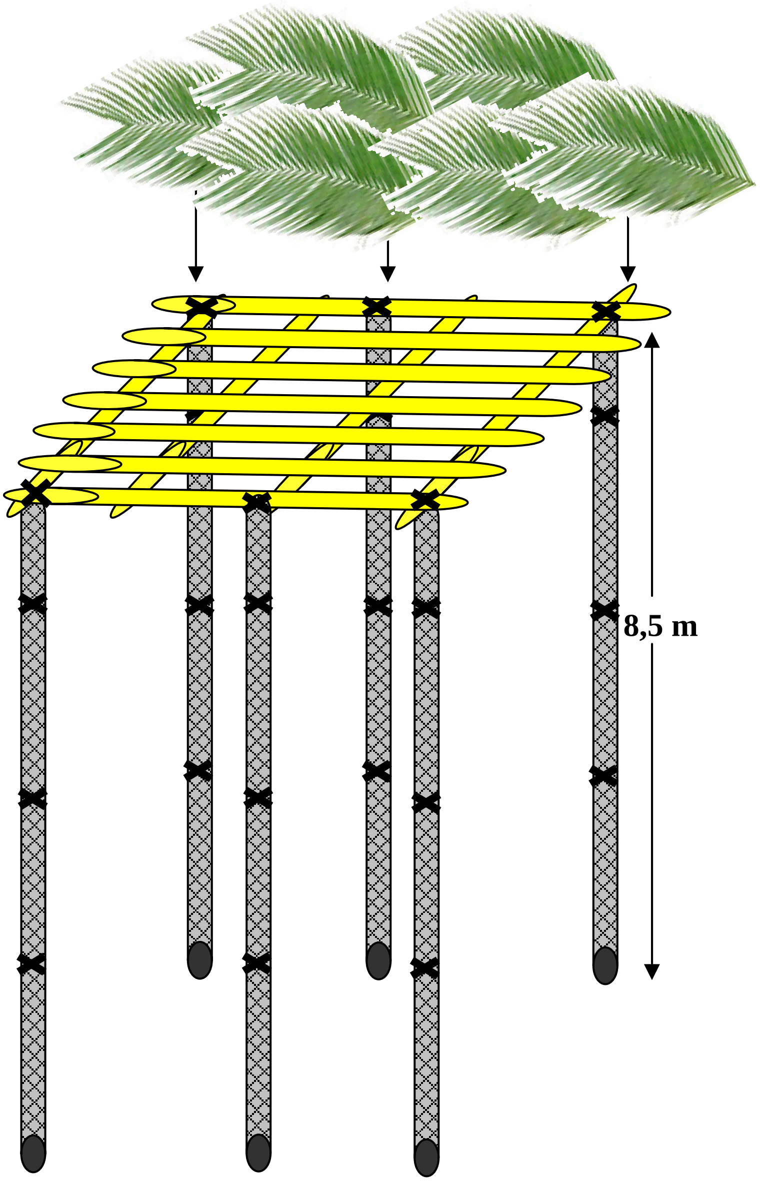

Fig. 13. Ecological FAD prototype, made of sisal net in "sausages".

Cost:

Item	Quantity	Cost (in euros)
Bamboo canes	10	7.5
Bamboo screening	1 (2 X 5 m)	19
Sisal net	6	60
Instrumented Buoy	1	1000
Total cost of FAD gear	1	**1086.5**

Ecological DFAD 2:

Half biodegradable materials: rack made of bamboo canes. Shadow, which is optional is provided with thin bamboo screening. Submerged structure is made of half biodegradable mussel ropes. Mussel ropes are hanging in "U", in this way, ropes would remain if any break occur. Bamboo canes and palm leaves are found elsewhere in tropical countries and are the cheapest materials to make the rack and the submerged structure of the FAD. Palm leaves are used in this model as an option to increase the underwater volume of the structure.

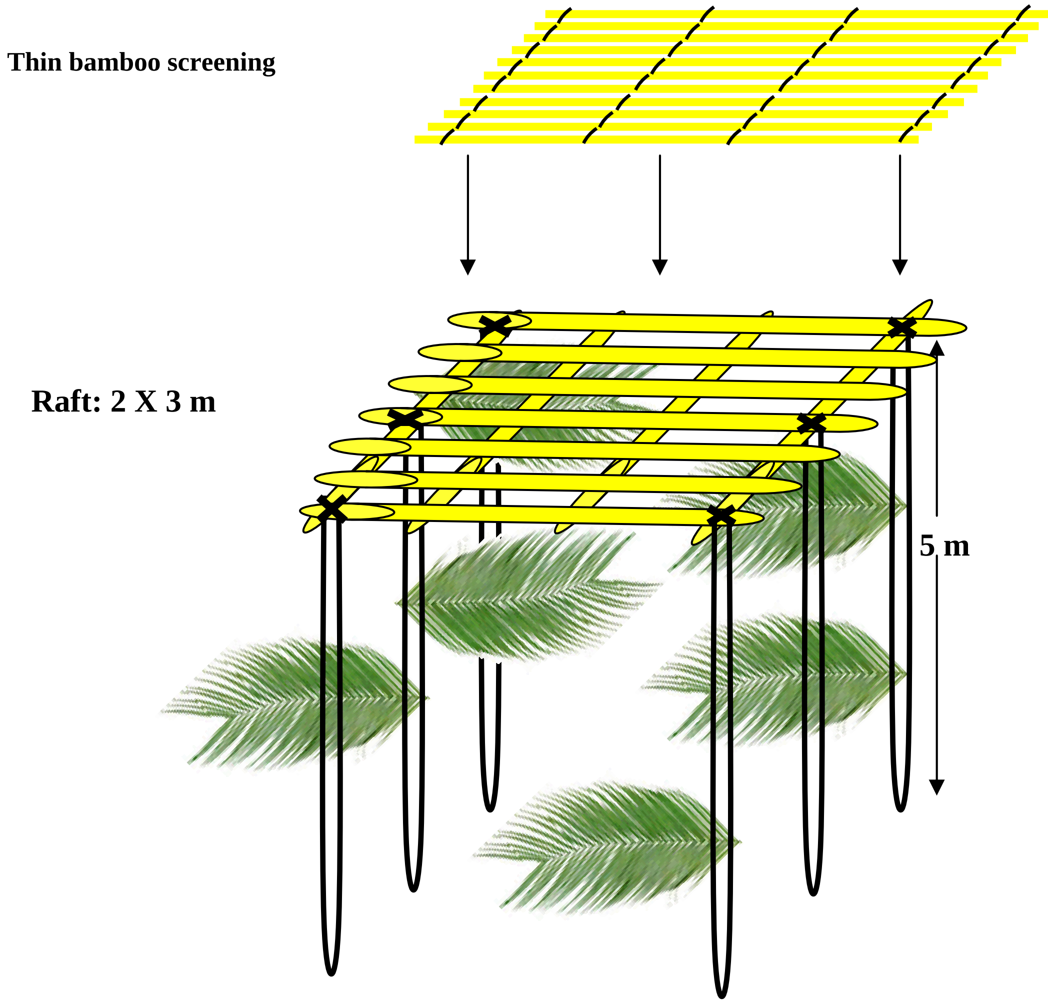

Fig. 14. Ecological FAD prototype made of mussel ropes

Cost:

Item	Quantity	Cost (in euros)
Bamboo canes	10	7.5
Bamboo screening	1 (2 X 5 m)	19
Mussel ropes	60 meters	60
Instrumented Buoy	1	1000
Total cost of FAD gear	1	**1086.5**

Acknowledgements

This study has been carried out with financial support from the Commission of the European Communities, specific RTD programme of Framework Programme 7, Theme 2 (Food, Agriculture, Fisheries and Biotechonology), through the research project MADE (Mitigating adverse ecological impacts of open ocean fisheries). It does not necessarily reflect its views and in no way anticipates the Commission's future policy in this area. The authors sincerely thank all French and Spanish fishing masters of tuna purse-seiners who kindly agreed to answer our questions.

References

Armstrong, W.A., and C.W. Oliver. 1995. Recent use of Fish Aggregating Devices in the Eastern Tropical Pacific tuna purse seine fishery: 1990-1994. National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, California. Admin. Rep. LJ-95-14. 47 pp.

Ariz Telleria, J., Delgado de Molina, A., Fonteneau, A., Gonzalez Costas, F., Pallares, P. 1999. Logs and tunas in the Eastern Tropical Atlantic: A review of present knowledge and uncertainties. Scott, M.D., Bayliff, W.H., Cody-Cody, C.E. and Schaefer, K.M., (Eds.) La Jolla, California; Scripps Institution of Oceanography

Bromhead, D., Foster, J., Attard, R., Findlay, J. Kalish, J. A. 2003. Review of the impact of fish aggregating devices (FADs) on tuna fisheries. Final Report to Fisheries Resources Research Fund. Australia: Bureau of Rural Sciences. 121 p.

Delgado de Molina, A., J. Ariz, P. Pallarés, R. Delgado de Molina, S. and Santiago Déniz. 2005. Project on new FAD designs to avoid entanglement of by-catch species, mainly sea turtles and acoustic selectivity in the Spanish purse seine fishery in the Indian Ocean. WCPFC Scientific Committee First Regular Session. 8-19 August 2005, Noumea, New Caledonia. FT WP-2.

Delgado de Molina, A., J. Ariz, J.C. Santana and S. Déniz 2007. Study of Alternative Models of Artificial Floating Objects for Tuna Fishery (Experimental Purse-seine Campaign in the Indian Ocean). IOTC–2006-WPBy – 05: 28 pp.

Dempster T., Taquet M. 2004. Fish aggregation device (FAD) research: gaps in current knowledge and future directions for ecological studies. Rev Fish Biol Fisheries 14(1): 21-42

Fonteneau A, Pallares P, Pianet R 2000. A worldwide review of purse seine fisheries on FADs. In: Le Gall J-Y, Cayré P, Taquet M (eds) Pêche Thonière et Dispositifs de Concentration de Poissons. Ifremer (Inst Fr Rech Exploit Mer) pp. 15-35. Plouzané: Edition Ifremer.

Fréon, P. and L. Dagorn (2000). "Review of fish associate behaviour: toward a generalisation of the meeting point hypothesis." Reviews in Fish Biology and Fisheries 10: 183-207.

Hall, M., García, M., Lennert, C., and Arenas, P. 1992. The association of tunas with floating objects and dolphins in the eastern pacific ocean: III. Characteristics of floating objects and their attractiveness for tunas, Inter-American Tropical Tuna Commission, La Jolla, CA., USA.

Ibrahim, S., Ambak, M.A., Shamsudin, L., Samsudin, M.Z. 1996. Importance of food aggregating devices (FADs) as substrates for food organisms of fish. Fish. Res., 27: 265-273.

Itano, D., Fukofuka, S., and D. Brogan. 2004. The development, design and current status of anchored and drifting FADs in the WCPO. 17th Meeting of the Standing Committee on Tuna and Billfish. Majuro, Marshall Islands. 9-18 August 2004. FTWG INF-3.

Itano, D., Fukofuka, S., and D. Brogan. 2007. A summary of operational, technical and fishery information on WCPO purse seine fisheries on floating objects. Scientific Committee Third Regular Session, 13-24 August 2007 Honolulu. WCPFC-SC3-FT SWG/IP-4: 62 pp.

Kawamura, G., Matsushita, T., Nishitai, M., Matsuoka, T. 1996. Blue and green fish aggregation devices are more attractive to fish. Fish. Res., 28: 99- 108

Kumoru, L. 2002. Status of fish aggregating devices in Papua New Guinea. 15th Meeting of the Standing Committee on Tuna and Billfish. Honolulu, Hawaii 22 – 27 July 2002. Working Paper FTWG – 12.

Moreno G., Dagorn L., Sancho G., Itano D., 2007*a*, Fish behaviour from fishers' knowledge: the case study of tropical tuna around drifting fish aggregating devices (DFADs). Can. J. Fish. Aquat. Sci. 64, 1517–1528.

Moreno G., Dagorn L., Sancho G., García D., Itano D., 2007*b*, Using local ecological knowledge (LEK) to provide insight on the tuna purse seine fleets of the Indian Ocean useful for management Aquat. Living Resour. 20, 367–376

Nelson, P.A. 2003. Marine fish assemblages associated with fish aggregating devices (FADs): effects of fish removal, FAD size, fouling communities, and prior recruits. Fish. Bull. 101(4): 835-850

Nelson, P. 2006. "Reducing Unintended Catch of Bigeye Tuna Near FADs," California Sea Grant Fisheries Newsletter, Fall, 2006.

Rountree, R.A. 1989. Association of fishes with fish aggregation devices: Effects of structure size on fish abundance. Bull. Mar. Sci. 44(2): 960-972.

Scott, M.D. 2007. IATTC Research on Reducing Shark Bycatch in the Tuna Purse-Seine Fishery in the Eastern Tropical Pacific Ocean. WCPO Scientific

Committee Third Regular Session, Honolulu, 13-24 August 2007, WCPFC-SC3-EB SWG/IP-3: 14 pp.