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Updated evaluation of drifting FAD construction materials in the WCPO

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Naiten Bradley Phillip Jr. and Lauriane Escalle [1]

[1] Oceanic Fisheries Programme, The Pacific Community (SPC)

Executive Summary

The use of drifting Fish Aggregating Devices (dFADs) in the WCPO purse seine fishery faces many management and development challenges, including ecosystems impacts such as ghost fishing, tuna school fragmentation, marine pollution and damage to coral reef or other coastal habitats. To mitigate these impacts, the Western and Central Pacific Fisheries Commission (WCPFC) requires the use of low entanglement risk dFADs and encourages the use of biodegradable materials in the construction of dFADs. This paper is an updated evaluation of dFAD construction materials, as recorded by observers over the last 10 years during deployments, fishing, servicing or visiting dFADs.

No temporal trend in material use was detected over the whole 2011–2020 period. Less than 3% of dFADs were made of only ‘natural’ (bamboos, trees, branches, natural debris, coconut fronds, planks, pallets and timber) materials. In contrast, 18–34% of dFADs were made of completely artificial materials (e.g., floats, metal or plastic drums, pipes, cords, ropes, sacks and bags). Looking at the raft and submerged part of the dFADs separately, it was found that the occurrence of fully natural rafts was rare, with most fleets (flag of vessel) using plastic-based floats to enhance buoyancy. The submerged appendages of most dFADs consist predominantly of artificial (i.e., plastic or metal based) materials with a combination of cord, net, sacking, or sheeting and weights. The use of nets on the dFADs appendages have the potential for the unintentional entanglements of sharks and turtles, i.e., ghost fishing, even on reef systems once detached from the raft. About 65–90% of dFADs, depending on the year considered, have at least some nets used as appendages as well as on the rafts. Less than 13% of observed dFADs had no nets at all. The fleets from Philippines, Tuvalu and Japan used the least netting on their dFADs (53, 19 and 16% of dFADs are net-free respectively, across all years). This study, based on observer records of dFAD materials, showed similar results to the previous paper presented to the Scientific Committee (WCPFC-SC14-2018/EB-IP-01).

In general, natural and low or non-entangling dFAD materials are rarely used in the WCPO. No changes in the design (i.e., low entanglement risk (mandatory as from 1st January 2020) or non-entangling FADs) or mesh size of net used was detected in 2020, since the implementation of the related Conservation and Management Measure (CMM). However, given the very recent nature of the CMM, any noticeable effect may take at least one to 2 years to be detected. To adequately notice such changes and monitor and evaluate materials and designs against the tropical tuna CMM, additional fields in relevant forms (e.g., observer data) would also be necessary to monitor the type of dFAD design (e.g., if present, net is tied in bundles or of small mesh size) used and whether a given material is biodegradable.

The high reliance of artificial materials and nets supports the findings of this previous paper. However, following WCPFC requirement and recommendation, non-entangling (i.e., low entanglement risk FADs mandatory as from 1st January 2020) and biodegradable dFADs are slowly being adopted. For example, some trials in partnership with governments, fishing industry and international non-profit organisations have recently started. Subsequent monitoring of the materials (cost, material availability and effectiveness) is needed during trial projects at the scale of the whole WCPO through the observer program, to understand the changes in dFAD design and materials used, and their implication for the fishery over time.

We invite WCPFC-SC16 to:

- Note that materials used in dFADs in the WCPO have been dominated by artificial and entangling materials, with high variability among fleets. The use of low entanglement risk and biodegradable dFADs has been limited.
- Reaffirm the commitment to reduce the use of plastic, entangling and non-biodegradable materials in the construction of dFADs in the WCPO to help reduce marine pollution and ecosystem impacts.
- Note that further studies are needed to quantify the effectiveness and the entanglement frequency of Species of Special Interest (SSI) in the WCPO on common FAD designs, but also on new low entanglement risk, non-entangling and biodegradable dFADs.
- Note the need for additional data fields or more systematic data to be recorded by the observers to adequately assess the designs, materials and type of dFADs deployed in the WCPO.
- Support on-going research activities and at-sea trials of biodegradable and non-entangling design options in the WCPO and provide corresponding advice to the FAD Management Options Intersessional Working Group.

Introduction

Drifting Fish Aggregating Devices (dFADs) are widely used in tropical tuna purse seine fisheries to enhance the probability of catching tuna. However, several adverse effects can result, such as relatively high catches of juvenile tuna and bycatch of non-target species, and ecosystem impacts (Balderson and Martin, 2015; Filmalter et al., 2013; Leroy et al., 2013).

DFADs consist of two parts: i) the raft itself, including components to ensure buoyancy (e.g., buoys, floats, drums, pipes), and which is often covered by old nets or sacking to limit detection by other vessels or to act as a shadow to attract fish; and ii) submerged appendages to increase drag, reduce drifting speed and increase fish attraction. The submerged appendages are of different sizes, shapes and depth. DFADs have been commonly constructed with non-natural materials that are cheap and readily available, for instance old buoys or drums and fishing nets. However, these artificial materials degrade slowly and contribute to marine pollution unless the dFAD is retrieved. Once abandoned or lost, dFADs may either sink, with impacts very difficult to measure, or they may strand on coastal areas (Escalle et al., 2020) and impact fragile ecosystems such as coral reefs. In addition, the presence of nets to cover the raft can lead to turtle entanglements, while underwater netting appendages can lead to both shark and turtle entanglements, which can continue when the dFAD is lost, through ghost fishing (Filmalter et al., 2013; Pilling et al., 2017). Most dFADs in the Western and Central Pacific Ocean (WCPO) have submerged appendages of 40–80 meters (Escalle et al., 2017; Murua et al., 2017).

To mitigate these impacts, the use of biodegradable and non-entangling dFADs (see Appendix 1) has been investigated worldwide (e.g., Lopez et al., 2016; Moreno et al., 2016). In the WCPO, some trials to test non-entangling and biodegradable dFADs have recently been implemented in the Federated States of Micronesia (FSM) in partnership with the government, fishing industry and the International Sea Food Sustainability Foundation (ISSF) (Moreno et al., 2020). These new designs of non-entangling and biodegradable dFADs started to be deployed early in 2020 and FSM plans to deploy about 100 biodegradable dFADs over the course of the year. In 2018, the Western and Central Pacific Fisheries Commission (WCPFC) implemented a measure on low entanglement risk dFADs (Appendix 1) that came into force 1st January 2020 (WCPFC, 2018). This includes the need for any dFADs deployed or drifting into the WCPFC convention area to present; i) a raft with no net or nets with a mesh < 7cm; and ii) submerged appendages with no net or net with a mesh < 7cm or tied tightly in bundles (paragraph 19 WCPFC, 2018). The measure also encourages the use of biodegradable materials in the construction of dFADs (paragraph 20; WCPFC, 2018).

In this paper, we evaluate the current materials used in dFAD construction based on records made by observers from 2011 to early 2020, with a focus on natural vs artificial materials and the presence of nets (i.e., entangling or low entanglement risk or non-entangling dFADs, see Appendix 1 for the different designs) used in any part of the dFAD (i.e., either on the raft or submerged appendages). First, patterns of natural and artificial material use in dFAD construction are examined over time and across fleets (i.e., flag country). Then, a more detailed examination of the different materials used for the raft and submerged appendages is presented.

Patterns of natural and artificial materials used

Since 2011 and the implementation of the GEN-5 form, observers have recorded, when possible, the materials of any dFADs encountered at sea, including during deployment, fishing, servicing or visiting a dFAD (note the difficulties for observers to access the materials of the submerged part of the dFAD when it is in the water, i.e., fishing, servicing or visiting activities). Materials considered as 'natural' in this paper include bamboos, trees, branches, natural debris, coconut fronds, planks, pallets, timbers. Any other material was classified here as artificial (i.e., plastic or metal based). We note that cords, ropes, sacks and bags could be of natural origin (see for instance the cotton ropes and canvas used in non-entangling and biodegrable dFADs tested in FSM; Moreno et al., 2020), but were assumed within this analysis to be artificial unless otherwise specified by the observer.

The use of natural materials in dFAD construction has been relatively consistent over the last 10 years. Most dFADs recorded had a raft with a mix of natural and artificial materials, for instance bamboos or planks reinforced by some buoys to enhance buoyancy; and artificial appendages (33–51% of dFADs, Figure 1). This is followed by completely artificial dFADs: the raft and appendages being made of artificial materials (18–34%). Less than 8% of dFADs had a natural raft with some artificial appendages. Finally, less than 3% of the dFADs were completely natural (Figure 1), mostly due to the raft being natural with no submerged appendages.

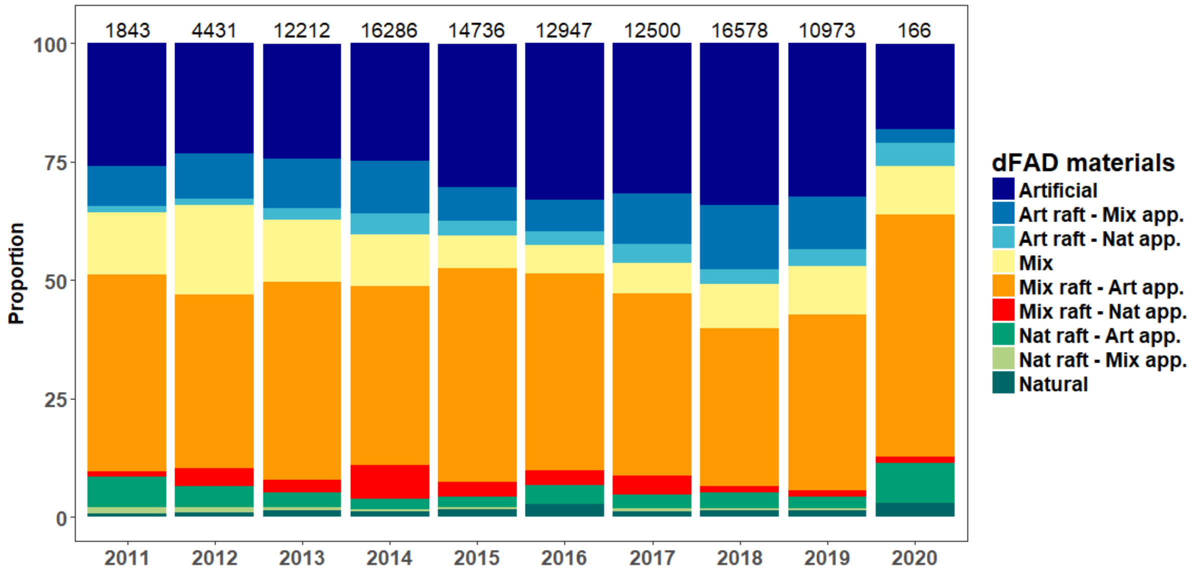

Figure 1. Proportion of dFADs per year constructed with natural (Nat), artificial (Art) or a mix of both materials in the design of the raft or the appendages (app.), as recorded by observers. Numbers on the top of the figure correspond to the number of dFADs with information on materials per year.

Floating objects found at sea are sometimes used by fishers, as they aggregate tunas, and are recorded by observers as logs[1]. These could include natural objects, potentially modified by fishers (e.g., using floats, bamboo and/or nets) or anthropomorphic debris found at sea. In these instances, the observer recorded that 50–80% of the logs were natural, and about 7–20% of logs had an additional mix of both artificial and natural materials as appendages (Figure 2).

[1] The way dFADs or logs are classified here are purely based on the observer record. A log that has been transformed by fishers using artificial materials may therefore sometimes by classified as log and sometimes as dFAD, depending on the observer.

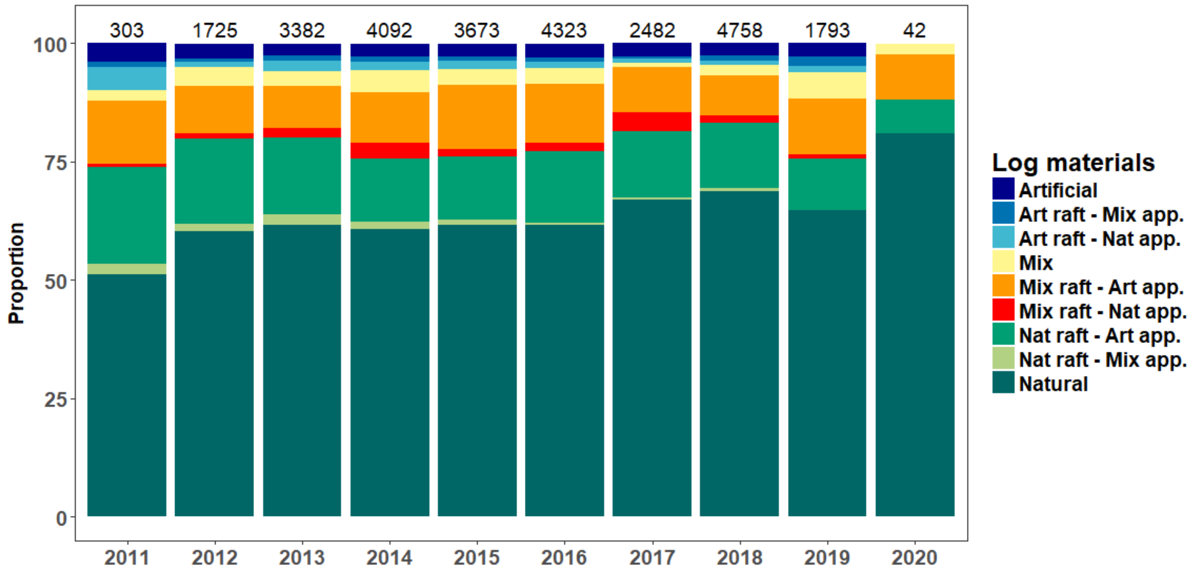

Figure 2. Proportion of logs per year constructed with natural (Nat), artificial (Art) or a mix of both materials in the design of the raft or the appendages (app.), as recorded by observers (materials described here can include non-modified logs, explaining the high proportion or fully natural ones). Numbers on the top of the figure correspond to the number of logs with information on materials per year.

To evaluate fleet-specific patterns of construction, observer information recorded during any FAD-related activity, i.e., FAD deployment but also, setting, visiting and servicing, were used. This may have added some noise in the analyses, as setting, visiting and servicing may occur on FADs that have been deployed by another fleet than the one considered. The bulk of dFADs deployed by fleet are made of i) completely artificial materials or ii) a mixed artificial/natural raft with artificial appendages (Figure 3). Some differences were detected for EU Spain, Ecuador and El Salvador, that use a dFAD design quite different from other fleets. DFADs deployed by these three fleets were dominated by a mixed artificial/natural raft with artificial appendages (51–80% of their dFADs). Fleets using the highest proportion of natural materials are Philippines, Solomon Islands, and Japan but that proportion remains minor (8–13% of their dFADs) (Figure 3). Regarding logs, patterns did not vary between fleets, and hence reflect the general pattern described previously (Figure 2 and 4). However, some fleets had no information on log materials recorded by observers, presumably as they performed very few log sets (Cook Islands and El Salvador).

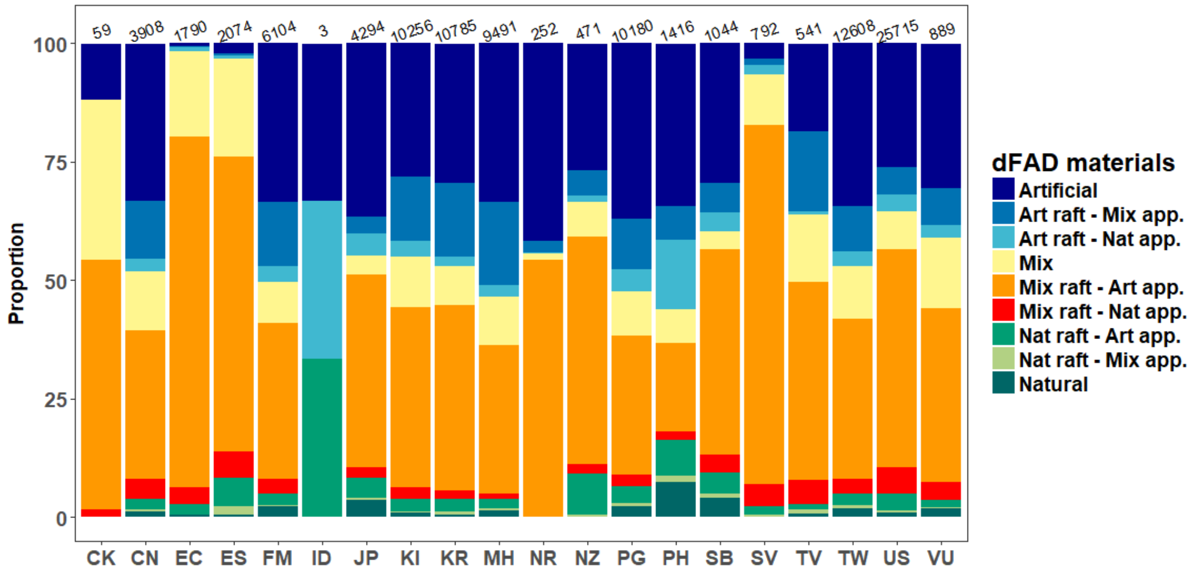

Figure 3. Proportion of natural (Nat), artificial (Art) or a mix of both materials in the design of the raft or the appendages (app.) of dFADs per fleet, as recorded by observers (2011–2020). Numbers on the top of the figure correspond to the number of dFADs with information on materials per fleet.

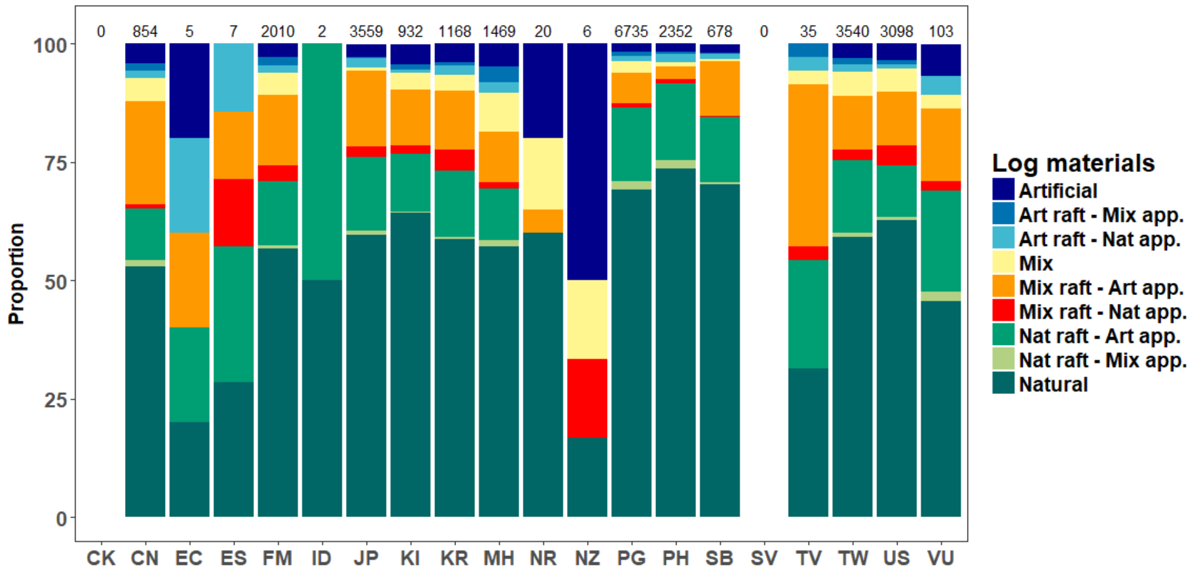

Figure 4. Proportion of natural (Nat), artificial (Art) or a mix of both materials in the design of the raft or the appendages (app.) of logs per fleet, as recorded by observers (2011–2020). Numbers on the top of the figure correspond to the number of logs with information on materials per fleet.

Details on the materials used in dFAD construction

Where natural materials are used in the construction of dFADs' rafts (see Figure 3), they include bamboo, logs (trunk, branches or other natural debris) and planks (including pallets, timbers or spools). Logs were the most commonly used natural material, followed by bamboo (Figure 5). Some fleets use specific designs (Figures 5 and 7) with a high dominance of i) bamboo (EU Spain, Tuvalu, El Salvador) or ii) bamboo and planks (Ecuador) for the raft, but no natural materials used in the submerged appendages (Figure 6). For the rest of the fleets, natural appendages were rarely used, but when present in appendages, included branches and coconut fronds. Note that when dFADs were recorded to be completely natural it was mostly due to the raft being natural with no submerged appendages.

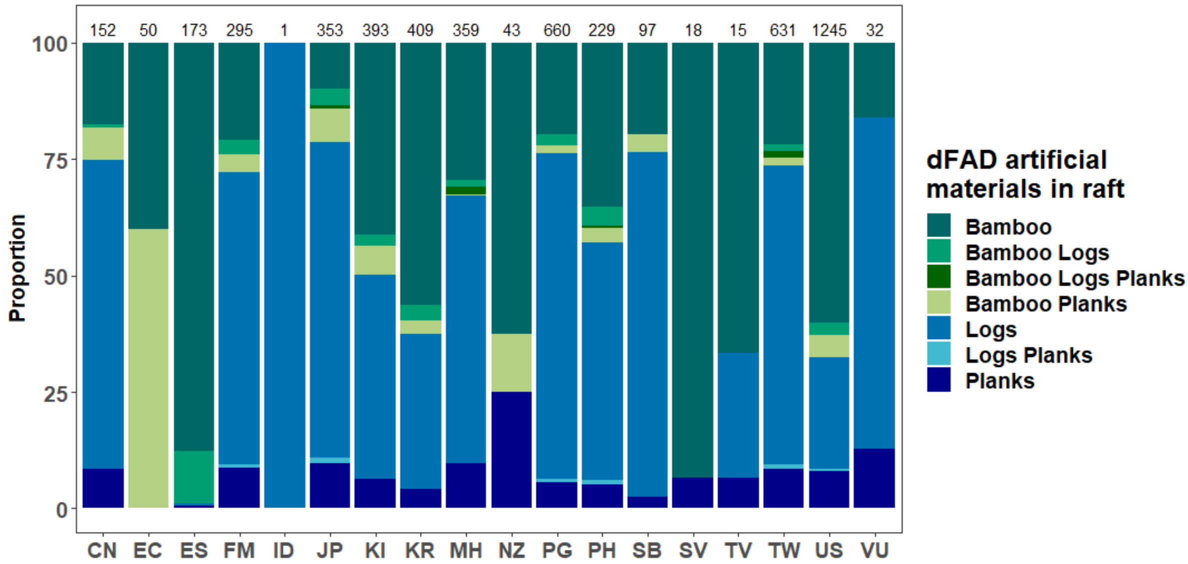

Figure 5. Natural materials used in the dFAD rafts, as recorded by observers (2011–2020). Numbers on the top of the figure correspond to the number of dFADs with natural materials in their raft.

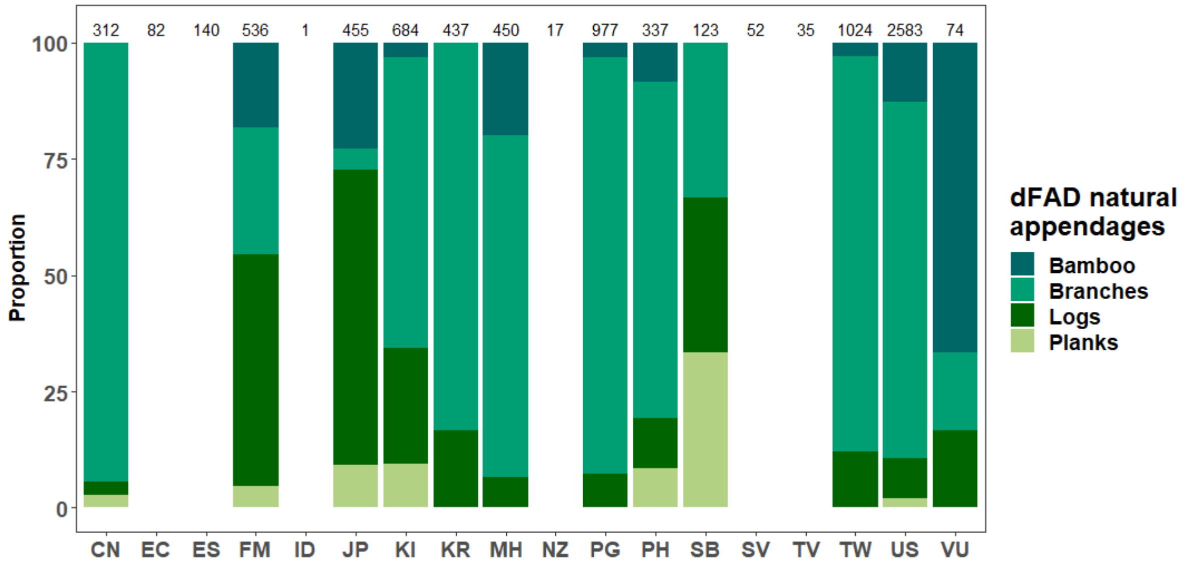

Figure 6. Natural materials (branches include coconut fronds; planks include pallets and timbers) used as dFAD appendages, as recorded by observers (2011–2020). Numbers on the top of the figure correspond to the number of dFADs with natural appendages, numbers > 0 with no coloured bars corresponds to FADs with no appendages recorded, i.e., the submerged part of the FAD is natural.

Artificial materials used in the dFAD rafts are mostly floats, which dominate dFAD construction for most fleets (Figure 7). However, some specific designs can be identified for some fleets. The Philippines fleet for instance used drums (plastic or metal drums). El Salvador and Ecuador used plastic pipes in 13–17% of their rafts containing artificial materials, and EU Spain used nets, cords or sacking in 10% of their rafts with artificial materials, where the nets, cords or sacking are likely used to reinforce or cover their bamboo rafts (Figures 5 and 7).

Finally, the types of artificial materials used in dFAD appendages are highly variable between and within fleets (Figure 8), but are mostly a combination of i) cord, net and weights; ii) net, sacking or sheeting and weight; iii) cord, net, sacking or sheeting and weights; or iv) cord and net.

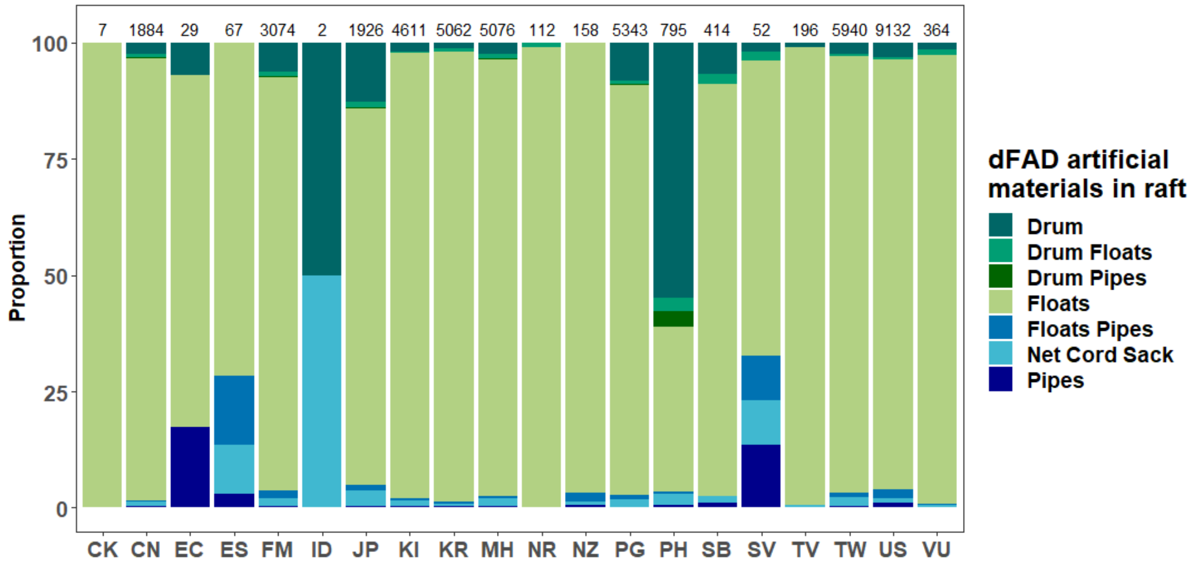

Figure 7. Artificial materials used in the dFAD rafts, as recorded by observers (2011–2020). Numbers on the top of the figure correspond to the number of dFADs with artificial materials in their rafts.

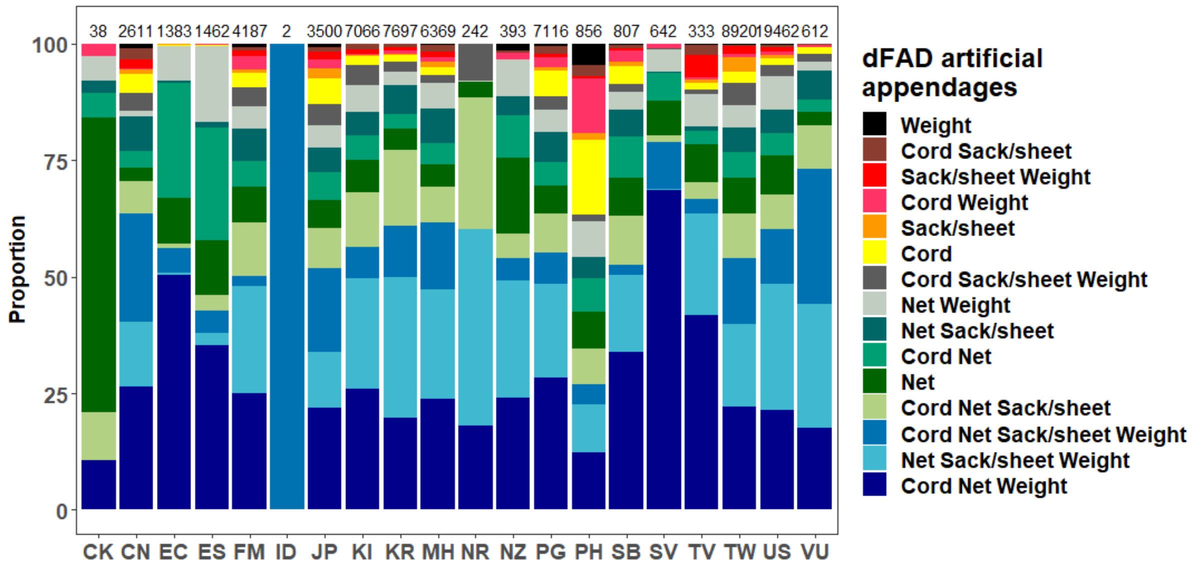

Figure 8. Artificial materials used as dFAD appendages, as recorded by observers (2011–2020). Numbers on the top of the figure corresponds to the number of dFADs with artificial appendages.

Non-entangling dFADs

The proportion of dFADs with some nets used in the raft or the appendages was investigated, as an indication of low entanglement risk/non-entangling dFADs (see Appendix 1 for main dFAD designs). Less than 15% of observed dFADs had no nets. While no clear temporal trend was detected, 2020 was the year, although still incomplete, with the highest percentage of FADs with no nets (Figure 9). Most dFADs have at least some nets as appendages (65–90%), with a slight increase in the use of nets in both appendages and raft over time (Figure 9). Philippines, Tuvalu and Japan used the least netting with 53%, 19% and 16% of their dFADs observed to have none (Figure 10). El Salvador, Ecuador and New Zealand tended to use nets as appendages but the use on the raft being rare.

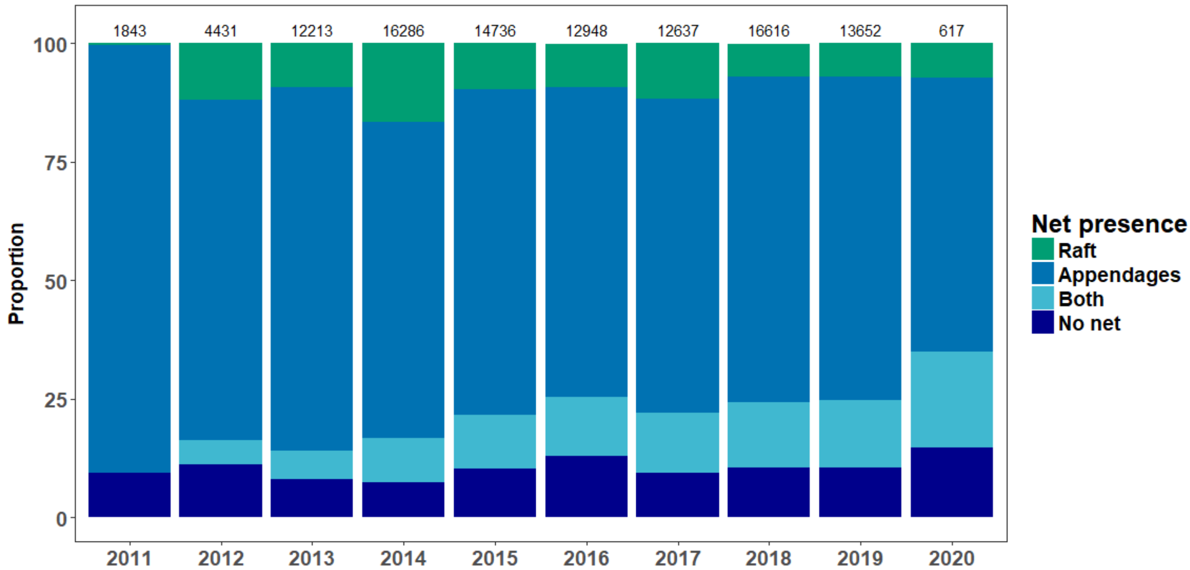

Figure 9. The use of nets in raft and appendages of dFADs, as recorded by observers per year. Numbers on the top of the figure correspond to the number of dFADs per year.

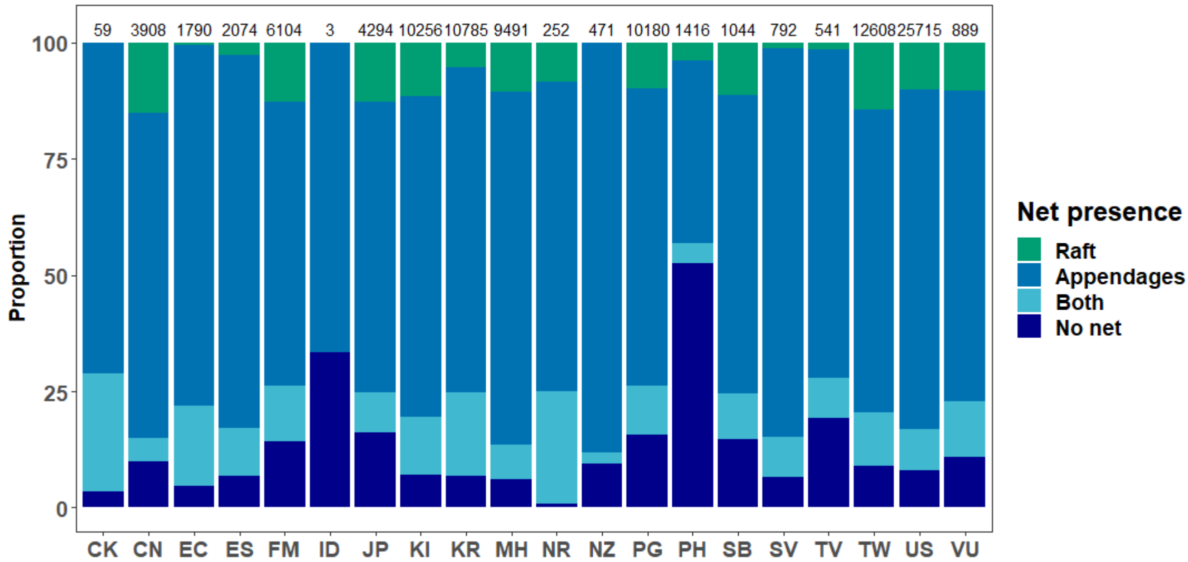

Figure 10. The use of nets in raft and appendages of dFADs, as recorded by observers per fleet (2011–2020). Numbers on the top of the figure correspond to the number of dFADs per fleet.

Discussion

Results presented in this paper, based on observer records of dFAD materials, showed similar results to a previous paper submitted to SC14 (Escalle et al., 2018). In particular, it was found that; i) no temporal trend in dFAD construction was detected, indicating that fleets have been using the same materials over the last 10 years; ii) very few natural materials have been used in dFAD rafts and submerged appendages in the WCPO; iii) floats, sometimes combined with logs are used by most fleets to ensure buoyancy of dFAD rafts; iv) submerged appendages tend to be constructed from artificial materials, with natural materials rarely used (e.g., branches and coconut fronds); and v) most dFADs included the use of nets, however a slight increase in the use of dFAD with no netting is detected for the first few months of 2020.

Pacific Island Countries and Territories (PICTs) have repeatedly voiced concerns about their islands receiving abandoned dFADs; with stranding of dFAD rafts and long entangling submerged appendages damaging fragile coral reef systems and contributing to already extensive coastal pollution brought by ocean currents. While recent studies have estimated that around 7% of dFADs become beached in the WCPO (Escalle et al., 2020, 2019), this is likely to be a significant underestimate given that most dFADs stop being monitored before reaching coastal areas. This finding triggered the need for data collection on lost and beached dFADs directly in PICTs, to assess the real beaching rate and explore the impacts of dFADs on coastal ecosystems (Escalle et al., 2020b).

The dominance of entangling dFADs use in the WCPO detected in this study could have deleterious effects. First, entanglement of Species of Special Interest (SSI; e.g., turtles, sharks) can occur at different stages of a dFAD's life, from the time drifting at-sea, through ghost fishing when the dFAD is lost or abandoned, to final stages if the dFAD strands and gets caught on coral reefs (Balderson and Martin, 2015; Filmalter et al., 2013; Pilling et al., 2017). Secondly, the current designs of dFADs and the materials used will have greater impact on coastal ecosystems than non-entangling or biodegradable FADs. It has recently being estimated that the currently assessed number of beached dFADs (i.e., 7%) affected 4 to 6 km^2 of coral reef habitat per year in Parties to the Nauru Agreement (PNA) countries (Banks and Zaharia, 2020).

When nets are used in dFADs, an important parameter to estimate for its entanglement potential is the mesh size (see Appendix 1). In this study, the investigation of net use through time and by fleet did not account for mesh size or the dFAD design (e.g., nets rolled up as sausages), which can reduce entanglement (low entanglement design, see Appendix 1). In general, when nets were used, they presented large size mesh nets (average of 9.2 cm for nets in appendages and 7.9 cm for nets to cover the raft, as recorded by observers for 2011–2020, but there is currently very limited data for 2020 as yet (i.e., 4,000 records with an average of 9.5 cm for nets in appendages and 7.6 cm for nets to cover the raft)), corresponding to high entanglement risk. However, these patterns vary among fleet, with some fleets using smaller average mesh size of less than 7 cm.

Since January 1st 2020, WCPFC requires dFADs deployed or drifting into the WCPO to be of lower entanglement risk (Appendix 1; Paragraph 19, WCPFC, 2018). Hence, a dFAD raft must either have no net, or net with a stretched mesh size of less than 7 cm (2.5 inches) and well wrapped around the whole raft so that there is no netting hanging below the dFAD. The design of the underwater or hanging part of a dFAD should also avoid the use of mesh net. If mesh net is used, it must have a stretched mesh size of less than 7 cm or be tied tightly in bundles or "sausages" with enough weight at the end to keep the netting taut down in the water column. Alternatively, a single weighted panel of small mesh size net (less than 7 cm stretched mesh size), or solid sheet as canvas or nylon can be used (Paragraph 19, WCPFC, 2018). Since 2017, WCPFC also encourages the use of biodegradable materials in the construction of dFADs (WCPFC, 2017).

In general, natural and low or non-entangling dFAD materials are rarely used in the WCPO. This could be due to the types of materials that are available depending on the fleet and the different ports of arrival, as well as the current tendency to recycle materials from purse seine activities (e.g., recycled purse seine nets, ropes, plastics). In addition, given the very recent nature of the Conservation and

Management Measure (CMM), any noticeable effect may take at least one to 2 years to be detected (especially given that very few data for 2020 are included here). Most fleets use floats or drums for the raft, which are not biodegradable (except EU Spain, Ecuador and El Salvador, that use bamboo), as well as artificial appendages including nets. Non-entangling dFADs are now widely adopted in other oceans (Murua et al., 2016) and trials of biodegradable dFADs have been implemented (e.g., Zudaire, 2017, Moreno et al., 2020). In the WCPO, while dFAD designs will have to evolve to comply with the current tropical tuna CMM (WCPFC, 2018), trials are needed to test the efficiency of new designs and to find appropriate alternative submerged appendages, as it is the largest component of dFADs and the one most impacting on coral reefs and entangling SSIs (Moreno et al., 2018). The depth and extent of the dFAD appendages are used to control the drifting speed of the dFAD, to provide bio-fouling opportunities, and shelter and shade for associated non-tuna finfish, all of which are felt to enhance tuna aggregation (Moreno et al., 2020; Pilling et al., 2017). Appropriateness of these new dFAD designs (e.g., cost, material availability) for the WCPO also needs to be investigated. Several trials involving collaboration between governments, industry and international non-profit organisations (FSM, Caroline Fisheries Corporation and ISSF) or led by fishing companies themselves, have recently started and results should help guide the transition to novel dFAD design and materials adapted to the WCPO. For instance, in the FSM testing of biodegradable materials, the submerged appendages of dFADs included bamboo, jute canvas, coconut fiber ropes, and stones placed inside the base of the bamboo; while the dFAD raft consisted of purse seine corks or floats wrapped with non-entangling net (small mesh size ≤ 7 cm) for buoyancy (Moreno et al., 2020). Note that this current study highlighted the high variability between fleets in the materials, and likely design, of dFADs use. This might therefore need to be considered when developing biodegradable FAD designs for all the fleets operating in the WCPO.

Considering the new dFAD designs and materials being tested and the WCPFC CMM that is directing the requirement for low entanglement risk dFADs, there is a need for detailed information on the materials used in dFADs construction. This should include their biodegradable nature, as well as the design of the dFAD itself. Currently, several materials recorded by observers could either be artificial or biodegradable (e.g., cords, ropes, canvas, nets, sacks and bags), but tests of the biodegradable nature of materials in the tropical marine environment are still required. In addition, while the presence of nets, and sometimes the mesh size (7% of observations), are recorded, there is generally no possibility to record the design of submerged appendages. For instance, if the net is tied in bundles, as is required for monitoring and evaluation against the tropical tuna CMM. Given the importance of this parameter to detect the entangling nature of a dFAD, emphasis should be made for observers to more systematically record mesh size and dFAD designs. Additional fields in relevant forms (e.g., observer data) would therefore be necessary to monitor the type of dFAD design and whether a given material is biodegradable. Most importantly, greater efforts to obtain data on mesh sizes used, including on all new FADs deployed, retrieved FADs or those that are found beached, should also be taken.

We invite WCPFC-SC16 to:

- Note that materials used in dFADs in the WCPO have been dominated by artificial and entangling materials, with high variability among fleets. The use of low entanglement risk and biodegradable dFADs has been limited.

- Reaffirm the commitment to reduce the use of plastic, entangling and non-biodegradable materials in the construction of dFADs in the WCPO to help reduce marine pollution and ecosystem impacts.
- Note that further studies are needed to quantify the effectiveness and the entanglement frequency of Species of Special Interest (SSI) in the WCPO on common FAD designs, but also on new low entanglement risk, non-entangling and biodegradable dFADs.
- Note the need for additional data fields or more systematic data to be recorded by the observers to adequately assess the designs, materials and type of dFADs deployed in the WCPO.
- Support on-going research activities and at-sea trials of biodegradable and non-entangling design options in the WCPO and provide corresponding advice to the FAD Management Options Intersessional Working Group.

Acknowledgments

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References

Balderson, S.D., Martin, L.E.C., 2015. Environmental impacts and causation of 'beached' Drifting Fish Aggregating Devices around Seychelles Islands: a preliminary report on data collected by Island Conservation Society. IOTC Tech. Rep. IOTC-2015-WPEB11-39 15pp.

Banks, R., Zaharia, M., 2020. Characterization of the costs and benefits related to lost and/or abandoned Fish Aggregating Devices in the Western and Central Pacific Ocean. Report produced by Poseidon Aquatic Resources Management Ltd for The Pew Charitable Trusts.

Escalle, L., Brouwer, S., Pilling, G., 2017. Report from Project 77: Development of potential measures to reduce interactions with bigeye tuna in the purse seine fishery in the western and central Pacific Ocean ('bigeye hotspots analysis'). WCPFC Sci. Comm. WCPFC-SC13-2017/MI-WP-07.

Escalle, L., Brouwer, S., Pilling, G., 2018. Evaluation of dFAD construction materials in the WCPO. WCPFC Sci. Comm. WCPFC-SC14-2018/EB-IP-01.

Escalle, L., Muller, B., Scutt Phillips, J., Brouwer, S., Pilling, G., PNAO, 2019. Report on analyses of the 2016/2019 PNA FAD tracking programme. WCPFC Sci. Comm. WCPFC-SC15-2019/MI-WP-12.

Escalle, L., Muller, B., Hare, S., Hamer, P., Pilling, G., PNAO, 2020. Report on analyses of the 2016/2020 PNA FAD tracking programme. WCPFC Sci. Comm. WCPFC-SC16-2020/MI-IP-14.

Filmalter, J., Capello, M., Deneubourg, J.L., Cowley, P.D., Dagorn, L., 2013. Looking behind the curtain : Quantifying massive shark mortality in fish aggregating devices. Front. Ecol. Environ. 11, 291–296. https://doi.org/10.1890/130045

ISSF, 2019. ISSF Guide for Non-Entangling & Biodegradable FADs. 9p.

Leroy, B., Phillips, J.S., Nicol, S., Pilling, G.M., Harley, S., Bromhead, D., Hoyle, S., Caillot, S., Allain, V., Hampton, J., 2013. A critique of the ecosystem impacts of drifting and anchored FADs use by purse-seine tuna fisheries in the Western and Central Pacific Ocean. Aquat. Living Resour. 26, 49–61. https://doi.org/10.1051/alr/2012033

Lopez, J., Ferarios, J.M., Santiago, J., Alvarez, O.G., Moreno, G., Murua, H., 2016. Evaluating potential biodegradable twines for use in the tropical tuna fishery. WCPFC-SC12-2016/EB-IP-11.

Moreno, G., Restrepo, V., Dagorn, L., Hall, M., Murua, H., Sancristobal, I., Grande, M., Le Couls, S., Santiago, J., 2016. Workshop on the use of biodegradeable Fish Aggregating Devices (FADs). ISSF Technical Report 2016-18A. International Seafood Sustainability Foundation, Washington, D.C., USA.

Moreno, G., Murua, J., Kebe, P., Scott, J., Restrepo, V., 2018. Design workshop on the use of biodegradable fish aggregating devices in Ghanaian purse seine and pole and line tuna fleets. ISSF Technical Report 2018-07. International Seafood Sustainability Foundation, Washington, D.C., USA.

Moreno, G., Salvador, J., Murua, J., Phillip Jr., N.B., Murua, H., Escalle, L., Zudaire, I., Pilling, G., Restrepo, V., 2020. A multidisciplinary approach to build new designs of biodegradable Fish Aggregating Devices (FADs). WCPFC Sci. Comm. WCPFC-SC16-2020/EB-IP-08.

Murua, J., Itano, D., Hall, M., Dagorn, L., Moreno, G., Restrepo, V., 2016. Advances in the use of entanglement-reducing drifting fish aggregating devices (dFADs) in tuna purse seine fleets. ISSF Technical Report 2016-08. International Seafood Sustainability Foundation, Washington, D.C., USA.

Murua, J., Itano, D., Hall, M., Moreno, G., Restrepo, V., 2017. Towards global non-entangling fish aggregating device (FAD) use in tropical tuna purse seine fisheries through a participatory approach. ISSF Technical Report 2017-07. International Seafood Sustainability Foundation, Washington, D.C., USA.

Pilling, G., Smith, N., Moreno, G., Van der Geest, C., Restrepo, V., Hampton, J., 2017. Review of research into drifting FAD designs to reduce species of special interest bycatch entanglement and bigeye/yellowfin interactions. WCPFC-SC13-2017/EB-WP-02.

WCPFC, 2017. CMM-2017-01 Conservation and management measure for bigeye, yellowfin and skipjack tuna in the Western and Central Pacific Ocean.

WCPFC, 2018. CMM-2018-01 Conservation and management measure for bigeye, yellowfin and skipjack tuna in the Western and Central Pacific Ocean.

Zudaire, I., 2017. Testing designs and identify options to mitigate impacts of drifting FADs on the ecosystem. IOTC-2017-SC20-INF07.

Appendix 1. Examples designs of dFADs with increasing risk of entanglement. Reproduced from ISSF (ISSF, 2019).