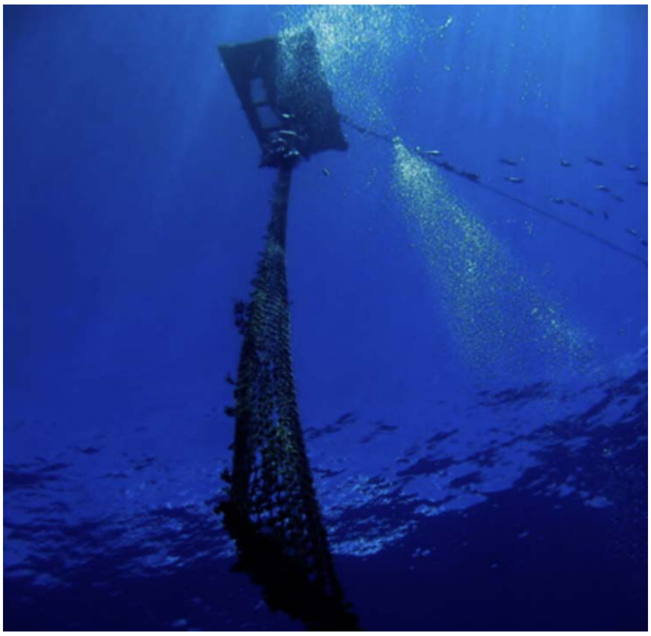

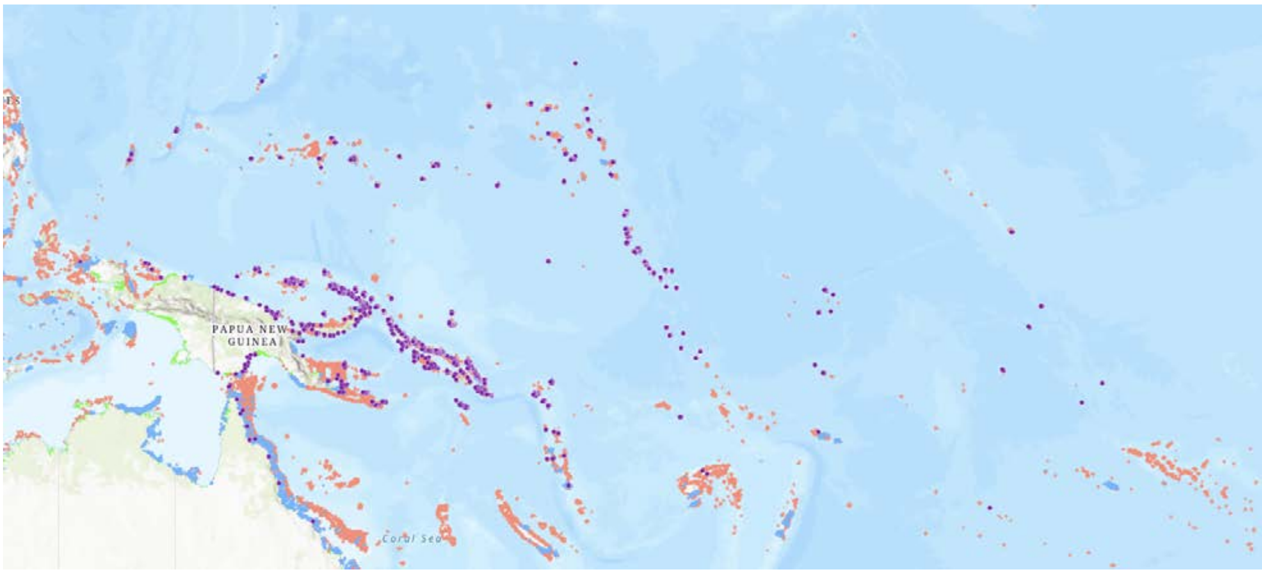

Characterization of the costs and benefits related to lost and/or abandoned Fish Aggregating Devices in the Western and Central Pacific Ocean

January 2020

Report Information

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Glossary

ALDFG……. Abandoned, lost or otherwise discarded fishing gear
BNER FAD ... Biodegradable Non-entangling Risk FADs
DFAD............ Drifting Fish Aggregation Device
CPCs .... Contracting Participating Countries
CPUE............ Catch Per Unit of Effort
CSIRO……… Australia's Commonwealth Scientific and Industrial Research Organisation
EEZ............... Economic Exclusive Zone
ENSO………. El Niño–Southern Oscillation
ERAEF………Ecological Risk Assessment for the Effects of Fishing
ERS .... Electronic Reporting System
FAD .... Fish Aggregation Device
FAME............ Fisheries, Aquaculture and Marine Ecosystems
FIMS .... Fisheries Information Management System
FSM .... Federated States of Micronesia
HER FAD...... Highest entanglement Risk FADs
IUU .... Illegal, Unreported and Unregulated Fishing
LER FAD....... Lowest Entanglement Risk FADs
MACBIO........ Marine and Coastal Biodiversity Management in Pacific Island Countries
MARPOL....... The International Convention for the Prevention of Pollution from Ships
NER FAD……Non-Entangling Risk FADs
PNA .... Parties to the Nauru Agreement
PNA TIA........ PNA Tracking Implementation Arrangement
PNG.............. Papua New Guinea
PS................. Purse seine
RMI .... Republic of the Marshall Islands
SICA…………Scale Intensity Consequence Analysis
SPC .... The Pacific Community
SSI................ Species of Special Interest
TAP............... Threat Abatement Plan
VMS.............. Vessel Monitoring System
WCPFC......... Western and Central Pacific Fisheries Commission
WCPO .... Western and Central Pacific Ocean

Executive Summary

1. The report examines the impact from the loss of Drifting Fish Aggregation Devices (DFADs) from the Western and Central Pacific purse seine fishery. Based on recent FAD deployments, in 2017-2019, between 44,700 and 64,900 FADs are estimated to have been deployed annually. Using the data available from the Parties to the Nauru Agreement (PNA) FAD Tracking Programme it is estimated that, 5,912 to 8,583 FADs were retrieved, 9,254-13,463 FADs beached and 29,534-42,881 sunk annually.

2. Drifting FAD (DFAD) currently in use throughout the World's oceans can be characterised in terms of 4 types: Highest Entanglement Risk FADs (HER FAD), Lesser Entanglement Risk FADs (LER FAD), No Entanglement Risk FADs (NER FAD) and Biodegradable No Entanglement Risk FADs (BNER FAD). The Western and Central Pacific fishery is in the process of transitioning from HER FADs to LER FADs, with the prospect of changing to NER FADs to be discussed at the 2020 Annual Meeting.

3. The PNA tracking programme identified beaching events for HER FADs. The Pacific Community (SPC) Division, Fisheries, Aquaculture and Marine Ecosystems (FAME), has also analysed beachings and connectivity between deployment locations and Pacific Islands coastlines using observed trajectories and Lagrangian simulations.

4. Beaching event frequency was explored by 1° grid cells in coastal areas. Papua New Guinea, Solomon Islands and Kiribati were associated with a higher number of beachings, representing 80% of the total, with considerably fewer beachings found in other PNA island countries (18%), and a very small number outside PNA waters (3%). Hotspot grid cells included Onotoa and Beru atolls, and the eastern part of Tabiteuea in Gilbert Islands, Kiribati; Ontong Java Atoll, Malaita North and Malaita South, in Solomon Islands; and the central part of New Ireland in Papua New Guinea. Beaching events outside the PNA zone may be underestimated due to geofencing, although the based on alternative information sources, the numbers are not likely to be hugely underestimated.

5. The fleets associated with higher numbers of beaching DFADs included Korea (31%), Taiwan (16%) and Kiribati (14%). FSM, China, PNG, Philippines, US and Marshall Islands fleets accounted for lower levels of beachings (4-8%), and Japan, much lower levels (2%).

6. The majority (92%) of the identified beaching events were likely to have occurred on coral reef habitat. The remaining events occurred either on seagrass habitat, mangroves or sandy beaches, where no coral reefs were mapped. Some FADs possibly impacted more than one type of habitat.

7. It is estimated that the range of DFADs and coral reefs interactions were between 8,534 and 12,391 per annum in the period 2017-2019. Of these interactions, 31% occurred in Solomon Islands, 30% in PNG, 17% in Kiribati, Gilbert Islands, 8% in Tuvalu, 6% in F. S. Micronesia, 4% in R. Marshall Islands, 1% in Nauru, and 0.5% in Palau, with the rest in non PNA countries.

8. Of the total coastal areas, the impact has been assessed as having affected cumulatively between 4 and 6 km^2 of coral reef habitat per year. It is highly likely that none of the corals survived the impact.

9. An environmental assessment, using Scale Intensity Consequence Analysis (SICA) estimates that the overall risk to Pacific habitats is Moderate. However, these impacts might vary considerably from Major to Minor, where there is likely to be specific concern on the impact of beachings in the 'hotspot' areas. These impacts are highly likely to be reduced with a change to NER and BNER FADS.

10. Four scenarios of future deployments have been explored: under current conditions, i.e. with traditional FADs, used over the next decade, this might lead to the degradation of 86 km^2 of coastal habitats and 270 km^2 of deep benthic habitats. In contrast, using biodegradable non-entangling FADs, with a three-year transition period when LER FADs could be used, and a limit of 200 FADs per boat (for current fleet level), the cumulative impact over a decade could be reduced to 9 km^2 coastal habitats and 33 km^2 of deep benthic habitats. Biodegradable FADs are not considered to have lasting environmental impact.

11. An economic assessment of the cost of coral reefs degradation due to beached FADs, estimates the economic impact at US$ 479,136 to US$ 695,664 per year of damage (in Net Present Value on 10 years). The range of impacts per country in PNA are from US$ 9,202 in R. Marshall Islands to US$ 221,653 in Solomon Islands. These costs are very small if taken as a percentage of income derived from purse seine access fees, i.e. less than 0.1% overall, and nowhere greater than 1%.

12. The value of the current impacts per hotspot are US$ 42,114, US$ 19,949, US$ 9,043.39 and US$ 19,516 for Malaita, Ontong Java, New Ireland and Southern Gilbert Islands respectively, or US$ 58/ beached DFAD, US$ 50/ beached DFAD and US$ 76/beached DFAD.

13. It has been difficult to estimate the impact of sunk FADs (lost FADs that are not retrieved and not beached). However, it is clear that the scale of lost gear is highly significant, set against the background of overall gear losses from fishing. Approximately 66% of all deployed FADs are expected to have sunk. This could mean that over 40,000 FADs annually (from the upper number from the upper range of DFAD deployed of 64,900 deployments/year). This represents around 4,000 MT of waste. Some of the lost gear, which may include FADs, accumulates in convergence zones of the oceans. No research has been undertaken to identify areas where FADs are sinking and how the deep currents move them. This issue could not be explored in depth, although this assessment highlights the fact that DFADs represent a very high proportion of the world's Abandoned, Lost or otherwise Discarded Fishing Gear (ALDFG). These lost FADs may sink in areas rich in seamounts. Seamount habitats are some of the richest biological hotspots in the oceans providing important habitats for coral, invertebrates, demersal fish. Also, some of these FADs may impact on unique deep-sea chemosynthetic communities from the bottom of the ocean which are poorly understood. Biodegradable FADS would be more likely to reduce the impact on the benthic substrate than other FAD types because the effects are less likely to be irreversible. These impacts are highly likely to be reduced with a change to BNER FADS.

14. The WCPFC Convention and almost all national fishery Acts define FADs as fishing gear. This means that a FAD drifting in any closed area such as territorial seas, a closed area around main Islands, or any other closed area, could be regarded as illegal fishing; a FAD drifting in a zone in which any vessel associated with the FAD is not licensed is regarded as illegal fishing; and for the PNA, a vessel with a FAD in the water anywhere, is interpreted as fishing, irrespective of the PNA VDS, which would most likely require vessels to purchase Vessel Days in all EEZs where FADs were drifting.

15. Under the draft PNA 4th implementation arrangement, due for possible implementation in 2021, vessel skippers will be obliged to report FAD deactivation. This does not preclude their vessels from their legal obligations. Parties may look to establish some form of sanction system or encourage a FAD retrieval programme where there are major risks of beaching events. These issues are likely to be more relevant to Solomon Islands, PNG and Kiribati.

16. All Parties, with the exception of FSM, are signatories to MARPOL, but this assessment concludes that MARPOL Annex V are guidelines and have not been

implemented in PNA countries. Adoption of an alternative legal instrument as an alternative to fisheries management legislation would weaken the current legislative obligations.

17. An assessment of purse seine company views identified that owners of DFADs should accept any damage caused by a DFAD, but also identified that the high at-sea operating cost for purse seine vessels makes it cost-prohibitive to retrieve distant DFADs. Some respondents commented that it is feasible to establish site-specific programmes that monitor DFAD satellite buoy data to determine when DFADs approach specific, sensitive sites so that the DFADs could be intercepted by locally based vessels before running aground;

18. Analysis of beaching events in island communities identified that only around half of the FAD components recovered included components other than FAD buoys, suggesting that the buoys had been dislodged from the FADs at some stage. FAD buoys were usually collected and used in some form, for example as lighting or water containers, but most were generally kept as souvenirs outside houses in the expectation that they had some value. Other FAD materials such as floats and netting were also retained, but rarely recovered from reefs.

19. Proposed actions for consideration to mitigate against FAD loss are as follows:

    a. Ensure that vessel owners are aware that DFADS constitute fishing activities and as such are liable sanctions for unauthorised fishing in unauthorised zones (EEZs where vessels have no access entitlement, territorial seas and closed areas). Hence, there is an emphasis on vessel owners in recovering FADs before entering these zones;

    b. Recovery options should be implemented, especially where the prospects for beachings are high – Solomon Islands, PNG and Kiribati, and such options can include two possibilities: Owner recovery through chartering vessels to recover FADs or a FAD Watch and recovery programme initiated through provincial programmes and funded by industry;

    c. A FAD Watch system that combines satellite trajectories with community collection systems, is worth exploring for hot spot areas. This type of arrangement is likely to be effective in intermediate to low risk areas. However, in any area where DFADs fail to be recovered, individual countries should be in a position to implement sanctions so as to encourage improved FAD management. The FAD Watch system would require purse seine vessel owners partner with national fisheries departments, local NGOs and/or coastal fishers to recover DFADs;

    d. Alternative funding scenarios could be considered whereby management fees are generated from the FAD charging system to allow for the cost of recovery. These funds would be allocated to all Parties but distributed on the basis of historic beachings;

    e. National government should set sanctions to deter beachings. It is recommended that these are based on a combination of a recovery cost along with the economic cost of the impact (US$ 1,250 + US$ 75), or in some cases higher, where FAD impacts are likely to have a higher economic impact, e.g. Palau;

    f. At present, adoption of 350 FADs per vessel is likely to accelerate the damage to coastal habitats in the Solomon Islands, PNG and Kiribati. The management authorities should therefore re-evaluate the limits set on the number of FADs to be carried. The figure of 350 FADs per vessel is not precautionary and is likely to significantly increase the impact of damage to coastal habitats, sea mounts and deep-water biota. Studies show that a realistic range for FAD numbers per vessel lies somewhere between 140 to 200 FADs per vessel.

g. It is noted that most Parties apply the ecosystem approach to fisheries management as a core objective of their fisheries acts. The ecosystem approach to fisheries strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries.

h. Whilst the overall risk and impact of FAD beachings is moderate across the PNA islands, the localised impacts for specific hotspots are a concern. These risks are inevitably going to increase if the number of DFAD deployments increase. The analysis first shows that the environmental impacts of changing to LER FADs and thereafter to NER FADs will be less than HER FADs. Changes to NER FADS will reduce, but not eliminate the environmental impact. The assumption is that a further change to BNER FADs, if operational from a fishing perspective, will lessen the impact further and are most likely to reduce the impact on coastal and deep-sea habitats.

1 Introduction

This report, funded by The Pew Charitable Trusts (Pew), is in support of preparatory work being undertaken by the Parties to the Nauru Agreement (PNA) as part of a Fish Aggregation Device (FAD) Management Scheme. The work, undertaken by Poseidon Aquatic Resources Management (Poseidon), is to quantify the environmental impact of FADs and to assess economic costs and benefits of FAD deployment and FAD collection, as well as to assess legal implications associated with impacts of lost and beached FADs.

The specific tasks required are as follows:

- Describe the types of FADs (1) high-entanglement, (2) lesser entangling FADs, (3) non-entangling FADs and (4) biodegradable and non-entangling design and Identify costs of construction, expected life span and replacement profiles;
- Identify the areas of lost FADs – beaching inside PNA zones, drifting outside PNA zones and sinking;
- Identify the type of habitats impacted - flora and fauna, such as coral reefs and nesting habitats (e.g. turtles and seabirds) and seabed type;
- Assess the non-market value associated with FAD impacts, together with the main costs and benefits;
- Identify the legal liability issues that can be assessed against interpretations of national and international laws;
- Identify industry views of on the issue of FAD losses
- Identify the impact of coastal communities from FAD beaching
- Identifying lessons learned from FAD recovery systems
- Identify the costs of alternative DFAD recovery options
- Set out possible strategies to focus on reducing the impact of FADs;
- Determine the costs of policing FAD recovery and the systems required to implement a recovery programme, the practicality of bonds, the practicality of alerts on approaching vulnerable habitats and operations to recover FADs.

2 Background and Purpose of Study

PNA introduced FAD buoy registration as an integral part of its Vessel Registration programme in 2015. Pew funded a PNA FAD buoy tracking scheme, with the movement of FADs detected through satellite buoys. The results were then analysed by the Fisheries, Aquaculture and Marine Ecosystems (FAME) Division of the Pacific Community (PC) (Escalle, Muller, Brouwer, Pilling, & the PNA Office, 2018; Escalle, Muller, et al., 2019).

Sixty two thousand five hundred and forty-four (62,544) deployments were tracked from 2016–2018. However, these represent around 40% of all FADs in the water (Escalle, Muller, et al., 2019, p. 19). The main deployments took place in Kiribati south of the Gilbert Islands and Kiribati east of the Phoenix Islands, Nauru, and to the east of Papua New Guinea (PNG), with high FAD densities found in Kiribati south of the Gilbert Islands and around the Phoenix Islands, Tuvalu, PNG, and the Solomon Islands.

Fifty-two per cent of FADs were classified as lost, 11% were retrieved; 8% were beached; 15% were deactivated due to unknown causes and 14% were deactivated by the fishing company and left drifting, unmonitored at sea (Lauriane Escale, pers com, 22 Oct 2019).

Whilst all the PNA islands experienced some beaching events, these events were more frequent off the east coasts of the Solomon Islands and Papua New Guinea (PNG), as well as in the Gilbert Islands (Kiribati). Ninety-seven to 98% of beached FADs were reported as having beached on the islands of the PNA, with a small number also found in Indonesia, Australia, Fiji, Vanuatu, Samoa and the Cook Islands. That said, the information on the fate of FADs outside PNA is fairly limited because most fishing companies geo-fence FAD buoy transmissions, which means that some information on FADs drifting outside PNA EEZs is removed prior to data transmissions (Escalle, Muller, et al., 2019).

The Pew funded work sought to look more closely at the impact of FAD losses on marine habitats with a view to providing strategy options on how best to mitigate against the impact of FAD losses. The work applied the beached FADs trajectories supplied by SPC and identified the habitats affected. Thereafter, the assessment examined both the environmental impact by means of risk assessment as well as an assessment of the economic impact of FAD losses on the coastal zones.

3 Types of FADs Deployed

Purse seiners use a variety of fishing practices to catch tuna. These include: Free school, where fish are caught without the aid of any man-made device; Log set, where fish are caught when setting on a natural FAD; Anchored FADs where FADs are man-made but anchored to the sea floor; and Drifting FADs, where FADs are man-made and drift with the ocean currents.

This work focusses first on the use and deployment of entangling drifting FADs, now currently applied in the Western and Central Pacific Ocean (WCPO), and assesses the impact of these against alternative 'lower risk' options, including lesser entangling FADs, non-entangling FADs and biodegradable non-entangling FADs (Figure 1).

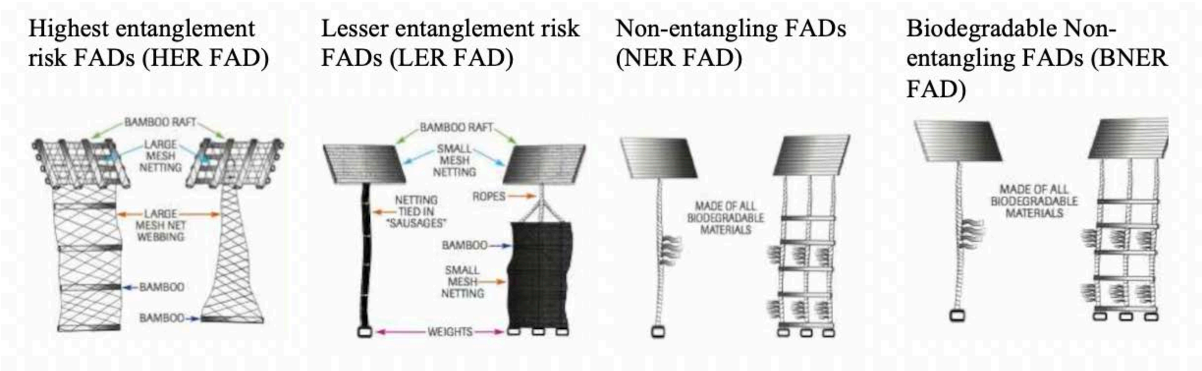


Figure 1. Types of Drifting FAD design.
Source: ISSF, 2018

Up until 2018, Highest entanglement FADs (HER FAD) were being deployed in the WCPO. The Western and Central Pacific Fisheries Commission (WCPFC) currently supports the application of Lesser Entanglement FADs (LER FAD) (para 19WCPFC, 2018) with the intention of further exploring the use of non-plastic and biodegradable materials. The WCPFC Science Committee Working Group will further consider the adoption of measures on the implementation of non-entangling and/or biodegradable material on FADs. **Error! Reference source not found.** presents a summary of the design components, materials used and costs for each DFAD type.

Table 1. The design components, costs and lifespan of each FAD type.

Design Component	HER FAD		LER FAD	NER FAD	BNER FAD
Shape	Rectangular raft of 4-6 m^2		Bamboo raft and floats	Bamboo raft or bundle	Rack
Material	Bamboo, net corks		Bamboo	Bamboo	10 bamboo canes, balsa or pinewood
Positioning Buoys	Satellite or acoustic buoys		Satellite or acoustic buoys	Satellite or acoustic buoys	Satellite or acoustic buoys
Cover	Layers of black net or black plastic sheet		Covered with small mesh layers of black net (<7cm), tightly wrapped around the raft with canvas cover over the small mesh layers	Cotton canvas cover, no netting	Palm leaves and cotton canvas

Design Component	HER FAD		LER FAD	NER FAD	BNER FAD
Floats	Trawl floats and PVC pipes or ethylene vinyl acetate copolymer attached to the upper part of DFAD		Ethylene vinyl acetate copolymer floats	Ethylene vinyl acetate copolymer floats	Ethylene vinyl acetate copolymer floats
Submerged structure	Hanging panel of netting (90 – 200mm)- variable number and length. Panels crossed by bamboo canes at 10-15 meters intervals, to keep the net open, with metal weight at the end. Most FADs in WCPO have a submerged structure of 40 – 80 meters (Murua, Moreno, Dagorn, Itano, & Restrepo, 2017)		Small mesh netting (<7cm stretched) tightly tied into bundles ('sausages')	Ropes, canvas or nylon sheets, or other non-entangling materials	Cotton ropes that do not allow the biofouling.
Construction cost per FAD excluding buoy	US$ 10-18		US$ 15-25 (reflects higher labour costs)	US$ 15-25 (reflects higher labour costs)	US$ 87
Operating cost	$25/buoy/month		$25/buoy/month	$25/buoy/month	$25/buoy/month
Expected lifespan	10-12 months, but up to 2 years		10-12 months, but up to 2 years	10-12 months	2 – 12 months
Replacement profiles	On land construction in Flag State ports		On land construction in Flag State ports	On land construction in Flag State ports	Some potential to construct on Pacific Islands, but much of the material e.g. bamboo and floats still need to be imported.

Source: Franco et al, 2009, Murua et al, 2017; Piling et al, 2017, Hernandez-Garcia et al, 2014, Goujon et al., 2012), Zudaire et al 2019.

All FAD systems use the satellite buoy, which is used by the vessels to track the FAD. Hydrostatic release units for buoys are not currently deployed but could be used so as to geo-locate buoys when the FAD sinks.

Highest entanglement Risk FADs (HER FADs) are no longer accepted in the WCPO but had been deployed up to the end of 2019. This FAD type was eliminated because of the risk in entangling Species of Special Interest (SSIs) such as sharks and rays, sea turtles, cetaceans, and sea birds. This report relies on the tracking of HER FADs. Some literature exists on comparative experiences of the impact of other FAD types in the Indian Ocean (Balderson & Martin, 2015).

The current WCPFC management measures (WCPFC, 2018) rules now require the deployment of Lesser Entanglement Risk FADs (LER FADs), but these retain the risk of the 'sausage' netting unravelling, and the FAD still contains a large amount of synthetic material – netting and floats.

Non-entangling FADs no longer contain netting, which are replaced by cotton canvas, but still use Ethylene vinyl acetate copolymer floats. This FAD type functions are identified as effective as the submerged structures in traditional FADs and are seen as effective as traditional DFADs but with no entanglement risk (Hernandez-Garcia, Santana Ortega, Ganzedo-Lopez, & Castro, 2014).

Each of the above FAD types are subject to water logging and are likely to lose buoyancy by 10-12 months but have been known to have a lifespan of up to 2 years. The materials (netting, canvas sheets and floats) are usually readily available and are usually built onshore where sufficient attention is paid to quality control so as to guarantee the longevity of the FAD (Pilling, Moreno, van der Geest, Restrepo, & Hampton, 2017). None of the materials used are biodegradable.

Biodegradable FADs are not as durable as the lifespan thresholds experienced with LER and NER FADs and may degrade or sink at a faster rate than other FAD types. The main challenge is with the loss of buoyancy in the bamboo with time due to seeping of water inside the cane´s air chambers. The lifespan can potentially be extended if FAD construction uses green or recently cut canes, and canes are coated in oil or wax. Plastic floats are still likely to be required.

The more the amount of netting used, the greater the risk of entanglement with corals and trapping of animals (Zudaire et al., 2018). Any synthetic materials are unlikely to deteriorate with a further risk of unobserved mortality of animals, if the raft sinks, or when beaching occurs. Biodegradable DFADs would also be expected to break apart at sea more quickly than conventional DFAD designs and therefore could reduce the overall risk of beaching events occurring (Davies, Curnick, Barde, & Chassot, 2017).

4 Quantifying Lost FADs

Lost FADs were defined as FADs that are lost for the company that owns them and have the potential to impact on various components of the marine ecosystem. The fate of these FADs can be i) beached FADs ii) sunk FADs or iii) stolen.

Lost FADs were identified and quantified as proportions of annual FAD deployments. The main sources of information used for this purpose were the PNA FAD tracking programme and the publications resulted from this program. Other sources of information used include the WCPFC website (www.wcpfc.int), Bycatch Management Information System website (www.bmis-bycatch.org) and other peer reviewed and grey literature.

4.1 FAD Tracking Program

4.1.1 Plotting the trajectories

The FAD-tracking programme was initiated in January 2016 to quantify and manage the number of drifting FADs (DFADs) deployed by the purse seine fisheries in the EEZs of PNA member countries. This programme required fishing companies to report data to the PNA via the satellite service provider. The reported data included the location and a time stamp recorded periodically by the satellite buoy attached to the DFAD (Escalle, Scutt Phillips, et al., 2019).

The buoys transmitted data from the moment they were activated, which could have been a few hours to several days before deployment, and continued to transmit until deactivation (Escalle, Scutt Phillips, et al., 2019). Transmission frequency (most hourly or daily) varied over time due to fishers setting different transmission modes. For example, lower frequencies were typically used when DFADs drifted away from main fishing areas or during the WCPO DFAD closure periods (Escalle, Scutt Phillips, et al., 2019).

These transmissions provided location data for when DFADs were drifting at sea, and also for when DFADs were on board a vessel, either before deployment or when recovered at sea (Escalle, Muller, et al., 2019). The authors classified positions into “at-sea” or “on-board”, according to a method developed by Maufroy *et al* (Escalle, Muller, et al., 2019; Escalle, Scutt Phillips, et al., 2019). For each DFAD tracked, a trajectory could by plotted from “at-sea” segments data. Most buoys (67%) had one segment and some (33%) had several (2–14) segments of drift positions. A buoy trajectory could have represented a single buoy deployed on several DFADs, following separate recovery and deployment events. For each segment, deployment position was estimated as the first “at-sea” position (Escalle, Scutt Phillips, et al., 2019).

4.1.2 Geo-fencing

A potential source of bias for the analyses and the interpretation of FAD tracking data was the practice of “geo-fencing”, i.e. the systematic modification of buoy transmissions by removing information from outside PNA EEZs prior to data transmissions. This resulted in gaps in DFADs trajectories (Escalle, Muller, et al., 2019). To compensate for this limitation, Escalle, Muller, et al. (2019) used a simulation method based on ocean currents to fill in trajectory gaps. Due to geo-fencing, the number of beaching events outside PNA may have been underestimated (Escalle, Scutt Phillips, et al., 2019). Lagrangian simulation experiments of virtual DFADs showed low particle densities in all coastal grid cells outside PNA EEZs, with the exception of two cells in Indonesia (Escalle, Scutt Phillips, et al., 2019), supporting a low interaction of lost FADs with areas outside PNA, thus the bias of geo-fencing is likely to be low.

4.2 Estimating the number of FAD deployments

Escalle, Brouwer, Pilling, and the PNA Office (2018) used two different approaches to estimate the total number of annual FAD deployments in WCPO. Based on purse seine fishery data for 2011–2017, the number of deployments recorded in the observer data, the observer coverage by vessel, and a clustering of vessels based on their FAD fishing strategy were used to estimate the total number of buoy (and FAD) deployments per vessel and overall in the WCPO. Using this method, a total estimated number of deployments between 21,000 and 51,000 per year in the WCPO for the 2011–2014 was obtained, with a sharp decrease thereafter, likely due to delays in receiving data for recent years (Escalle, Brouwer, et al., 2018).

The second approach combined fishery data and the PNA FAD tracking data and only covered 2016 and 2017, with precise estimates only possible for some vessels. At the scale of the WCPO, 30,700–56,900 deployments were estimated in 2016 and 44,700–64,900 in 2017 (Escalle, Brouwer, et al., 2018). Although the number of deployments could have increased in 2017 compared to 2016, this is not necessarily evident because the lower estimate for 2017 is lower than the higher estimate for 2016. There are no deployment estimates available for 2018 and 2019 although, based on consultations with industry, these are expected to be at the higher end of past estimates (Les Clark, pers com, October 2019).

The number of vessels operating in PNA EEZs has been quasi-stable at about 275 from 2010 to 2015 to drop to 244 in 2017 then increase 254 in 2019 (Parties to the Nauru Agreement, 2019). For this assessment, several scenarios were considered: i) a similar number of FADs will continue to be deployed in the next decade (64,900 – the higher bound of the interval was considered only under a precautionary approach to account for the highest reasonable risk when the exact number of deployments is not known), ii) the number of deployments will increase up to 350 active FADs per vessel (this is equivalent to approximately 518 deployments per vessel, (Escalle, Brouwer, et al., 2018) and will be achieved in the next decade if deployments increase by 5% per year from 2017 level), iii) the number of deployments will decrease to 200 per vessel within the next decade to be in accord with research findings by Lennert-Cody, Moreno, Restrepo, Román, and Maunder (2018).

4.3 Estimating the number of lost FADs

Escalle et al (Escalle, Muller, et al., 2018; Escalle, Muller, et al., 2019) analysed the spatio-temporal distribution of buoy deployments, the number of FADs at sea, FAD densities and the fate of FADs at the end of their trajectories.

Based on data from PNA FAD tracking program, Escalle, Muller, et al. (2019) classified DFADs as: i) still drifting, if the last position was "at-sea" and within the main purse seine fishing grounds (141°W, 210°E, 8°N, 12°S); ii) lost, according to the refined approach, if the last position was "at-sea" but outside the fishing grounds of the company owning it; iii) recovered if the last position was "on-board" of a vessel; or iv) beached if the last position was "at-sea" and within 10 km of shore and at least the last three positions at 0m, <10m, or <100m from each other.

Under the refined classification, the majority of FADs were lost (52%), with 30% drifting within the fishing grounds of all PNA purse seiners, and 22% outside the main fishing grounds. The remaining FADs were either retrieved (11%), beached (8%), or still drifting (29%) (Escalle, Muller, et al. (2019), with a correction for beached FADs, pers comm Lauriane Escalle 18 Oct 2019). Out of those still drifting on the main fishing grounds (29%), about a half were deactivated by the parent company (during FAD closures or at the end of the year or geo-fenced) and left drifting unmonitored (14%). The rest were deactivated due to unknown causes (about 15%). The authors hypothesized these unknown causes might have been: sinking, appropriation of the FAD by another company (buoy exchanged) or malfunctioning buoy (Escalle, Muller, et al., 2019). About 4% of all FADs that were classified in the latter category (i.e. deactivated for unknown causes) had last position within 50 km of a coast, having a higher probability to beach not long after deactivation. These DFADs were classified as pre-beached (Escalle, Muller, et al., 2019). Table 2 provides a summary of the final classification (revised according to pers comm Lauriane Escalle 18 Oct 2019).

Table 2. FAD classification by terminal position (retrieved, lost, beached or drifting) - results based on FADs from companies with at least three purse seiners and with the last transmission in the dataset before July 2018 (12,315 FADs)

FAD category	FAD sub-category: %of total tracked FADs	% of total tracked FADs by category
Retrieved	On company fishing grounds: 6.01%	10.93%
	Outside company fishing grounds: 4.92%	
Lost	Within PNA main fishing grounds: 29.51%	51.86%
	Outside PNA fishing grounds: 22.35%	
Drifting and deactivated	Deactivated by the fishing company (end of the year, FAD closure, geo-fencing): 14.00%	29.39%
	Deactivated by unknown cause: 11.54%	
	Pre-beached: 3.85%	
Beached	Beached: 7.82%	7.82%

Source: pers comm Lauriane Escalle 18 Oct 2019

4.3.1 Annual beached and sunk DFADs (2017-2019)

Method

The revised classification of lost FADs from Table 2 and the number of DFAD deployments (Escalle, Brouwer, et al., 2018) were used to calculate the annual number of beached and sunk DFADs for 2017-2019 period (Box 1).

Except for "retrieved' FADs, all the other categories become lost FADs at the end of their lifespan. Because this assessment is based on limited information, it is aimed to be precautionary and assume the highest probability of impact shown by the available evidence. The fate of "pre-beached" FADs was assumed beached as a "worst-case" scenario and these were added to the 'beached" category. The fate of all FADs that were neither retrieved or beached was assumed "sunk" after a maximum period of 24 months from deployment (Pilling et al., 2017). A direct estimate of sunk PNA DFADs was not available from research literature.

To estimate the annual number of sunk DFADs, the "stolen" ones (called "recycled" later) needed to be accounted for. These are DFADs that become lost for the primary owner company and are appropriated by another company (buoy exchange). This practice occurs worldwide and helps reduce the number of unmonitored drifting FADs in the oceans (Gilman et al., 2018). Once receiving a new buoy, the FADs are no longer lost and they enter the monitored FADs cycle: some are retrieved, some beach, some become lost again. According to a stakeholder survey on FAD identification of ownership, respondents reported that they lose about 21% of their satellite buoys due to FAD exchange (Gilman et al., 2018) (see Box 1).

Box 1. Calculation protocol for annual estimates of retrieved, beached and sunk FADs.

It was assumed that in the year 2017, 44,700 were deployed. Out of these, at the end of the year, 10.93% were retrieved, 11.67% were beached and pre-beached, 51.86% were lost, 14% were deactivated by their owning company and left drifting, 11.54% were still drifting before they lost signal due to unknown causes.

In 2018, out of the lost and still drifting within PNA fishing grounds (29.51%), a number of DFADs equivalent to 21% of 2017 deployments (i.e. 9,387) were recycled by buoy exchange, and entered the monitored cycle: 10.93% of these were retrieved, 11.67% beached, 51.86% became lost, 14% were deactivated by their company and 11.54% lost signal due to unknown causes and still drifting. *(To be noted that for model simplification, it was assumed this process occurred the following year and FADs that were exchanged when still active, although this could have occurred at any time and some unexplained deactivations could have been attributed to FAD exchanged (Escalle, Scutt Phillips, et al., 2019), nevertheless this is unlikely to significantly bias the end result because the numbers obtained would be the same).*

In 2018, 11.67% of all other DFADs that were still drifting (lost and deactivated) beached.

All DFADs not retrieved or beached that were deployed in 2017 were assumed to sink by the end on 2018.

Results

The annual estimates for beached and sunk DFADs (2017-2019) are presented in Table 3.

Table 3. Annual estimates for retrieved, beached and sunk DFADs
- based on the classification from Table 2 and lower and upper annual DFAD deployment levels estimated in section 4.2).

Number of deployed DFADs per year	Number of retrieved DFADs per year	Number of beached DFADs per year	Number of sunk DFADs per year
44,700 - 64,900	5,912 – 8,530	9,254 – 13,436	29,534 – 42,881

Limitations

This is a simplified model that aims to inform on the possible magnitude of the impact of lost DFADs. Due to the limitations of the data used which are discussed in Escalle, Muller, et al. (2019) and in Escalle, Brouwer, et al. (2018), and due to the fact that DFADs dynamics are not fully understood, these values may be under- or overestimated.

4.3.2 Projections for the number of lost DFADs in 2020-2029

Method

WCPFC CMM 2018-01 requires all FADs deployed from 1 January 2020 to be LER FADs and specifies that NER FADs shall be considered for adoption at the 2020 meeting of the Commission (WCPFC, 2018).

To estimate the magnitude of possible cumulative impact over the next 10 years, a series of "what if" scenarios were considered:

Scenario 1: No action – traditional DFADs (HER FADs) will continue to be used for the next 10 years with

a. constant rate of deployment of a maximum[1] of 64,900 DFADs/year. This makes a precautionary allowance to assume a higher number of FADs in use.
b. 5% yearly increase in deployment from baseline of 64,900 DFADs/year. This makes allowance for a gradual increase in deployment from the current level of around 180-200 active FADs per vessel to 350 (the limit set out in WCPFC CMM 2019-01), equivalent to 518 deployments per vessel.

Estimated beaching FAD impact for HER FAD was set at 500 m^2 per FAD[2].

Scenario 2: lower entanglement DFADs (LER FADs) will be deployed for three years to allow transitioning to non-entangling DFADs (NER FADs) which will be used for the rest of the seven years with

a. constant rate of deployment of maximum 64,900 DFADs/year
b. 5% yearly increase in deployment from 64,900 DFADs/year

Estimated FAD impact for LER FAD was set at 500 m^2 per FAD[3], estimated impact of NER FADs was set at 50 m^2 considering that most designs include only ropes (Table 1) in the submerged structures and the total impact surface will be much smaller.

Scenario 3: LER FADs will be deployed for three years to allow transitioning to biodegradable non-entangling DFADs (BNER FADs) which will be used for the rest of the seven years with

c. constant rate of deployment of maximum 64,900 DFADs/year
d. 5% yearly increase in deployment from 64,900 DFADs/year

Estimated FAD impact for LER FAD was set at 500 m^2 per FAD (as above), estimated impact of BNER FADs set at 50 m^2 considering that most designs include only ropes in the submerged structures and the total impact surface will be much smaller. It is possible that BNER FADs will have a shorter life and more deployments will be necessary. In addition, BNER FADs will have the advantage that will degrade and the impacts of lost FADs that are not retrieved

[1] The higher bound of the estimate was used as precautionary approach under uncertainty when the exact number of deployments is not known and in order to prepare contingencies for the highest probable risk and prevent irreversible impact and high costs to communities and industry (see Precautionary Approach: http://www.fao.org/3/W1238E01.htm).

[2] For traditional FADs the area of impact for one FAD was set at 500m^2 based on the fact that most FADs in WCPO have a tail of 40-80m long (Murua et al., 2017) and 2m wide, and a floating structure of 6-9m^2. Using a precautionary approach, the average surface (127.5 m^2) of the FAD was multiplied by 4 then rounded to 500. The multiplication factor was not scientifically derived although was chosen based on evidence of multiple impacts (contact with multiple habitats) for some FADs. Using a precautionary approach in conditions of uncertainty, (http://www.fao.org/3/W1238E01.htm#ch1.1.2), the possibility that all DFADs could have multiple impacts could not be excluded.

[3] LER FAD might still use netting panels with smaller mesh size or netting tightly tied into bundles (sausages). The bundles were shown to unravel and to become entangling, although this might not be a problem for active FADs if they are built on land by specialised personnel according to standard procedures. Nevertheless such FADs using "sausage" appendages might not work in the WCPO conditions as they didn't work in the Atlantic Ocean (Murua et al., 2017) and netting panels will need to be used. In consequence, while LER FADs will have a lower impact on wildlife entanglement, their impact on habitat will probably be similar to that of HER FADs.

will have a lower impact in the environment and the impact will not be irreversible.

Scenario 4: LER FADs will be deployed for three years to allow transitioning to BNER FADs which will be used for the rest of the seven years but with a lower limit set on FAD numbers at 200[4].

Estimated FAD impact was set the same as for scenario 3.

Results

Scenario 1

This scenario is unlikely because steps have already been taken towards the use of FADs with lower risk for the environment. Nevertheless, it was considered to contrast it with the other two scenarios.

a) The following were assumed: maximum rate of deployment does not increase from current levels and DFADs are retrieved, beach and become lost at rates similar to the current ones. From 2020 to 2029, 649,000 traditional DFADs will be deployed, 84,343 will be retrieved, 128,498 will beach and 385,427 will sink. If the impact area estimated is close to the actual one, for the ten-year period, approximately 64 square kilometers of coastal habitat and over 193 square kilometers of benthic oceanic habitat will be impacted. This estimation does not consider that some impact might overlap, thus the total area might be overestimated.
b) If the rate of deployment will increase 5% per annum, 816,395 DFADs will be deployed in 2020-2029 period, 116,652 will be retrieved, 171,651 will beach and 539,791 will sink. This is equivalent with the degradation of 86 square kilometers of coastal habitats and 270 square kilometers of benthic oceanic habitats.

For details see Appendix 1

Scenario 2

So far, no research has been undertaken to compare the rate of beaching of HER FADs with that of LER FADs. Some information can be inferred from Maufroy, Kaplan, Chassot, and Goujon (2018) who have estimated DFAD beachings in the Atlantic Ocean (8.7%) for the 2007-2015 period. The authors emphasize that during the 2010's, the European purse seine fleets fishing in the Atlantic Ocean have progressively transitioned towards lower entanglement FADs. Maufroy et al (2018) however, do not indicate a change in the rate of beaching events after LER FADs have been introduced. The same rates of beaching were applied to LER FADs in this scenario as for the HER FADs in Scenario 1.

Also, there is limited information on the beaching behavior of NER FADs, mainly because this type of FAD is not yet widely used. Balderson and Martin (2015) suggest that some FADs with no nets in the submerged parts, instead of being caught on coral reef, might slide by the coast and avoid beaching altogether, thus the rate of beaching would be lower. Also, completely non-entangling FADs with bamboo floating structures are likely to become waterlogged before they hit the reef and beaching rate might be lower. However, empirical evidence, although very limited and not from WCPO, does not support a lower beaching rate for NER FADs. Island Conservation Society (ICS) collected information on beached DFADs around Seychelles between 2011- 2015. For FADs that had the submerged parts still attached, the ratio of FADs using nets rolled up in "sausage" (LER FAD) to DFADs using synthetic rope (NER FAD at

[4] (Lennert-Cody et al., 2018) examining rates of return per deployment for this fleet segment found that the greatest rate of return occurred at 200 DFAD deployments per vessel.

least for the submerged part) was 3.2 (62.1%:19.5%). This is similar to the ratio of these FAD types intercepted by the ICS before beaching in the Indian Ocean during 2011-2017, which was 3.4 (Zudaire et al., 2018). Although the impact of completely non-entangling DFADs, when beached, is most likely different than that of lesser entanglement DFADs and that of traditional FADs, there is no evidence at this stage that their rate of beaching is lower, and the same rates were assumed.

a) In this scenario, in the transition period, 194,700 LER FADs will be deployed, 24,260 will be retrieved, 34,446 will beach, and 85,762 will sink. This corresponds to a potential degradation of 17 square kilometers of coastal habitats and 43 square kilometers of benthic habitats. Then, 454,300 NER FADs will be deployed, 60,083 will be retrieved, 94,052 will beach and 300,166 will sink. This means that, if the estimation of impact area is a reasonable approximation, another 5 square kilometers of coastal habitat and 15 square kilometers of benthic oceanic habitat will potentially be impacted. A total of 22 km^2 of coastal habitat and 58 km^2 benthic oceanic habitat will potentially suffer impact.
b) With increased deployment (5% annual increase), 204,597 LER FADs will be deployed, 25,416 will be retrieved, 35,894 will beach, and 87,906 will sink. This means that 18 km^2 of coastal habitat 44 km^2 of benthic oceanic habitat might be degraded during this period. After the transition, 611,708 NER FADs will be deployed, 80,232 will be retrieved, 124,008 will beach and 384,922 will sink. This might be equivalent with another 6 km^2 of coastal habitats and 19 km^2 of benthic oceanic habitats degraded by 2029. Overall, in this scenario, 24 km^2 of coastal habitat and 63 km^3 of benthic oceanic habitat might be impacted by lost FADs in a decade.

   Details are presented in Appendix 1 .

Some of the damage resulted from the impact might be irreversible, especially when FADs made from synthetic materials remain in place and continue to damage benthic habitats and do not allow recovery. Nevertheless, having a smaller overall impact area, the cumulative damage will be less and LER FADs and NER FADs represent a good solution as an intermediary phase while developing BNER FADs.

Scenario 3

This scenario is the same as scenario 2 with the difference that the non-entangling FADs will be made from biodegradable materials.

In recent years, developing and testing biodegradable DFADs has become a primary research area (Moreno et al., 2019) although there is no information available to be able to project the rate of beaching for this type of FADs (if different than for traditional FADs). Preliminary analysis of the effectiveness of FADs made from biodegradable materials has shown mixed results. The durability of biodegradable materials tested was lower than that of the control NER FADs, especially when canvas was used to cover floating structures, while some biodegradable ropes in the tail structures were still in good condition after four months at sea (Zudaire et al., 2019). Possibly, these FADs will break apart before they beach, and the impact area of each part resulted will be smaller. Also, the impact will not be irreversible as all parts (or most) are biodegradable.

a) In this scenario, in the transition period, 194,700 LER FADs will be deployed, 24,260 will be retrieved, 34,446 will beach, and 85,762 will sink (same as in Scenario 2). This corresponds to a potential degradation of 17 square kilometers of coastal habitats and 43 square kilometers of benthic habitats. Then, 454,300 BNER FADs will be deployed, 60,083 will be retrieved, 94,052 will beach and 300,116 will sink if the rates of beaching and sinking will be the same, although these FADs may break apart before beaching or sinking, and the impact area for each part will be smaller, and possibly the pieces will be more spread out. Because of the high number of FADs, there will be physical impact, although the impact is unlikely to be irreversible. A cumulative impact for biodegradable FADs cannot be calculated but is assumed non-significant.

b) With increased deployment (5% annual increase), 204,597 LER FADs will be deployed, 25,416 will be retrieved, 35,894 will beach, and 87,906 will sink. This means that 18 km^2 of coastal habitat 44 km^2 of benthic oceanic habitat might be degraded during this period. After the transition, 611,708 BNER FADs will be deployed, 80,232 will be retrieved, 124,008 will beach and 384,922 will sink. As explained above, although physical impact is expected, because the FADs are biodegradable, the impact will not be irreversible. It is not possible to calculate the cumulative impact for biodegradable FADs although long-term impact is assumed to not be significant.

Scenario 4

The number of vessels fishing in PNA EEZs is taken to be the average that operated in 2018 and 2019 (249) and each will deploy 200 DFADs per year in 2020-2029 to total deployments of 49,800 dFAD/year. In the transition period, 149,400 DFADs will be deployed, 18,616 will be retrieved, 29,159 will beach, 65,808 will sink. This means that 9 km^2 and 33km^2 of oceanic benthic habitat might suffer degradation over a decade.

After the transition period, 348,600 BNER FADs will be deployed, although the number of beachings cannot be determined (BNER FADs might break apart before they beach). Ultimately, all biodegradable DFADs will probably beach or sink in the form of small parts which are unlikely to create irreversible damage to the habitat.

Details are presented in Appendix 1

Limitations

The same limitations from section 4.3.1 apply, adding the limitation of making projections for the future in conditions of high uncertainty.

Table 4. Projected impact of lost DFADs.
Four modelled scenarios with different types of DFADs deployed in 2020-2029 period.

Scenario	Total beached	Total sunk	Total area of coastal habitat degradation (from beached DFADs) (km^2)	Total area of benthic habitat degradation (from sunk DFADs) (km^2)
1.a Traditional DFADs, constant deployment (64,900/year)	128,498	385,927	64	193
1.b Traditional DFADs, with 5% annual increase	171,651	539,791	86	270
2.a Traditional DFADs for three year (transition period) + non-entangling DFADs thereafter, constant deployment (64,900/year)	128,498	385,927	22	58
2.b Traditional DFADs for three year (transition period) + non-entangling DFADs thereafter, with 5% annual increase (64,900/year)	171,651	539,791	24	63
3.a Traditional DFADs for three year (transition period) + biodegradable non-entangling DFADs thereafter, constant deployment (64,900/year)	34,446	85,762	17	43
3.b Traditional DFADs for three year (transition period) + biodegradable non-entangling DFADs thereafter, with 5% annual increase (64,900/year)	35,894	87,906	18	44
4. Traditional DFADs for 3 year and biodegradable DFADs thereafter with a limit of 200 FADs/vessel (for 249 vessels)	29,159	65,808	9	33

Note 1: For scenarios 3 and 4, the beached and sunk DFADs presented in the table are for the three-year transition period when lower entanglement DFADs will be used.
Note 2: The impact from biodegradable DFADs are not included in the table because this type of FADs is not considered to have long term impact.

4.4 Sunk DFADs

A decade ago, Macfadyen, Huntington, and Cappell (2009) reported that information on the contribution of lost FADs to marine litter was scarce. After a massive expansion of DFAD fishing, ten years later, Richardson, Hardesty, and Wilcox (2019) make a similar claim, that the issue has not received much attention.

While FAD beaching has received some attention, the magnitude of the impact of sinking DFADs has not been considered. If in 2007, out of about 9,000 FADs in IATTC, 90% were retrieved (Macfadyen et al., 2009), in 2019, in WCPO, out of 64,900 FADs, only 11% were probably retrieved. From the calculations in this assessment, over 66% of the FADs deployed annually in the WCPO sink. There has been no requirement so far for the retrieval of lost FADs, nor is it feasible for fishers to do so (e.g. Gillman et al 2017).

It is not clear what the impact of these FADs is, when and where they sink, and where they are taken by the deep oceanic currents. Various authors have modelled the dynamics of

ALDFG in the oceans showing a tendency to accumulate in ocean convergence areas (Figure 2).

A noteworthy fact is that areas of possible accumulation in the Pacific Ocean (Figure 2) are also areas rich in seamounts (Figure 3). It is commonly accepted that seamounts represent some of the richest biological hotspots of the oceans, providing habitats for coral, demersal fish and sharks (Jupiter, McCarter, Albert, Hughes, & Grinham, 2019). In addition, the abyssal plains are home to a diversified fauna of chemosynthetic communities that are poorly understood (Samadi et al., 2015). These vulnerable communities could be threatened by sinking DFADs.

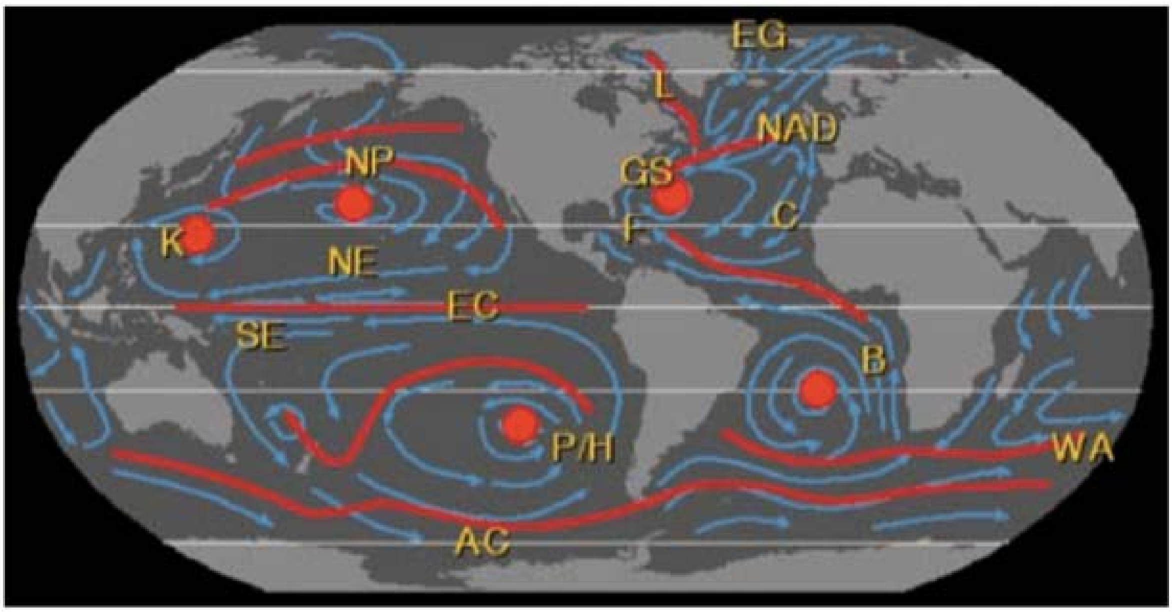


Figure 2. Possible areas of accumulation of ALDFG
Area of accumulation shown in red circles. Source: Macfadyen et al. (2009)

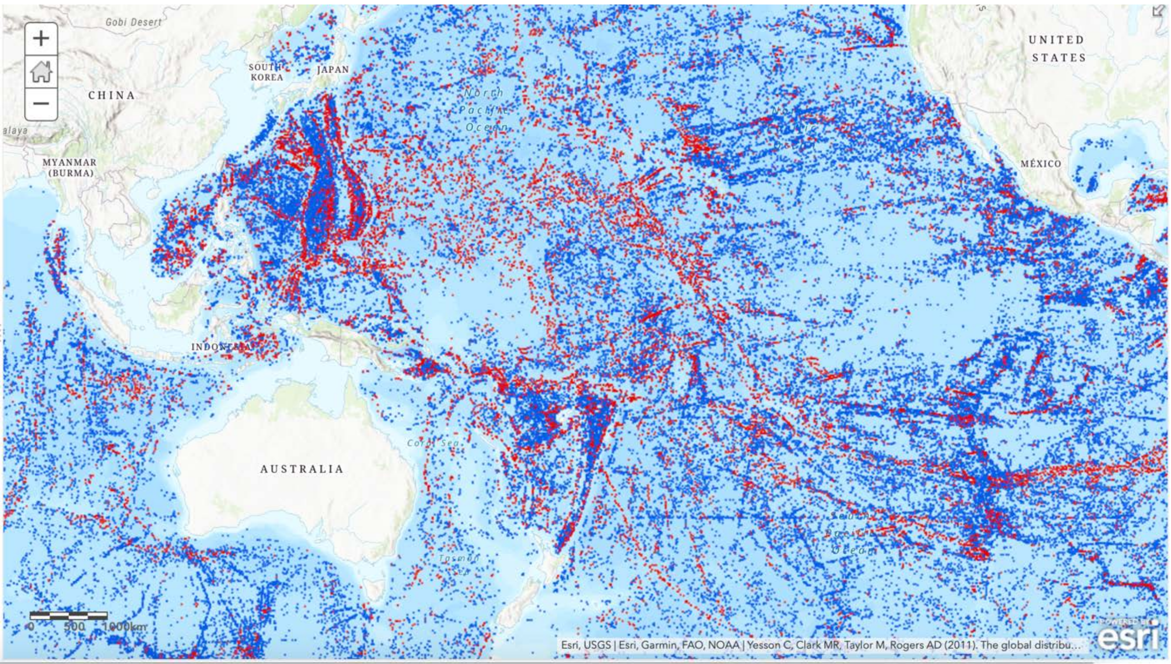


Figure 3. The distribution of seamounts and knolls in Pacific Ocean.

- seamounts in red, knolls in blue Source: https://data.unep-wcmc.org

5 FAD Beaching and Habitat Impact

Escalle, Scutt Phillips, et al. (2019) have analysed the distribution of FAD beaching events in the WCPO as well as the environmental and operational drivers of beaching. FAD beaching events and their corresponding deployment locations were analysed using data from 22,620 drifting FADs deployed in the WCPO in 2016–2017 (Escalle, Scutt Phillips, et al., 2019). In addition, the trajectories of over 1.5 million virtual drifting FADs were studied using Lagrangian simulations (Escalle, Scutt Phillips, et al., 2019).

The authors found that 5.8% of observed trajectories ultimately beached (Escalle, Scutt Phillips, et al., 2019). To be noted is that this result differs from the percentage presented in section 4.3 because it is based on a different subset of the FAD tracking data from years 2016 and 2017 only. The largest number of beaching events were in the EEZs of Papua New Guinea (483), Solomon Islands (379), Kiribati Gilbert Islands (155) and Tuvalu (117). Beaching events were studied at 1° grid cell resolution level. There was a weak but statistically significant positive relationship between local FAD density and the number of beaching events in that cell. However, some cells were more prone to beaching given high FAD density than others. Beaching prone cells were mostly found in the southwest area (Papua New Guinea and Solomon Islands) in quarters 2, 3 and 4, but also some in the southeast area (in Nauru, Kiribati Gilbert Islands and Tuvalu).

Beaching in Papua New Guinea and the Solomon Islands appeared to be strongly related to both large-scale ocean circulation and local processes while in Tuvalu, beaching seemed to have been influenced by the convergence effects of large-scale oceanic circulation leading to a high density of DFADs in the area. In Tuvalu, coastal cells had relatively higher densities of drifting FADs than elsewhere, regardless of the type of simulated deployment scenario, although in the *observed deployment* scenario these were three times higher than for the *uniform deployment scenario* (Escalle, Scutt Phillips, et al., 2019). Lower levels of beaching of DFADs in the northern hemisphere (Federated States of Micronesia and Republic of the Marshall Islands), corresponded to relatively lower levels of deployment. In contrast, there were high rates of beaching in Kiribati, Gilbert Islands. These appeared to be influenced primarily by DFAD deployment drivers (Escalle, Scutt Phillips, et al., 2019).

5.1 Identifying Beaching Habitats

The SPC and PNA have provided a dataset extracted from the PNA tracking program, identifying terminal positions of 1933 buoys attached to FADs that were considered beached at the end of their trajectory. In addition, a full trajectories dataset for these buoys has also been provided. The trajectories dataset included data for beached FADs identified through the PNA FAD tracking data associated with deployments and drift tracks of FADs between 1 January 2016 and 8 December 2018. It comprises of 1,395,347 position transmissions linked with the date and time of transmission. The datasets include transmissions from 407 FADs that beached in 2016, 898 FADs that beached in 2017 and 627 FADs that in 2018. The final positions were mapped and used to identify habitat impact at a regional scale. However, final positions transmitted by the buoy might not have been the first beached positions (a FAD could have had multiple habitat contact or local people might have moved the buoy). For this reason, FAD trajectories were mapped and the movements at the end of the trajectory of the beached FADs were analysed at local scale for beaching hotspots (where the risk of cumulative impact was higher).

5.1.1 Identifying Habitat Impact at Regional Scale

Beaching events distribution by coastal state and flag

Most beaching events occurred within the PNA EEZs borders, although a small percentage of FADs beached in other areas, as presented in Table 5.

Table 5.The distribution of PNA FAD beaching events by EEZ, 2016-2018.

Beaching EEZ	**Percentage of all beaching events**			
PNA +Tokelau	**2016**	**2017**	**2018**	**Average**
PNG	33.91%	34.19%	34.71%	34.30%
Solomon	23.59%	31.85%	29.46%	29.33%
Kiribati	18.43%	13.59%	17.83%	15.99%
Tuvalu	7.86%	8.02%	6.21%	7.40%
FSM	7.13%	5.57%	4.94%	5.69%
RMI	5.16%	3.01%	3.18%	3.52%
Nauru	0.74%	0.78%	1.43%	0.98%
Palau	0.25%	0.45%	0.32%	0.36%
Tokelau	0.74%	0.00%	0.16%	0.21%
Outside PNA				
Indonesia	0.49%	0.78%	0.64%	0.67%
Australia	0.00%	0.89%	0.48%	0.57%
Vanuatu	0.25%	0.67%	0.32%	0.47%
Fiji	0.74%	0.22%	0.00%	0.26%
Cook	0.49%	0.00%	0.16%	0.16%
Guam	0.25%	0.00%	0.00%	0.05%
Samoa	0.00%	0.00%	0.16%	0.05%

Source: PNA FAD tracking trajectories

Figure 4 shows the distribution of FAD beaching, by flag, against each country coastline. Three flag states associated with higher beaching numbers include Korea (31%), Taiwan (16%) and Kiribati (14%). FSM, China, PNG, Philippines, US and Marshall Islands account for lower levels of beaching (4-8%), and Japan, much lower levels (2%), which is indicative of the countries low FAD dependency.

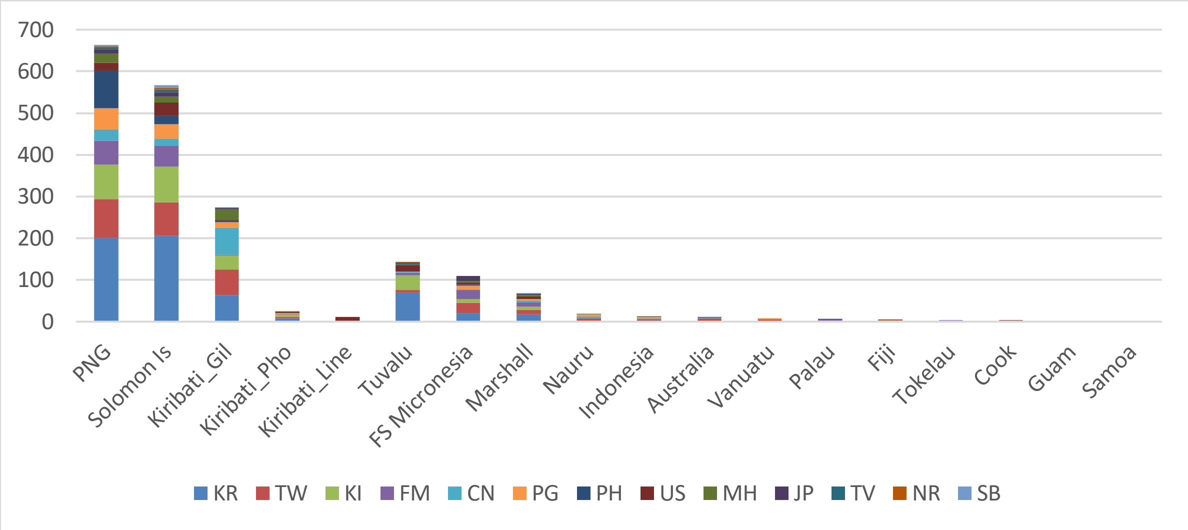


Figure 4. Number of FADs beached in Pacific Island countries by flag, 2016-2018.
Source: PNA FAD programme

PNG, Solomon Islands and Kiribati coastlines accounted for 80% of all beachings, and other PNA countries a further 18%. The results show a very low impact level on non-PNA countries, Indonesia, Australia, Vanuatu, Fiji, Guam (US), Cook Islands and Samoa 3%. As noted earlier, geofencing may have lead to an underestimation of the level of impact on non PNA zones, but these were still likely to be at a low level. Indicative of this is the number quoted by Great Barrier Reef Marine Parks Authority, which was 11 in two years (24 months up to May 2018) (Phil Koloi, pers. comm, May 2018), as opposed to 10 from the PNA FAD trajectories for the same beaching area.

Beaching events by habitat type

The UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) datasets for global distributions of warm water corals, mangroves and seagrass habitat (https://data.unep-wcmc.org) and PNA FAD tracking program data were used to identify beaching habitats at a regional scale. Using a free ArcGis account, final positions of the beached FADs and UNEP-WCMC datasets were mapped over the World Topographic Map (Figure 5). For each beached FAD on the map, the habitat type was visually analysed and recorded in an excel file, then summarised with pivot tables.

Majority (92%) of the identified beaching events occurred on coral reef habitat. The remaining events occurred either on seagrass habitat, mangroves or sandy beaches, where no coral reefs were mapped. A small proportion of FADs had the final positions in the ocean, from a few hundred meters to a few kilometres away from the coast. Some beached FADs possibly impacted more than one type of habitat, for example, the final position was on mangrove habitat, but the FAD had to pass over coral reefs in order to reach that position (e.g. Figure 6). In this way, 7% of the FADs probably had impact on coral reef and mangrove habitat while 9% of FADs had impact on coral habitat and seagrass meadows.

In Papua New Guinea, there was a higher variability of beaching habitats, with 82% being coral reefs, 12% mangroves and 7% seagrass (with some overlap between coral habitat, mangroves and seagrass) and 14% on sandy beaches. In other EEZ over 90% of beachings occurred on coral reef habitat, e.g. Solomon Is and Tuvalu. In reef countries, such as Kiribati, Federated States of Micronesia (FSM), the Republic of Marshall Islands (RMI), Palau and Tokelau, all beachings were on coral reef habitat except for the FADs with final position away from the coast (where FADs may have been caught on submerged physical structures). In cases where beachings occurred on coral reefs, some atolls and reef islands also support dense seagrass meadows on their lagoon facing sides (Chuuk Lagoon in FSM, Tabiteuea and Maiana in Gilbert Islands, Kiribati, Figure 6). In such cases, these habitats were also affected.

Table 6 presents the percentage distribution of beaching events in each EEZ by habitat type.

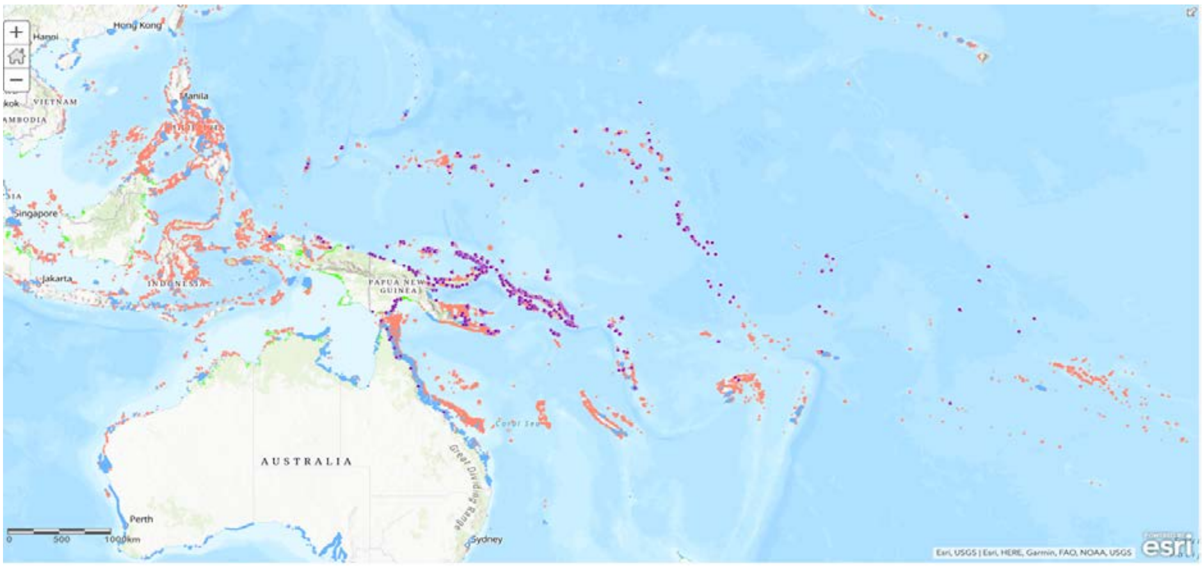


Figure 5. Final positions of beached FADs identified through PNA FAD tracking program
- relative to the distribution of coral reef (orange), seagrass (blue) and mangroves (light green) habitat. Source for habitat layers: https://data.unep-wcmc.org

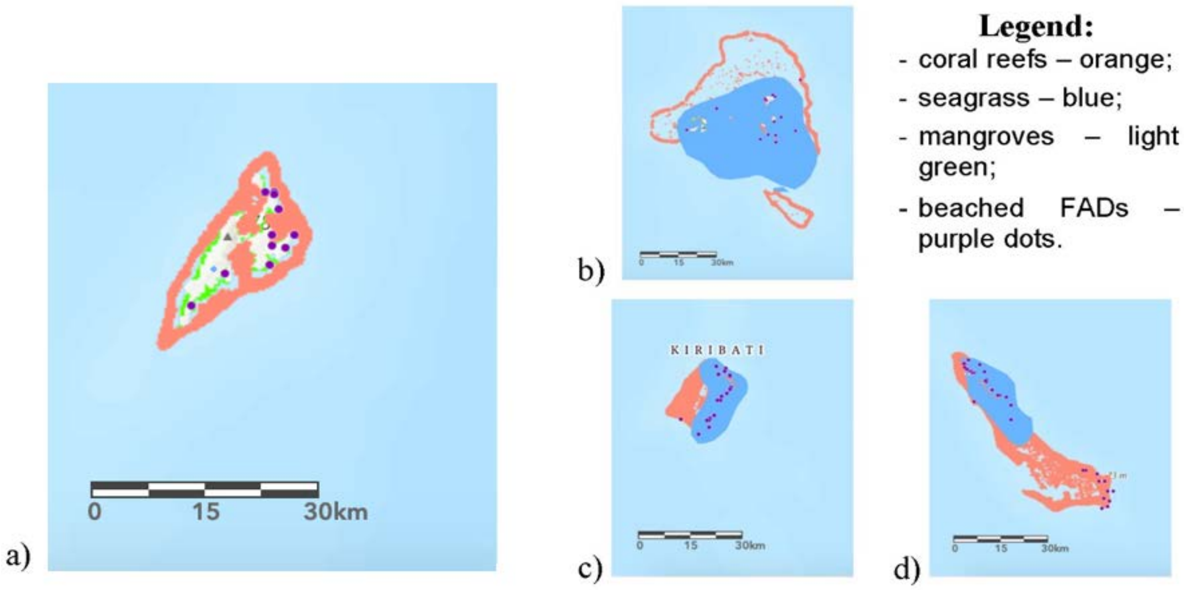


Figure 6. Examples of beached FADs with impact on multiple habitat types.
Final positions of beached FADs on a) Yap's coast, Micronesia; b) Chuuk Lagoon, Federated States of Micronesia, c) Maiana Atoll, Gilbert Islands, Kiribati, d) Tabiteuea, Gilbert islands, Kiribati. Source for habitat layers: https://data.unep-wcmc.org)

Table 6. Percentage distribution of beaching events by habitat type.
Greyed rows correspond to PNA EEZs plus Tokelau.

EEZ	No of beachings	Coral Reef	Mangroves	Seagrass Meadows	Sandy Beach	Deep Habitat
PNG	663	82%	12%	7%	14%	3%
Solomon Islands	567	97%	10%	4%	0.4%	2%
Kiribati, Gilbert Islands	273	99%	0%	20%	0%	1%
Kiribati, Phoenix Islands	25	96%	0%	0%	0%	1%
Kiribati, Line Islands	11	100%	0%	0%	0%	0%
Tuvalu	143	96%	0%	0%	0%	4%
FSM	110	100%	6%	23%	0%	0%
RMI	68	100%	0%	0%	0%	0%
Nauru	19	100%	0%	0%	0%	0%
Palau	7	100%	57%	57%	0%	0%
Tokelau	4	100%	0%	0%	0%	0%
Indonesia	13	62%	0%	0%	48%	0%
Australia	11	100%	0%	36%	0%	0%
Vanuatu	9	100%	0%	11%	0%	0%
Fiji	5	100%	0%	40%	0%	0%
Cook Islands	3	100%	0%	0%	0%	0%
Guam	1	100%	0%	0%	0%	0%
Samoa	1	100%	0%	0%	0%	0%

Source: PNA FAD tracking trajectories

5.1.2 Identifying Habitat Impact at Local Scale in Beaching Hotspots

This desktop analysis used beached FADs final positions and trajectories datasets to overlay FADs positions on high resolution satellite images from Google Earth Pro and identify the affected habitats at a local scale.

Using satellite imagery for coral reef habitat identification

Remote sensing, including satellite imagery, has been used to map and classify coral reefs for decades (e.g. Kuchler, 1986) although recently, it has become a keystone technology to quantify the distribution of the coral reef communities (Purkis, 2018). Currently, remote sensing is used also to detect changes in shallow benthic habitats following major disturbance events such as mass coral bleaching (Li, Schill, Knapp, & Asner, 2019). Under the Khaled bin Sultan Living Oceans Foundation Global Reef Expedition (KSLOF-GRE) programme, high resolution seafloor habitat and bathymetry maps have been developed for 65,000 km^2 of coral reef using DigitalGlobe (now Maxar Technologies) satellite imagery and calibrated by field observations (Purkis et al., 2019). This proves that freely available high-resolution satellite imagery provided by Maxar Technologies through Google Earth is a valid tool for habitat identification, especially for coral reef identification. This study used Google Earth Pro v7.3 to access satellite images provided by Maxar Technologies and to identify beaching habitats. Pacific Ocean habitat maps from KSLOF-GRE were used as reference for identifying coral reef habitats, reef types and zones as well as other habitat types (https://maps.lof.org/lof).

Coral reef types and zones

While reef type descriptions are generally accepted, with the main types being fringing reefs, barrier reef and atolls, several authors describe reef zonation differently. To be consistent with the habitat maps used as reference, for this project, Khaled bin Sultan Living Ocean Foundation (KSLOF) terminology and reef zones descriptions were used (Table 7).

Table 7. Coral reef zonation

- adapted after Khaled bin Sultan Living Oceans Foundation's Coral Reef Ecology Curriculum and habitat mapping.

Reef Zone	Description	Natural conditions	Coral growth and biodiversity
Reef Crest	- the highest point of the reef that breaks waves and receives the full impact of wave energy - can be exposed to air at low tide (KSLOF, 2014)	- highest natural disturbance and harsh living conditions (KSLOF, 2014)	- very low - dominated by coralline red algae - named also algal ridge (KSLOF, 2014)
Fore Reef	- part of the reef that extends from the reef crest into the ocean - it slopes downward and can reach great depths (KSLOF, 2014) - - can be interrupted by terraces or sediment flats https://maps.lof.org/lof	- high only in the shallow zone - low in the intermediary zone (5- 20m deep) (KSLOF, 2014)	- the highest coral growth and species diversity is found in the intermediary zone of the fore reef with low wave action, good water flow and sufficient light for the symbiotic algae - coral diversity and cover declines in shallower and deeper parts but some species have adapted to living in different conditions (KSLOF, 2014)
Back Reef	- area that slopes into a lagoon - often shallow and it can be exposed during the low tide (KSLOF, 2014)	- low wave energy - shallow and deep zones - (KSLOF, 2014)	- isolated coral patches - sediment and rubble dominated - can be colonised by seagrass or macroalgae - https://maps.lof.org/lof
Lagoon and lagoonal reefs	- a pool of seawater highly or partially enclosed within a reef formation (atolls) or between a reef and shorelines (barrier reefs) - (KSLOF, 2014)	- lower wave energy - tidal fluctuations - shallow currents - can have complex bottom structures with coral pillars, pinnacles and bommies - (Barott et al., 2010)	- emergent coral reef on back reef slope 6-25m (Crean, 1977) - high coral growth on other reef structures emergent from the bottom of the lagoon (pinnacles, bommies) - higher growth and diversity in areas with higher water flow - (Barott et al., 2010)
Reef Flat	- area behind the reef crest that is protected from the wave action - on KSLOF-GRE maps this area belongs to "back reef" - can extend from meters to kilometres - a few centimetres to a few meters deep (KSLOF, 2014)	- low wave energy - low dissolved oxygen - high temperatures - exposed to air at low tide (KSLOF, 2014)	- low biodiversity in general (only species that have adapted to these extreme environmental conditions) (KSLOF, 2014)

Method

Last segment positions "at-sea" for each FAD ID (each buoy) were extracted from the PNA FAD tracking trajectories dataset and sent to a sub-contracted ArcGIS expert for mapping. Google Earth layers of the trajectories of beached FADs were created for each beaching EEZ and each year (2016, 2017 and 2018). For each buoy, last positions in its trajectory were selected beginning with the final point, point by point, until all the potential habitat impact points were found, and potential habitats affected identified. Data for each FAD were entered into an Excel file in as standard information, as well as more detailed notes. The standardised information that was collected included the FAD ID, time and date of the last transmission, if the last transmission was from shore, from a residential area or if the FAD was still at sea, if the FAD was still moving or not, what was the beaching habitat, other habitat types likely impacted, if there were multiple impacts and if the final location was different than that of the beaching location (if the buoy was probably moved by people). Additional non-standardised information was collected for each FAD, consisting of a description of the pattern of last movements, the time spent in different locations and anything unusual.

Escalle, Muller, et al. (2019) mapped the density of beaching events identified from the FAD tracking programme during 2016-2018 period at a scale of 1° grid cell and identified beaching hotspots (Figure 7). For this project, the beaching hotspot map was used to identify hotspot cells and explore habitat impact at beaching sites in these hotspot areas. Beaching hotspot areas were chosen as being at a higher risk of impact from beaching.

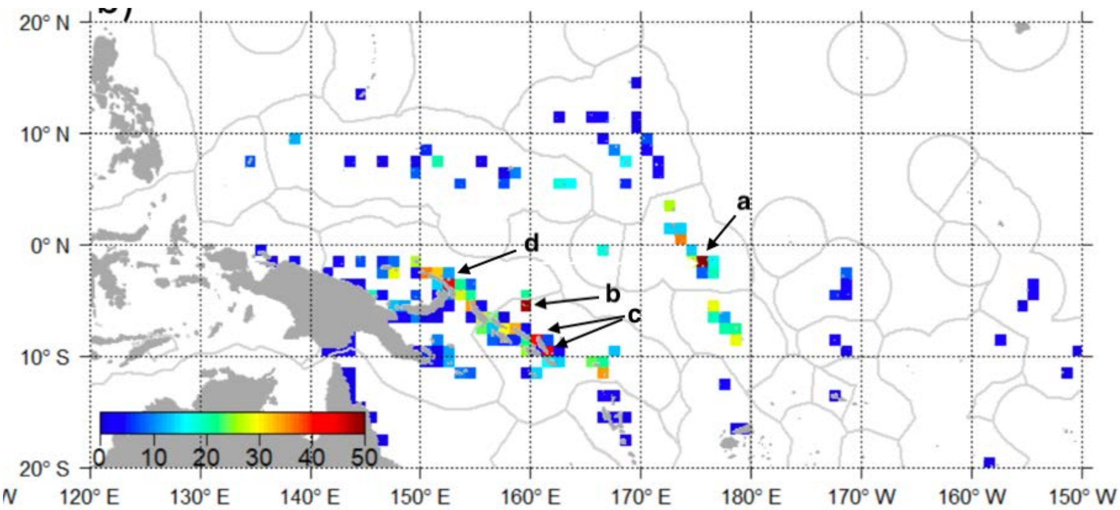


Figure 7. Density map of final position of FADs considered beached in 2016–2018 period

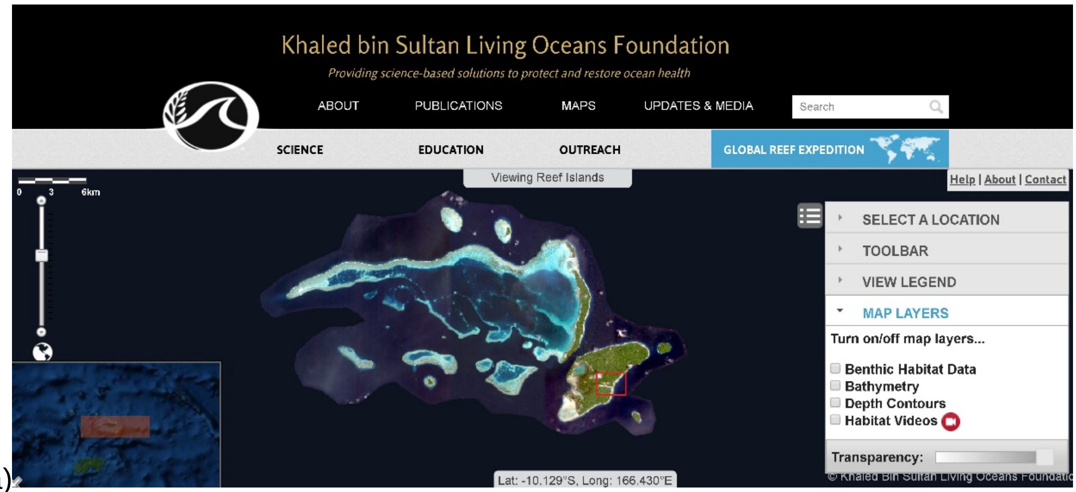
- (in number of beachings per cell) (adapted from Escalle et al 2019). Note: highest density hotspots are indicated with letters: a) Kiribati, Gilbert Islands, b), c) Solomon Islands, d) PNG.

<u>Habitat Identification</u>

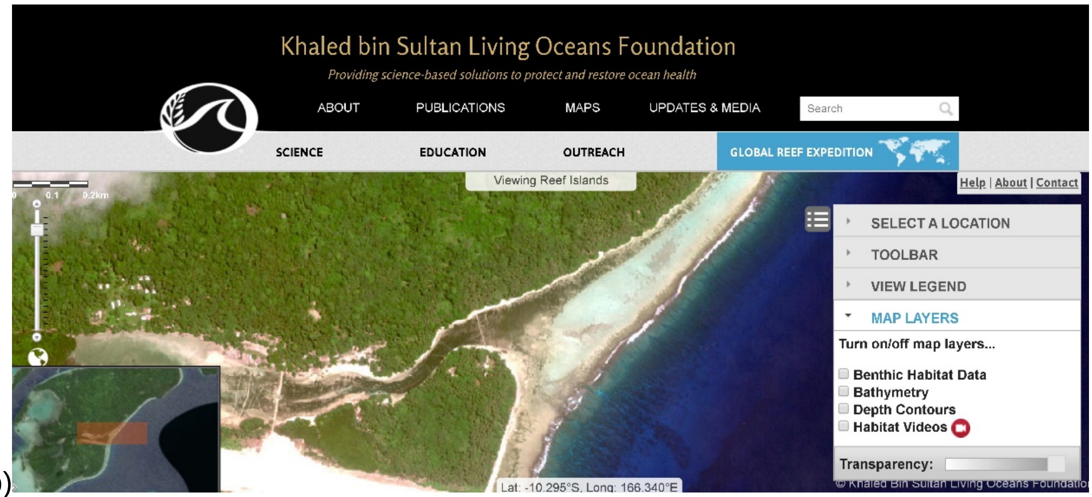
Beaching habitats were identified using high resolution imagery provided by Maxar technology through Google Earth, and comparing with images with similar habitats where habitat mapping was available from KSLOF-GRE. Some examples are provided in the figures below.

Example 1 (reef island)

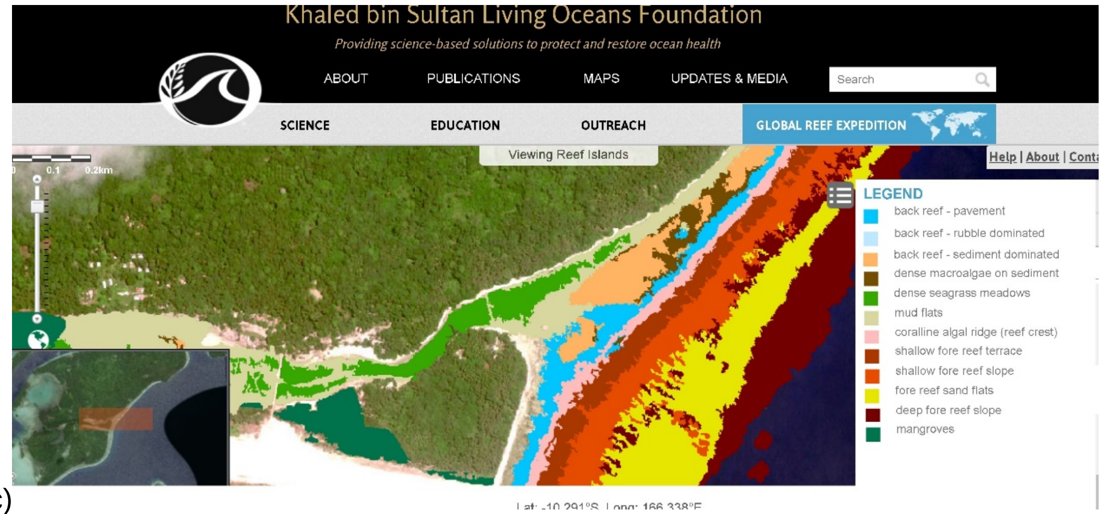
Reference habitats - Reef Islands, Solomon Islands:



a)



b)



c)

Figure 8. Examples of habitat maps of a reef island used as reference.
Reef Islands habitat maps (Solomon Islands) - part of the Khaled bin Sultan Living Oceans Foundation – Global Reef Expedition habitat mapping program: a) general view of the island group; b) high resolution of the selected area; c) habitat mapping of the selected area. Source: https://maps.lof.org/lof

Example hotspot habitats identified – Ulava Island (Ulawa), Solomon Islands:

a)

b)

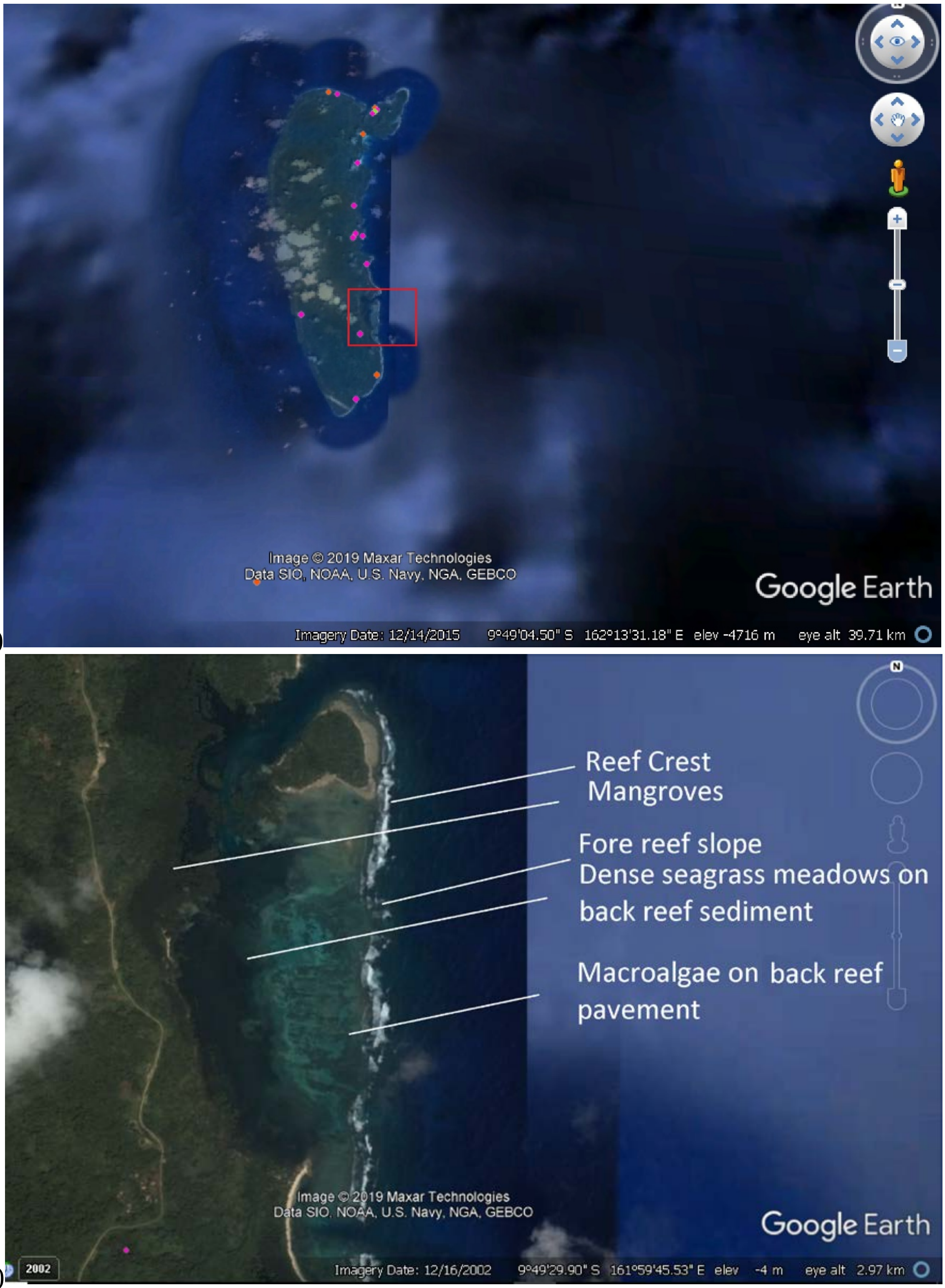


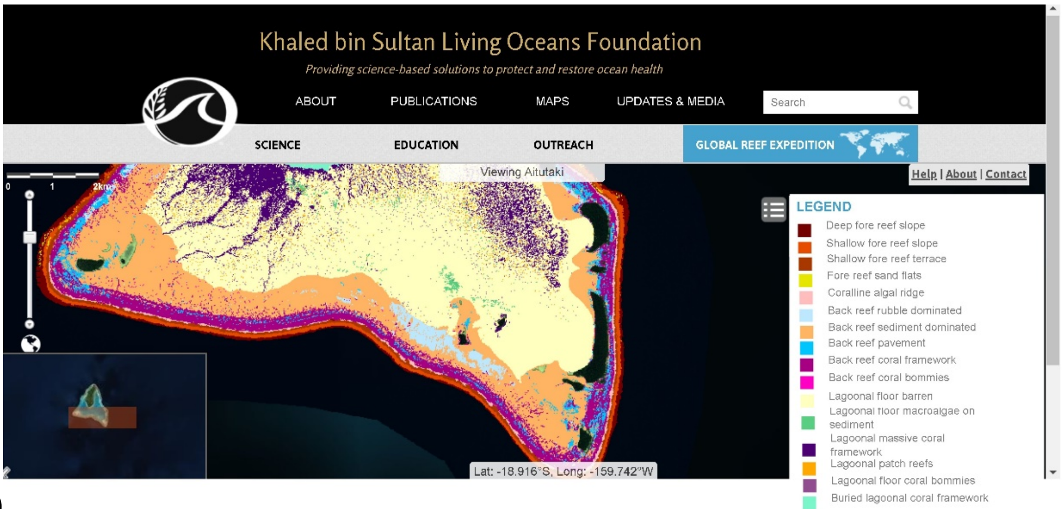
Figure 9. Examples of habitat types identified based on reference satellite images of areas where habitat maps were available

a) Site location - Ulava Island, Solomon Islands. Markers represent beached DFAD: green – 2016, pink – 2017, orange -2018.

b) Area included in the red square in a) with habitat types identified by comparing satellite images with those for sites with habitat mapping available (Figure 8)

Example 2 (atoll)
Reference habitats: Aitutaki Island, Cook Islands:

a)

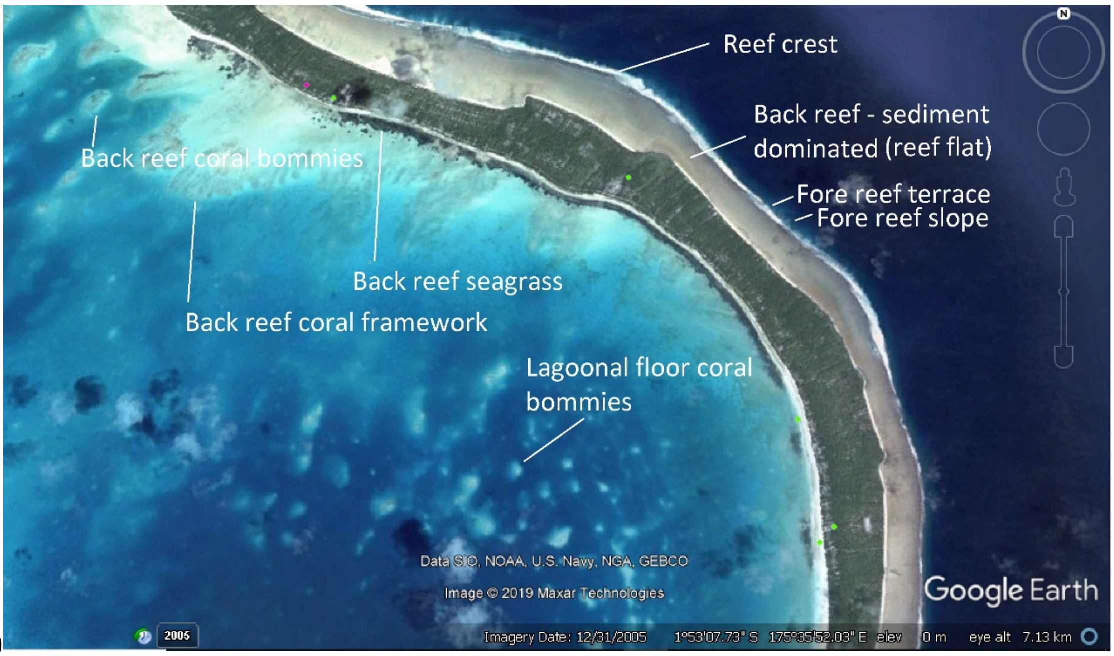


b)

Figure 10. Examples of habitat map of an atoll used as reference.
Aitutaki Island, Cook Island, is part of the Khaled bin Sultan Living Oceans Foundation – Global Reef Expedition habitat mapping program. a) satellite image of the island; b) habitat mapping of the selected area (within the red square). Source: https://maps.lof.org/lof

Example hotspot habitats identified: Onotoa Atoll, Gilbert islands

a)



b)

Figure 11. Examples of habitat types identified based on habitat maps and satellite images used as reference.

a) Site location - Onotoa Atoll, Gilbert Islands. Coloured dots represent beached DFADs: green – 2016, pink – 2017, orange -2018.

b) Selected area with habitat types identified by comparing satellite images of the two sites (Figure 10 and Figure 11)

Results

Final beaching locations within red hotspot cells identified by Escalle, Muller, et al. (2019) are presented in Table 8.

Table 8. Beaching locations within 1°grid cells

Beaching frequency (approximate value based on colour)	EEZ	Beaching Location
50 beachings/year	Kiribati (Gilbert Islands)	Onotoa, Tabiteuea (East), Beru atolls
50 beachings/year	Solomon Islands	Ontong Java Atoll
40 beachings/year	Solomon Islands	Malaita Island (North and South)
40 beachings/year	PNG	New Ireland central area and Lihir Island
35 beachings/year	Kiribati (Gilbert Islands)	Maiana, Kuria, Aranuka atolls
35 beachings/year	PNG	New Hanover, New Ireland, Buka Is (Bougainville Province)
35 beachings/year	Solomon Islands	Santa Isabel, Utupua, Ndeni Islands
30 beaching/year	Tuvalu	Nanumea, Funafuti, Nukufetau Atolls
30 beaching/year	Kiribati (Gilbert Islands)	Tabiteuea (West)
30 beaching/year	Solomon Islands	Choiseul Is (South-East)
30 beaching/year	PNG	Manus Is

– Red cells are beaching hotspots (frequency colour corresponds to the colour of the cell on the map in Figure 7).

Final movements of 266 DFADs that beached in hotspot cells presented in Table 8 were analysed to identify beaching sites and habitat impacts as described in Method section. To be noted that this number does not represent the complete number of beachings that occurred in these hotspots between 2016-2018 because not all companies sent data to the FAD tracking program. Seven different types of habitat were identified as beaching habitats: fore reef terrace/slope; lagoonal reefs (including lagoonal floor and back reef coral reef bommies and pinnacles); reef flat (or back reef flat) - sediment dominated; seagrass meadows on back reef sediment; seagrass meadows on inner shelf; mangroves. In addition, some DFADs were probably attached in deep water and habitats were not visible on satellite images. A few buoys transmitted last positions from residential properties and prior transmitted positions did not allow identification of a beaching site.

The most sensitive habitat identified, with rich coral growth and supporting the highest biodiversity, included the shallow slope and terrace parts of the fore reef (KSLOF, 2014). Overall, 47 DFADs were identified as possibly being caught at subsurface levels on the fore reef slope (18% of hotspot beachings). These DFADs had the last several positions at sea, near the shore but away from the reef crest (1-200m) and had limited movements (up to 200m between transmitted positions, with time intervals of several hours to days between transmissions).

The second most sensitive habitat identified includes the lagoonal reefs which can support rich coral growth and faunal biodiversity, depending on conditions of light and water flow. Lagoonal reefs were affected when DFADs beached on atolls such as those from Gilbert Islands hotspot or Ontong Java form Solomon Islands (9% of hotspot beachings). Sometimes, DFADs entered the lagoons of the atolls through channels and had multiple contact with lagoonal reefs. DFADs with impact on lagoonal reef did not beach on those reefs, they usually beached on the back reef lagoonal side.

Most beachings were on reef flat habitat (32% of hotspot beachings), characterised by low biodiversity due to exposure to extreme conditions. Nevertheless, to reach the reef flat, a DFAD would have had to pass the fore reef slope with rich biodiversity of corals and other associated fauna and it is possible that some DFADs beaching on the reef flat had an impact on the fore reef slope as well. However, judging by the time it took for a DFAD to reach the reef flat, this impact is likely to have been low. Most DFADs took less than a day to travel the distance from the last offshore position to the reef flat, with no indication of stopping on the reef slope. When the reef flat was very narrow and the tail of the DFAD could have still been on the fore reef slope, even if the transmission was from the reef flat, the fore reef slope habitat was considered the main impacted habitat.

In several cases, DFADs beached multiple times affecting various coral reef habitats (9% of all hotspot beachings). This included almost all in Malaita, Solomon Islands and 3 around New Ireland in PNG. When this happened, the DFAD first beached on fore reef slope of a small island closed to the main island, then it became free just to get caught again on an isolated reef, then beached on the main island, on reef flat.

Seagrass meadows growing on back reef or, in a few cases where a fringing reef could not be identified, on the inner shelf, were affected by beaching in 6% of the cases while mangroves, in 2% of the cases. One beaching occurred in a bay with muddy bottom, on the eastern coast of Ulava, Solomon Islands and no biota could be identified.

For 14% of the DFADs beached in hotspots, beaching habitat could not be identified because their last position was at sea, away from the coast (too far to accept the possibility that they might be caught on the fore reef), and benthic habitats were not visible on the satellite images. Some of these DFADs might have still been moving and beached at a later time. For an additional 9% with final locations transmitted from residential areas, beaching sites could not be identified.

Gilbert Islands Hotspot

Gilbert Islands hotspot cell comprises Onotoa and Beru atolls as well as the eastern part of Tabiteuea Atoll ((a) in Figure 7). From PNA FAD tracking data, 20% of all beaching events in Gilbert Islands EEZ during 2016-2018 occurred in this hotspot (54 events identified). For two of the 54 buoys, no movement could be identified for the entire last segment “at-sea”, all transmissions being from land and were re-classified as not beached because they have not been deployed.

Over a half of the buoys that beached in Gilbert Islands hotspot (54%) had their final positions in residential areas. This probably suggests the buoys, and potentially other materials, had been retrieved from the beaching sites by local population. It is impossible to determine if some buoys were already detached when collected by people or the locals have detached them before collection as opposed to the entire FAD being cleared. Depending on the state of degradation of the FAD materials on the beached FAD, people are likely to recover anything that can be used, e.g. bamboo canes to be used for fences, nets to be used as fishing nets and satellite buoys to be converted into solar power lights (Maurice Brownjohn, pers com 28 Sept 2019) but a complete clearing of beaching sites beached FADs is not guaranteed.

The ability to estimate how quickly a clean-up (at least partial) of the beaching sites takes, was limited by the buoys’ transmission patterns. Most buoys had transmissions at least every hour while others once a day. A small number of buoys had transmissions with irregular patterns, from a few hours to several days or weeks intervals. Nevertheless, it could be determined that beached buoys were often collected within 24h (48% of collected buoys) and in most cases within a week from beaching (93% of collected buoys).

Out of those that were not collected, 88% were still at sea, with half of those possibly still moving (not yet beached) while the other half were stranded. When the final position was at a certain distance from the coast, with a single transmission from that position, it was difficult to identify if the FAD was stranded or still moving. These FADs were considered as possibly still moving, not yet beached, and the habitat affected could not be identified. When there were more transmissions from the same position over at least several hours (more transmissions with the same time stamp not considered), those FADs were considered stranded. Habitat types affected by FAD beaching in Gilbert Islands hotspot are presented in Table 9.

Table 9. Number of beachings by habitat type and in Gilbert Island hotspot, Kiribati, 2016-2018.

Hotspot	Habitat type	No Beachings	Collected by locals
Total Gilbert Islands Hotspot: Beru, Onotoa and Tabiteuea (East)	Fore reef terrace/slope	1	1
	Lagoonal reefs	4	1
	Reef flat, sediment dominated	24	22
	Seagrass meadows on back reef pavement	2	2
	Deep habitats (unknown)	8	0
	Unknown (still moving or beaching site cannot be identified)	13	2
	Total	**52**	**28**

Source: Appendix 2

Solomon Islands Hotspots

Three high density beaching hotspots ((b) and (c) in Figure 7) were identified in Solomon Islands. The highest density hotspot was Ontong Java Atoll (b with~50 beachings/year, Figure 7). The other two high density beaching hotspots (c with~40 beachings/year, Figure 7), are located around Malaita Island (north and south). Twenty nine percent of all Solomon Islands beachings occurred in these three hotspots, more-or-less evenly distributed among the three hotspots (9.4% Ontong Java, 10% in Malaita South and 9.4% in Malaita North). Out of the 164 buoys analysed, 104 (63%) seemed to be on land in built-up areas thus, it was assumed they were collected by local population. As mentioned before, it is not expected that a total clean-up occurred in those cases but at least the buoy was collected and maybe other materials from the FAD construction that could be used. Time to collection was often within 24 hours of beaching (56%) and for most, within week (83%). Out of the beached buoys that were not retrieved (57), 75% were still at sea. Some of these were stranded in deep waters (11) or caught on fore reefs (17), in some cases after impact on multiple reefs (5), and a few were still moving (not yet beached). Three buoys with final position in one of the Solomon Islands hotspots seemed to have transmitted positions from land for the whole "at-sea" segment (moved on land among residential locations) and were not considered beached. Table 10 shows a summary of the habitat types affected by beaching in Solomon Islands hotspots (more details are presented in Appendix 2).

Table 10. Number of beachings by habitat type in Solomon Islands hotspots 2016-2018.

Hotspot	Habitat type	No Beachings	Collected by locals
Solomon Islands Hotspots: Ontong Java, Malaita North and Malaita South	Fore reef terrace/slope	35	20
	Lagoonal reefs	19	15
	Reef flat, sediment dominated	44	34
	Multiple impact on various reef habitats	20	11
	Seagrass meadows on back reef pavement	3	3
	Mangrove	9	4
	Unknown (still moving or beaching site cannot be identified)	20	18
	Deep habitat (unknown)	15	2
	Total	**161**	**108**

Papua New Guinea

The PNG beaching hotspot is situated around the centre of New Ireland main island and several surrounding small islands, as well as Lihir Island ((d) in Figure 7). Although a third of all beachings identified from PNA FAD tracking programme occurred in PNG, only 7% of all PNG beachings were in this hotspot. During 2016-2018 FAD tracking period, 48 beaching events were identified as having occurred here. Most beaching events occurred around New Ireland (63%) and Lihir Island (21%) with the rest of beachings on Mali, Masahet, and Sanambiet Islands.

Seventy three percent (73%) of all FADs that beached in this hotspot had their final position on residential grounds suggesting that the satellite buoys and possibly other materials were collected by locals. Over a half of the buoys collected were collected in 24 hours of beaching and 89% were collected within a week. For DFADs with final positions on residential grounds, most frequent beaching habitat was reef flat (25% of all beachings in this hotspot), followed by seagrass habitat (21% of beachings) and fore reef slope (17% of beachings). Most seagrass habitats affected were on reef framework (17% of beachings).

Beached DFADs that did not transmit their final positions from residential areas were, in general, still in the water, attached to fore reef (8% with some with multiple impact), or on reef flat (8%), and some with their last position away from the coast (maybe caught on a submerged reef or similar deep structure, 4%). For a minority of beached FADs, the type of habitat impacted culd not be determined, and a few were probably still drifting.

Habitat types affected by FAD beaching in New Ireland - Lihir hotspot are presented in Table 11 (see Appendix 2 for more details).

Table 11. The number of beachings by habitat type in PNG hotspot 2016-2018.

Hotspot	Habitat type	No Beachings	Collected by locals
New Ireland-Lihir Hotspot	Fore reef terrace/slope	11	8
	Reef flat, sediment dominated	16	12
	Multiple impact on various reef habitats	3	2
	Seagrass meadows on back reef pavement	8	8
	Seagrass meadows	2	2
	Mangroves	2	2
	Deep habitat (unknown)	2	0
	Unknown (still moving or beaching site cannot be identified)	4	1
	Total	**48**	**35**

6 Identification of FAD impacts and Ecological Risk Assessment

Ecological risk assessment for effects of fishing (ERAEF) is a procedure for identifying and prioritising the risks posed to marine ecosystems by commercial fisheries (Hobday et al., 2007). It was developed by CSIRO to be used as part of Australian Fisheries Management Authorities (AFMA) ecological risk management (AFMA, 2017) and also adapted to be used within the Marine Stewardship Certification Risk Based Framework (MSC, 2018).

ERAEF proceeds through four stages of analysis: scoping; an expert judgment-based Level 1 analysis (SICA – Scale Intensity Consequence Analysis); an empirically based Level 2 analysis (PSA – Productivity Susceptibility Analysis); and a model-based Level 3 analysis. This hierarchical approach provides a cost-efficient way of screening hazards, with increasing time and attention paid only to those hazards that are not eliminated at lower levels in the analysis. Risk management responses may be identified at any level in the analysis.

An important aspect of the risk assessment process is the involvement of stakeholders that take part in the activities being assessed. Stakeholders can make important contributions by providing expert judgment, fishery-specific and ecological knowledge (Hobday et al., 2007). The risk of impact from beaching DFADs would normally be assessed under a complete ERAEF that would assess all fishing activities and all the effects of fishing on the components of the ecosystem. Moreover, such assessment would require dedicated workshops with scientists, fishers, managers, NGOs and other stakeholders. Here Level one of the ERAEF process was applied to assess the risk of FAD beaching to habitats identified in beaching hotspots in section 5, for information purposes only. The available published research and the analyses performed in this study were used to inform the risk assessment.

SICA uses a "worst-case" scenario approach to screen out components at low risk. For this reason, only the most vulnerable sub-component (habitat) is selected to be assessed at Level 1. Shallow slope/terrace portion of the reef was selected as the most vulnerable sub-component because this habitat is likely to have the highest coral cover and biodiversity and to contribute the most to the benefits from coral ecosystem services (see Table 18, Appendix 3).

Before proceeding with the assessment, operational objectives need to be set (what is the situation desired to be achieved). The number of DFAD beachings should not lead to significant reduction of coral reef habitat).

Error! Reference source not found. presents the scores and the rationales for SICA analyses applied to assess the risk of FAD beaching to beaching hotspot areas and to WCPO overall. Detailed scoring methodology is available in Appendix 3

Table 12. Scale, Intensity, Consequence Analysis scoring table for beaching hotspots and WCPO overall.

Direct impact of Fishing	Hazard related to fishing activity	Presence (1) Absence (0)	Spatial scale of Hazard (1-6)	Temporal scale of Hazard (1-6)	Sub-component	Unit of analysis	Operational objective (from Table 18, Appendix 3	Intensity Score (1-6)	Consequence Score (1-6)	Confidence score (1-2)	Rationale
Addition of non-biological material, smothering and killing corals	Beached FADs	1	1	6	Habitat type	Fore reef terrace/slope Gilbert Islands, Kiribati	1	3	3	1	Cumulatively, the area affected by beaching impacts in Kiribati overall is less than 1km^2 because of the small overall area of the atolls thus, spatial scale is less than 1nm. Temporal scale is six because beachings occur frequently in Onotoa, probably daily, and the impact may to produce permanent damage. Beachings on fore reef slope were rare in Gilbert Islands hotspot, although all beachings on reef flat may also impact on fore reef slope. Intensity score is 3 because beaching events are frequent and broader effects may occur even though they are not distinguishable from other environmental effects and human impacts. Consequence score is 3 due to the high frequency of beachings and high uncertainty of the effects of traditional DFADs beaching on coral reefs. Balderson and Martin (2015) have found that a high proportion of the beached FADs did not have the submerged parts attached when they beach which means that they probably detach and remain on coral reefs in sensitive areas like fore reef slope. Confidence is low because the impacts of beached FADs are not completely understood.
Addition of non-biological material, smothering and killing corals	Beached FADs	1	1	6	Habitat type	Fore reef terrace/slope Ontong Java Solomon Islands	1	4	4	1	In Ontong Java fore reef slope is the most frequently affected habitat. Cumulative impacts are less that 1km^2 annually (considering 500m^2 impact area per DFAD beached – see section 5). Temporal scale score is maximum (6) due to the high frequency of beachings in this hotspot. The intensity score is higher than for Gilbert Islands hotspot because a higher number of FADs have their final position on fore reef slope habitat. Another important feature in Ontong Java is that a high number of beaching DFADs had multiple impact. It is likely that wider and longer-term impacts are occurring, thus consequence score is 4. Confidence score is 1 because the uncertainty is still high, and the impacts of FADs are not completely understood.

Direct impact of Fishing	Hazard related to fishing activity	Presence (1) Absence (0)	Spatial scale of Hazard (1-6)	Temporal scale of Hazard (1-6)	Sub-component	Unit of analysis	Operational objective (from Table 18, Appendix 3	Intensity Score (1-6)	Consequence Score (1-6)	Confidence score (1-2)	Rationale
Addition of non-biological material, smothering and killing corals	Beached FADs	1	1	6	Habitat type	Fore reef terrace/slope Malaita, Solomon Islands	1	4	4	1	The highest number of beachings on fore reef slope were identified in Malaita. Cumulative impacts are less that 1km^2 annually, and temporal scale score is 6 due to the high frequency of beachings in these hotspots (north and south). The intensity score is 4. A high number of beached DFADs had multiple impact, i.e. beach more than once. It is likely that wider and longer-term impacts are occurring, thus consequence score is 4. Confidence score is 1 because the uncertainty is still high, and the impacts of FADs are not completely understood.
Addition of non-biological material, smothering and killing corals	Beached FADs	1	1	6	Habitat type	Fore reef terrace/slope New Ireland, PNG	1	4	3	1	In PNG, beaching events are more spread out, with only 7% occurring in the beaching hotspot. Also, habitat types affected are more divers, with only 82% of the beachings being on coral reefs. Spatial scale score is one for the same reasons as above. A high proportion of beachings were on fore reef slope and also all beachings on reef flat probably impact on fore reef slope first; this combined with the high number of beachings per year suggest that an intensity score of 4 is appropriate. Identified multiple impacts were infrequent in this hotspot. A consequence score of 3 might be appropriate. Confidence score is 1 because the uncertainty is still high, and the impacts of FADs are not completely understood.
Addition of non-biological material, smothering and killing corals	Beached FADs	1	2	6	Habitat type	Fore reef terrace/slope WCPO	1	3	3	1	Spatial scale is 2 because the cumulative area impacted was found to be between 4 to 6 km^2. Temporal scale is the same as above. The intensity scale is 3 because at present, coral reefs in the Pacific are still delivering key ecosystem services and many Pacific islands depend on this natural capital for survival. Consequence scale score is 3 because beaching events are widespread and frequent, and the impacts are not yet understood.

Although DFAD beachings are localised events they are widespread and frequent, and their consequences are likely to have long lasting effects which are not completely understood at this stage, even if currently these effects and are undistinguishable from other environmental and human impact effects. Consequence scores higher than 2 represent moderate and high risks that require management action for risk reduction.

7 Assessment of economic value lost from habitats impacted by beached DFADs

Recognising the value of the ecosystems and the services they provide as fundamental to human wellbeing, livelihoods and even survival, is the first step towards sustainable use and management of these services. Although economic marine ecosystem valuations have been attempted for decades (Costanza et al., 1998), the concept of ecosystem service has gained a broader attention since 2005 when the United Nations' Millennium Ecosystem Assessment (MEA) was published (Millenium Ecosystem Assessment, 2005). This was followed by the UN Environment's Programme for ecosystem services valuation for policy makers between 2007 and 2010, the Economics of Ecosystems and Biodiversity (TEEB) (TEEB Foundations, 2010).

Present assessment aims to identify the value of forgone benefits from ecosystem services in WCPO due to DFAD beaching events (the costs of FAD beaching to local communities). As most beaching events occur on coral reef habitat, coral reefs are the focus of this economic valuation.

7.1 Methodology

7.1.1 Ecosystem Valuation

MEA defines 'ecosystem services' as:

> …"the benefits people obtain from ecosystems. These include *provisioning services* such as food and water; *regulating services* such as regulation of floods, drought, land degradation, and disease; *supporting services* such as soil formation and nutrient cycling; and *cultural services* such as recreational, spiritual, religious, and other nonmaterial benefits." (Millenium Ecosystem Assessment, 2005, p. v)

Expanding on this definition, one of TEEB's key messages is that the importance of the ecosystem services, although socially constructed (i.e. a service has value as long as it meets a human need) has to be considered together with the intrinsic value of biodiversity (i.e. for its own sake) (TEEB, 2013).

Marine ecosystem service valuation (Figure 12) refers to the process of quantifying the benefits humans derive from marine ecosystems in monetary units (MACBIO, 2017).

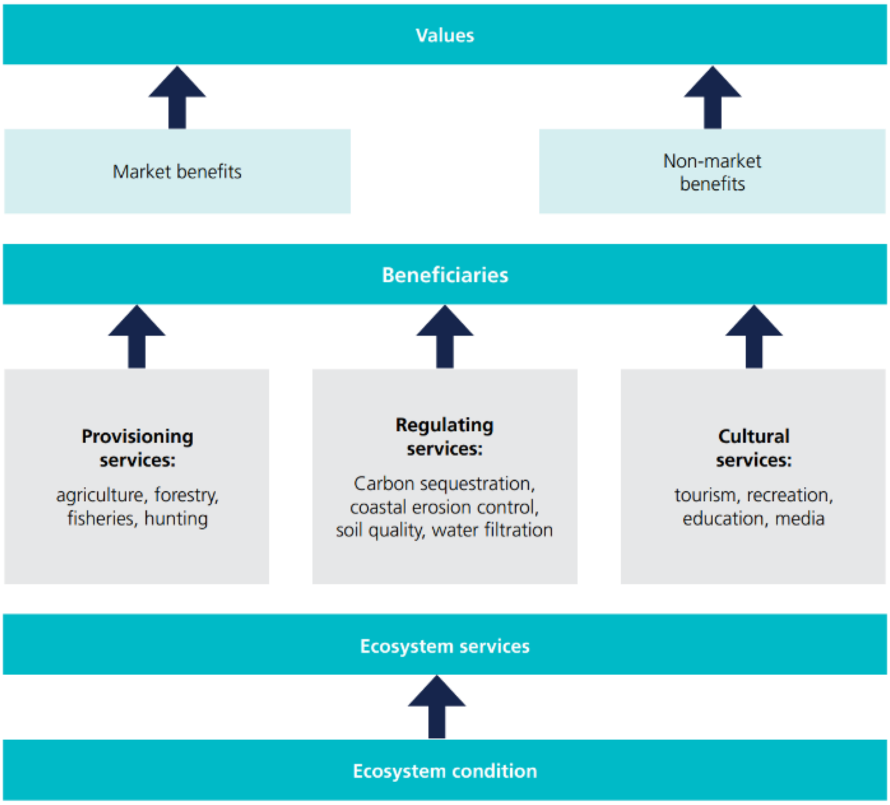


Figure 12. Conceptual framework of valuing ecosystem services
(source: UNEP (2014)

The economic value of marine resources is the net benefit, to people, of marine ecosystems services, whether or not there is a market or monetary transaction involved. A net benefit is calculated as the gross value of an activity or product, minus costs, such as the cost of boats, nets, and wages for a fishing fleet (Salcone, Brander, & Seidl, 2016). Economic value is split into consumer surplus and producer surplus (Figure 13). **Producer surplus** is the benefit received by firms who sell or trade a good or service and is produced in a market (Salcone et al., 2016). **Consumer surplus** is a measure of the benefit that consumers derive from the consumption of a good or service over and above the price they have paid for it. It is the difference between the price consumers pay for a good and their willingness to pay for it. Consumer surplus can exist whether there is a market or not (Salcone et al., 2016). For example, fisheries resources offer benefits to those who harvest and sell seafood products on a market and to those who buy the products, as well as to those who harvest and consume the seafood products themselves (no market is involved). For market transactions, the economic value to businesses or sellers is synonymous with profit, or value added (Salcone et al., 2016). Non-market ecosystem services can only be measured in terms of consumer surplus, that is, the benefit people receive from using or consuming a nature-based good or service (Salcone et al., 2016). Calculating consumer surplus from ecosystem services is often difficult because it requires knowing consumers' maximum willingness to pay (WTP) for that benefit (Salcone et al., 2016).

In the case of ecosystem services, the quantity available is supplied by nature, it is not determined by producers. The quantity of ecosystem service that is 'supplied' is not controlled by market processes but by decisions regarding ecosystem protection, land use, management, access, etc. The ecosystem service does not have a supply curve in the conventional sense that it represents the quantity of the service that producers are willing to supply at each price (such as in Figure 13). Also, the beneficiaries of many ecosystem services pay nothing (e.g. coastal protection provided by coral reefs). In this case, the WTP and consumer surplus are equal and there is no producer surplus (Salcone et al., 2016).

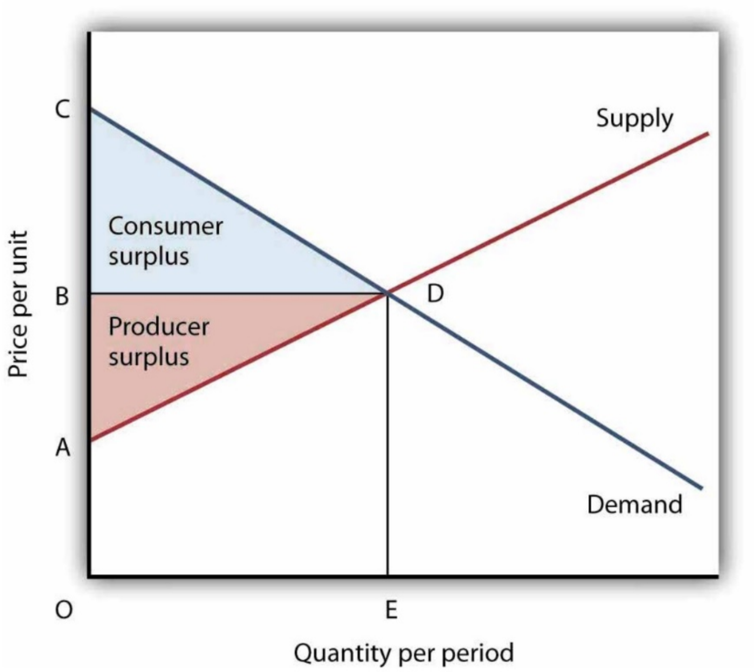


Figure 13. Supply and demand curves for a hypothetical good or service with producer and consumer surplus

Source: Rittenberg and Tregarthen, 2009 in Salcone et al. (2016)

7.1.2 Total Economic Value

'Total Economic Value' (TEV) (Figure 14) of an ecosystem service is the sum of all the net benefits humans receive from that ecosystem service including direct use, indirect use, and non-use "existence" values (Salcone et al., 2016). TEV represents the full benefit humans receive from ecosystem functions including all market and non-market values (Salcone et al., 2016). In practice, data is rarely available to estimate TEV. The best an ecosystem service valuation can do is to get as close to TEV as possible (Salcone et al., 2016).

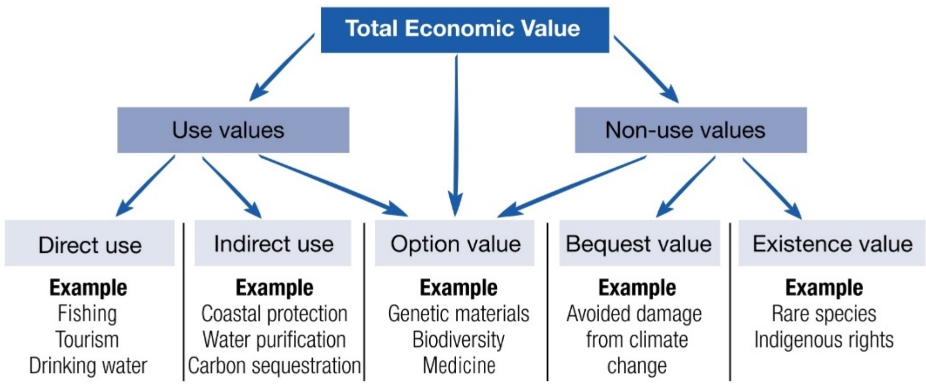


Figure 14. Total economic value
Source: Van Beukering et al., 2007

Brief explanations of the meaning of each type of value are given in Table 13.

Table 13. Types of values addressed in ecosystem services valuation.

Value type	Value sub-type	Meaning
Use values	Direct use value	Results from direct human use of biodiversity (consumptive or non-consumptive
	Indirect use value	Derived from the regulation services provided by species and ecosystems
	Option value	Relates to the importance that people give to the future availability of ecosystem services for personal benefit (option value in a strict sense)
Non-use values	Bequest value	Value attached by individuals to the fact that future generations will also have access to the benefits from species and ecosystems (intergenerational equity concerns)
	Altruist value	Value attached by individuals to the fact that other people of the present generation have access to the benefits provided by species and ecosystems (intragenerational equity concerns)
	Existence value	Value related to the satisfaction individuals derive from the mere knowledge that species and ecosystems continue to exist

Source: Pascual et al, 2010

7.1.3 Ecosystem Valuation Approaches

Laurans et al. (2013) found that three complementary approaches have been used to valuate ecosystem services from coral reefs: i) the economics of degradations, ii) the economics of protection and iii) the economics of welfare.

The "economics of degradation" valuation aims to demonstrate the negative impact of certain economic activities on coral reefs when external costs associated with that activity are considered (Laurans et al., 2013). "External costs" are costs created by the activity of an economic agent but borne by different agents. Usually, the agent who creates the external costs does not consider them and does not integrate them in their business' bottom line (Laurans et al., 2013). An example is that of costs from blast fishing, a destructive fishing method when coral habitats, upon which other important fish depend, are destroyed. In this case, other subsistence or commercial fisheries and tourism bear the costs (Laurans et al., 2013).

The economics of protection and management of natural resources involves the valuation of benefits from marine biodiversity conservation and management. Such studies have highlighted that the net benefits that accrue from conservation policy outweigh by far the costs of conservation and this provides a strong message in support of the conservation and management of such ecosystems (Laurans et al., 2013).

The economics of welfare derives from the recognition of the human being dependence on the provision of coral reef services and the contributions of coral reefs to coastal and national economies (Costanza et al., 1998; Laurans et al., 2013; Millenium Ecosystem Assessment, 2005). Such studies provide an overall value of the coral reefs, generally in terms TEV, which allows the identification of economic agents and sectors that are associated with the components of the TEV. Economics of welfare analyses are intended to demonstrate the economic importance of coral reefs to stakeholders, especially when their behaviour is likely to influence the reefs condition (Laurans et al., 2013).

7.1.4 Ecosystem Service Valuation Methods

Economic methods used to calculate the value of ecosystem services can be divided into four categories

1. Direct market methods
2. Revealed preferences
3. Stated preferences

1. Direct market methods

Direct market valuation methods are divided into three main approaches: (a) market price-based methods, (b) cost-based methods and (c) methods based on production functions. The main advantage of using this type of methods is that they use data from actual markets, and thus reflect actual preferences or costs to individuals. Moreover, such data – prices, quantities and costs – exist and thus are relatively easy to obtain (Pascual et al, 2010).

Market price-based approaches are most often used to obtain the value of provisioning services, since the commodities produced by provisioning services are often sold on markets, for example fish markets. In well-functioning markets, preferences and marginal cost of production are reflected in a market price, which implies that these can be taken as accurate information on the value of commodities. The price of a commodity times the marginal product of the ecosystem service is an indicator of the value of the service. Consequently, market prices can be good indicators of the value of the ecosystem service that is being studied (Pascual et al, 2010).

Cost-based approaches are based on estimations of the costs that would be incurred if ecosystem service benefits needed to be recreated through artificial means. Different techniques exist, including: (a) the *avoided cost method*, which relates to the costs that would have been incurred in the absence of ecosystem services, (b) the *replacement cost method*, which estimates the costs incurred by replacing ecosystem services with artificial technologies and (c) the *mitigation* or *restoration cost method*, which refers to the cost of mitigating the effects of the loss of ecosystem services or the cost of getting those services restored (Pascual et al, 2010).

Production function-based methods (PF) estimate how much a given ecosystem service (e.g. regulating service) contributes to the delivery of another service or commodity which is traded on an existing market. In other words, the PF approach is based on the contribution of ecosystem services to the enhancement of income or productivity (Pascual et al, 2010).

Direct market methods, although easy to apply, have some limitations. If markets do not exist either for the ecosystem service itself or for goods and services that are indirectly related, then the data needed for these methods are not available. In cases where markets do exist but are distorted, for instance because of a subsidy scheme or because the market is not fully competitive, prices will not be a good reflection of preferences and marginal costs. Consequently, the estimated values of ecosystem services will be biased and will not provide reliable information to base policy decisions on (Pascual et al, 2010).

2. Revealed preferences

Where there is no direct market for ecosystem goods and services, individuals often reveal their preferences for the goods and services through related purchases or economic activities. For example, even though there may not be a fee to enjoy snorkelling, people spend money on fuel, boats, food, travel, and gear in order to snorkel over the coral reefs. Most of those expenses, if not all, can be attributed to their desire to perform this activity and enjoy the beauty of corals and the associated fauna. This is a basic example of the *travel costs method,* which estimates the demand for a natural site or activity by calculating the costs individuals willingly incur to visit the site or participate in the activity (Salcone et al, 2016, Baker & Ruting, 2014).

Another way individuals reveal their preferences is through the purchase of property that have varying non- market attributes. For example, when individuals purchase a home they are paying for the attributes of the home and also for non-market attributes such as a good view or proximity to the beach. Those non-market attributes are often ecosystem services (Salcone et al, 2016, Baker & Ruting, 2014).

In revealed preferences methods, market imperfections and policy failures can distort the estimated monetary value of ecosystem services. Good quality data on each transaction are needed, large data sets, and complex statistical analysis. As a result, revealed preference approaches are expensive and time-consuming. These methods have the appeal because they rely on actual/ observed behaviour but their main drawbacks are the inability to estimate non- use values and the dependence of the estimated values on the technical assumptions made on the relationship between the environmental good and the surrogate market good (Pascual et al, 2010).

3. Stated preferences

One way to estimate the value of a good or service is to simply ask individuals how much they would be willing to pay or what they would be willing to trade for the good or service. *Stated preference methods* are most commonly applied to non-marketed goods or services because markets cannot be used to reveal individuals' preferences. The existence value of natural ecosystems, reserving the opportunity for future uses (*option value*) and the value of nature to future generations (*bequest value*) are non-market ecosystem services (Salcone et al, 2016).

The main types of stated preference techniques are:

- *Contingent valuation method* (CV): Uses questionnaires to ask people how much they would be willing to pay to increase or enhance the provision of an ecosystem service, or alternatively, how much they would be willing to accept for its loss or degradation.
- *Choice modelling* (CM): Attempts to model the decision process of an individual in a given context (Individuals are faced with two or more alternatives with shared attributes of the services to be valued, but with different levels of attribute (one of the attributes being the money people would have to pay for the service).
- *Group valuation*: Combines stated preference techniques with elements of deliberative processes from political science and are being increasingly used as a way to capture value types that may escape individual based surveys, such as value pluralism, incommensurability, non-human values or social justice (Pascual et al, 2010).

The validity of stated preference methods has been debated. The main criticism is that these techniques may provide less reliable estimates when people have a low understanding of, or familiarity with, the good being valued (Baker & Ruting, 2014). There is also a controversy that non-use values can be measured in monetary terms, for example if a bequest value or a religious value can be considered in the same framework as an economic value of production (Pascual et al, 2010).

7.1.5 Economics of Degradation and Ecosystem Accounting

Ecosystem degradation arises when the condition of an ecosystem asset declines over time as a result of economic and other human activity (Ogilvy et al, 2018). Ecosystem degradation undermines human wellbeing and sustainable development. Overall responsibility lies with national governments, although a concerted effort by business and other organizations is necessary to take responsibility for their actions. Efforts are made by businesses and governments to account for natural resources by applying accounting principles (Ogilvy et al, 2018).

The United Nations Statistical Commission has endorsed the integrated system of environmental-economic accounting (SEEA) that describes a statistical framework for recording the interactions between the national economy and the nation's environment. The

SEEA framework applies the same accounting principles and measurement boundaries as used for the standard economic accounts described in the System of National Accounts (SNA) and hence allows for direct integration of environmental and economic data (Ogilvy et al, 2018).

Ecosystem accounting involves four key steps:

- spatially delineating different ecosystem types (forests, wetlands, grazing lands, etc.) within
- a broader area of interest (e.g., pastoral lease, river catchment, country) where each instance of an ecosystem type (e.g., a patch of forest) is considered an ecosystem asset;
- assessing the condition of each ecosystem asset, usually based on a range of ecological variables including species diversity;
- measuring the flow of ecosystem services generated by that asset (provisioning services; regulating services; or cultural services);
- assessing the relative value of the benefits obtained from those services (valuation).

Ecosystem services valuation for Ecosystem Accounting requires methods that are compatible with SNA.

7.2 Cost of Beaching – Economic Valuation of Ecosystem Service Lost in the WCPO

Coral reefs are essential for the livelihood of many Pacific Island countries. Island countries have fragile economies due to their relatively high dependence on natural resources, higher risk of natural calamity, poverty rates and low human capital capacity (Laurans et al., 2013). Despite the importance of coral reefs in the Pacific Island countries, in general, they remain exposed to a variety of threats: climate change, coastal development and overfishing (Moritz et al., 2018). In addition, cumulative impact from DFAD beaching on coastal and marine habitats in WCPO, which are external costs of fishing industry, might significantly contribute to ecosystem degradation.

In order to valuate costs of beaching to Pacific Island countries, this study uses an *economics of degradation* approach. The valuation is based on direct market methods and use-values. This means that consumer surplus and non-use values were not included. Environmental economics valuation techniques can be used to estimate consumer surplus although including it in the current valuation was not considered appropriate.

Including consumer surplus would overestimate the value of the coral reef ecosystem services to local communities because a large proportion of the consumer surplus accrues to foreign recipients. For example, the economic value of commercial fishing may accrue mainly to foreign fishing fleets and foreign consumers. The consumer surplus of tourism may also accrue primarily to foreign visitors (Salcone et al, 2016).

The valuation of non-use values involves greater challenges than that of use values since non-use values are related to moral, religious or aesthetic features for which markets usually do not exist. Non-use values in general involve the production of *experiences* that occur in the person's mind (Pascual et al, 2010). Such experiences can only be valuated using stated preferences methods which require financial resources and time (to design and administer individual surveys). Even if such methods could be used for this study, it is likely that people in different countries and with different backgrounds value ecosystem services very differently and the results obtained would not be directly comparable and could not be used. For example, international experts would place a higher non-use value on the degradation of coral reef habitats than Pacific Island countries. The latter based on for example the cost of cleaning beaches, whereas, international experts would place a value on safeguarding reef habitats on a global perspective.

The method used here is consistent with Ecosystem Accounting framework which does not include amounts of consumer surplus or non-use values because these amounts are not compatible with the System of National Accounts (Ogilvy et al, 2018, Atkinson & Obst, 2017).

7.2.1 Method

Valuation of Coral Ecosystem Services – Use Values

Several TEEB-inspired country studies have been undertaken in Pacific Islands under the Marine and Coastal Biodiversity Management in Pacific Island Countries (MACBIO) project (http://macbio-pacific.info/). Salcone et al. (2016) set out a methodology for assessing the market values of key coral ecosystem services valuated under the MACBIO project: inshore commercial and subsistence fisheries, tourism, coastal protection and mineral extraction.

For this assessment, inshore commercial and subsistence fisheries, tourism and coastal protection services have been considered. Mineral extraction was not considered to be impacted by beached FADs and it was not included in the cost of beaching. The methodology described in Salcone et al (2016) was followed here, aiming to obtain an average total economic value (TEV) [5] of a square metre of coral reef for each country, then estimate an

[5] The TEV calculated here does not include consumer surplus and non-use values

annual cost of beaching for each country (Table 14). Estimates of coral reef areas for each country were found in Chin et al. (2011). The cost of beaching in a certain country was calculated based on the percentage of total beachings occurring in that country and the percentage of beachings occurring on coral reefs in the respective country. To estimate total impacted area by country, the number of beachings on coral reefs in a country was multiplied by the average impact surface which was considered 500m^2 per traditional DFAD (for a rationale for choosing 500m^2 see section 4.3.2).

Example:

> FAD Beaching Cost in PNG = All PNA FAD Beachings (e.g. 13,436) x % Beachings in PNG (i.e. 34%) x % Beachings on Coral in PNG (i.e. 82%) x average area impacted/DFAD x TEV /m^2 coral reef in PNG

The impact on coral reefs is considered to have long term effects. Moritz et al. (2018) found that most coral reefs in the Pacific took about a decade to recover after the major disturbance events, although not all recovered completely. The cost of beaching was calculated as the Net Present Value (NPV) for ten years to reflect the forgone ecosystem services for the 10 years recovery period. Van Beukering, Brander, Tompkins, and McKenzie (2007) recommended a discount rate for the calculation of the NPV for environmental studies of 3.5%, value which has been used here.

The discount rate value for ecosystem services is highly debated. The rationale for using a discount rate to estimate a value of a good in the future is based on people's time preference (ADB, 2013). However, using a discount rate might reduce long-term ecosystem value to become insignificant in the future and this might raise ethical concerns (Vasquez-Lavín et al., 2019). Thus, NPV is dependent on the level and the type of discount rate used (i.e. constant or decreasing with time). A 3.5% discount rate does not significantly reduce the value of a square meter of coral reef ten years from now and it was considered appropriate. A survey of discount rates literature found that developing countries in general apply higher discount rates than developed countries (ADB, 2013). An analysis of discount rates used in Pacific valuation studies showed that the most commonly used rate (mode) is 10% (relatively high) and the average rate is 6.8% (Salcone et al 2016). A rate of 6.8% was also used for current valuation as sensibility analysis although discount rates higher than 3.5% were not considered likely for coral reef habitat.

<u>Subsistence fishing</u> refers to harvesting of seafood species that are consumed, given, or exchanged by fishers without any monetary transaction, thus in the absence of a market. In Pacific Island countries, particularly in rural coastal areas, subsistence fishing contributes significantly to household diets and therefore has substantial economic value (Gillett & Tauati, 2018). Subsistence fishing is supported by healthy habitat conditions. Market valuation can be used to estimate subsistence surplus from subsistence fishing (a non-market value), for example, by subtracting the costs of fishing from the average market price of fish (if the same kind of fish or other substitute protein foods were to be bought from the market) (Salcone et al., 2016). In the case of subsistence fishery, the producers (harvesters) are also the consumers thus the surplus created is both producers and consumers (Table 14, Col 4):

Subsistence fishing Surplus = Subsistence Harvest$_{(kg)}$ X Price Protein Equiv ($) – Harvest Costs ($)

<u>Inshore Commercial/Artisanal fishing</u> also relies on fishing from reefs, lagoons and estuaries. Commercial food caught from this sector represents household-scale and industrial-scale harvesting of fish and invertebrates for sale locally, regionally or internationally. Producer surplus can be calculated by subtracting the costs of fishing from the total revenue of fishermen (Salcone et al., 2016) (Table 14 Col 3). Inshore commercial fisheries also facilitate consumer surplus by offering product to market for consumption, although this is not included because consumer's WTP is not known.

Artisanal/commercial fisheries producer surplus = Artisanal/commercial Fishing Revenue ($) – Artisanal/commercial Fishing Costs ($)

Tourism and recreation. Tourists are attracted to islands and coastal destinations for their warm climates, gorgeous beaches, and captivating marine activities. Tourists reveal their appreciation for marine and coastal ecosystems through their choices of activities and their expenditures on those activities. Marine and coastal ecosystems also provide a wealth of opportunities for tourism and recreation by local residents. The value of domestic tourism and recreation may be less visible in markets but nevertheless contributes substantially to human welfare.

The producer surplus of a tourism activity is the revenue from tourists' expenditures minus the costs of providing the service. Reefs, beaches and ocean biodiversity contribute to the tourism activities. The ecosystem contribution factor (ECF) is the degree of association between marine and coastal ecosystems and different tourist activities (Salcone et al., 2016). Producer surplus value of the ecosystem services can be calculated by multiplying the ECF by the difference between the tourists' expenditures and the tourism industry's costs (Salcone et al., 2016) (Table 14, Col 6):

Producer surplus ($) = Total Tourism Revenue ($) – Tourism Industry Costs ($) X Ecosystem Contribution Factor (ECF)

The consumer surplus enjoyed by tourists is the difference between what they would be willing to pay for activities, travel and lodging, and what they actually paid. This will depend on many factors including those of individual tourists, and it is beyond the capacity of this project to collect such information.

Coastal protection. Coastal areas, particularly on small atolls, are extremely vulnerable to flooding and erosion from tidal currents and wave action. Coral reefs and seagrass beds provide protection from damaging waves and storm surges. Coral reefs can reduce wave energy up to 97% (Beck, 2014). The value of coastal protection is represented by the value of damage avoided due to the presence of coral reefs. MACBIO studies have estimated coastal protection for Solomon Islands, Fiji and Vanuatu. For all the other countries the values have been estimated based on The Nature Conservancy's website, Mapping Ocean Wealth (maps.oceanwealth.org), which does not provide exact values for each country but only colour coded ranges, thus the values used here may not be accurate. The length of coast for each country in a certain range of value has been measured and a total value for the country has been estimated. To be noted is that not every island had built capital valued over 1million US dollars (the lower limit of the range) thus for some countries the estimate for coastal protection is zero, although this does not mean their reefs do not offer coastal protection but rather, it could not be estimated (Table 14, Col 7).

Valuation of Coral Ecosystem Services – Non-Use Values

In addition to the use values, ecosystem services include non-use values. For developing countries, poverty levels affect how a community values ecosystem services. A high dependence on natural resources imply a high use value, although poverty might push people to exploit resources for short term survival with less regard for long term sustainability of those resources (e.g. bequest and existence value). This issue has been debated and some authors believe that non-use values for ecosystem services in developing countries are non-existent (UNEP, 2014). Nevertheless, there has been little research on the importance of such non-use values of the environment to communities in developing countries and in particular in Pacific Islands.

O'Garra (2007) found that Fiji residents were willing to contribute a mean 3.03 hours of their time (worth US$ 6.15–11.83 per month per individual) or donate an average of US$ 4.78 per individual per month (US$ 57.45 per individual per year) to conserve their traditional fishing grounds. This value is an option or *bequest value*. Although the nominal values per individual may seem small, note that the average monthly household income for local residents was US$ 174.94. Therefore, individuals' mean *willingness-to-pay* to conserve this marine resource represented 2.7% of their income (O'Garra 2007).

A survey of respondents, undertaken for this project, determined that FAD clearing would take approximately 12 hours, but it is not clear how many of the FADs included the full set of gear, and in most cases, it would appear that FAD buoys and floats were removed, but in 50% of the cases, there was no netting attached. It was also suggested that artisanal fishers would not remove any other attachments from the nets. Non-use values were not included in this valuation due to the unavailability of information and difficulty to collect such information from Pacific Island countries. This limitation might have resulted in the underestimation of total cost of damage from to beached FADs.

7.2.2 Results

Total Economic Value

The results of this economic valuation have shown that coral reefs in the PNA countries plus Tokelau benefit communities US$ 495,884,989 (PNA, 2018) annually for a total surface of 35,148 km^2 of coral reefs (Table 14) or \$14,108/km^2 annually. This value however may be highly underestimated because not all facets of ecosystem services have been captured in this valuation. For non-PNA countries, including some with extensive coastal areas and highly developed fishing industries, coral reef annual TEV estimates were much higher than for PNA countries.

Table 14. Summary assessment of ecosystem services valuations for all coral reef habitat by country.

Country	Coral reef area (km2)	Inshore commercial - Net value added	Subsistence- Net value added	Fishing total ($)	Tourism and recreation ($)	Coastal protection ($)	Total ($)	Overall value /km2 ($)	Overall value / m2 ($)
PNG	14,535	18,015,400	66,885,000	84,900,400	56,563,916	26,171,580	167,635,896	11,533	0.012
Solomon Is	6,743	18,015,400	38,220,000	56,235,400	15,800,000	18,804,520	90,839,920	13,472	0.013
Kiribati	3,041	21,064,160	21,785,400	42,849,560	3,900,000	7,055,460	53,805,020	17,693	0.018
FS Micronesia	4,925	4,781,010	6,793,605	11,574,615	16,150,000	-	27,724,615	5,629	0.006
Marshall Is	3,558	4,157,400	5,733,000	9,890,400	346,000	5,859,000	16,095,400	4,524	0.005
Nauru	15	451,771	401,310	853,081	8,439	-	861,520	57,435	0.057
Palau	966	2,397,434	2,388,750	4,786,184	90,978,000	-	95,764,184	99,135	0.099
Tokelau	155	277,160	668,850	946,010	-	1,149,197	2,095,207	13,517	0.014
Tuvalu	1,210	831,480	2,168,985	3,000,465	306,337		3,306,802	2,733	0.003
Total PNA	**35,148**	**69,991,215**	**145,044,900**	**215,036,115**	**184,052,692**	**59,039,757**	**458,128,564**	**13034**	**0.013**
Australia	348,000	0	0	342,483,000	3,842,000,000	31,889,010	4,216,372,010	12,116	0.012
Cook	528	415,740	527,436	943,176	21,244,592	53,070	22,240,838	42,123	0.042
Fiji	6,704	30,487,600	30,576,000	61,063,600	574,000,000	8,485,000	643,548,600	95,995	0.096
Guam	225	199,555	80,262	279,817	3,632,129	267,670	4,179,616	18,576	0.019
Indonesia	No data	No data	No data	No data	No data	No data	No data	No data	No data
Samoa	402	13,858,000	9,555,000	23,413,000	13,479,050	-	36,892,050	91,771	0.092
Vanuatu	1,803	3,065,390	5,350,800	8,416,190	12,310,000	18,370,000	39,096,190	21,684	0.022
Total non PNA	**357,662**	**48,026,285**	**46,089,498**	**436,598,783**	**4,466,665,771**	**59,064,750**	**4,962,329,304**	**13,874**	**0.014**

Source: Summary calculations are shown in Appendix 4. Principal sources for extrapolation include Chin et al (2011) (for Coral reef areas), Gillette, R. and Tauati, M.I (2016) (Catch tonnages and prices), Phil James, SPC (2016) (for subsistence and artisanal fisher costs), MACBIO, 2015 (for Solomon Islands, Kiribati, Fiji and Vanuatu estimates of fishing, tourism and coastal protection values), http://maps.oceanwealth.org/# for estimates of tourism values (Palau, FS Micronesia, Marshall Is and Guam) Deloittes (2017) (Australia) (for calculation of Great Barrier Reef values for fishing, recreation and tourism). Note that the coastal protection figures were only available for Solomon Is, Fiji and Vanuatu, for the rest of the countries these have been estimated from http://maps.oceanwealth.org/#

Cost of Damage (NPV)

Using a discount rate of 3.5%, and assuming a ten years recovery period for coral reefs, total annual estimated of cost of beachings for the PNA countries was from US$ 479,136 to US$ 695,664 (Table 15Table 15), with an average cost of US$ 55/FAD (see Appendix 5). Highest to lowest impacts are shown in Table 15 below. The total annual estimated costs for the non PNA countries ranged from US$ 556 to US$ 38,230, although these values may to be underestimated i) due to a possible underestimation of the number of beachings outside PNA countries and ii) due to an underestimation of the coral reef ecosystem services. A sensitivity analysis with 6.8% discount rate (average discount rate applied by Pacific countries) the results were not significantly different.

Table 15. Summary Total Economic cost NPV (10 years)

Country	High estimate (64,900 deployments and 13,353 beachings /year)			Low estimate (for 44,700 deployments and 9,254 beachings per year)			NPV of damage/ FAD (US$)
	No beachings on coral	Area impacted (m²)	Cost of beaching (NPV in US$)	No beachings on coral	Area impacted (m²)	Cost of beaching (NPV in US$)	
Solomon Is	3,823	1,911,450	221,653	2,633	1,316,505	152,663	58
PNG	3,779	1,889,451	187,575	2,603	1,301,353	129,191	50
Kiribati	2,126	1,063,168	161,918	1,465	732,253	111,520	76
Nauru	132	66,033	32,645	91	45,480	22,484	247
FS Micronesia	765	382,297	18,525	527	263,306	12,759	24
Palau	49	24,328	20,760	34	16,756	14,298	427
Tuvalu	954	477,107	11,223	657	328,606	7,730	12
Marshall Is	473	236,329	9,202	326	162,771	6,338	19
Tokelau	28	13,902	1,618	19	9,575	1,114	58
PNA	**12,128**	**6,064,064**	**665,118**	**8,353**	**4,176,604**	**458,098**	**55**
Fiji	33	16,506	13,639	23	11,369	9,394	413
Vanuatu	63	31,279	5,838	43	21,543	4,021	93
Australia	76	38,230	3,987	53	26,331	2,746	52
Cook	21	10,426	3,780	14	7,181	2,604	181
Samoa	7	3,475	2,746	5	2,394	1,891	395
Guam	7	3,475	556	5	2,394	383	80
Non PNA	**207**	**103,392**	**30,546**	**142**	**71,211**	**21,038**	**148**
Total	**12,335**	**6,167,456**	**695,664**	**8,496**	**4,247,814**	**479,136**	**203**

Source: Appendix 5

Higher estimates for cumulative cost of damage per year in beaching hotspots ranged from US$ 13,130/year in central New Ireland, PNG, to US$ 42,144/year in Malaita (north and south hotspots together), Solomon Islands (Table 16).

Table 16. Cumulative cost of damage per year in beaching hotspots.

Hotspot	High estimate (for 64,900 deployments and 13,353 beachings per year) in US$	Low estimate (for 44,700 deployments and 9,254 beachings per year) in US$	NPV of damage/FAD in US$
Gilbert Islands hotspot (Onotoa, Beru and Eastern Tabiteuea)	**29,145**	**19,516**	**76**
Malaita North, Solomon Islands	**19,949**	**13,740**	**50**
Malaita South -Ulava, Solomon Islands	**22,165**	**15,266**	**50**
Ontong Java, Solomon Islands	**19,949**	**13,740**	**50**
New Ireland - Lihir, PNG	**13,130**	**9,043**	**58**

These results show that although the cost of damage caused by one beaching FAD might be low, cumulative cost could be significant if traditional FADs continue to be used.

The cost per DFAD takes account of a deep tail of netting as is the case for the traditional FAD (HER FAD). The costs are expected to be much lower for the non- entangling FADs. Probably the impact surface will be 10% of the surface used for these estimates (500m^2/FAD[6]) because of the lower overall surface that will come in contact with the habitat and the lower likelihood of the submerged structures getting caught on outcrop habitat structures. LER FADs that are lost and never retrieved will still have long lasting effects on the ecosystem due to the non-degradable nature of the materials they are built with.

Although biodegradable FADs will not have long term negative effects on the ecosystem when lost, they are still be expected to have temporary physical impact if they beach on sensitive areas, with corals not being able to survive, although the area affected will be much lower than for traditional FADs (for the same reasons as for non-entangling FADs)

[6] For traditional FADs the area of impact for one FAD was set at 500m^2 based on the fact that most FADs in WCPO have a tail of 40-80m long (Murua et al., 2017) and 2m wide, and a floating structure of 6-9m^2. Using a precautionary approach, the average surface (127.5 m^2) of the FAD was multiplied by 4 then rounded to 500. The multiplication factor was not scientifically derived although was chosen based on evidence of multiple impacts (contact with multiple habitats) for some FADs. Using a precautionary approach in conditions of uncertainty, (http://www.fao.org/3/W1238E01.htm#ch1.1.2), the possibility that all DFADs could have multiple impacts could not be excluded.

8 Legal liability

8.1 Definition of fishing gear

The use of drifting FADs falls within the WCPF Convention definition of 'fishing' at all stages of use, from deployment to recovery, including the drifting stage when the FAD is 'soaking' and remotely aggregating fish. The Convention (Part 1 Article 1 subsection iii and iv, WCPFC, 2004) defines fishing very broadly to include engaging in any other activity which can reasonably be expected to result in *(iii) the locating, catching, taking or harvesting of fish for any purpose; and (iv) placing, searching for or recovering fish aggregating devices or associated electronic equipment such as radio beacons*. The current regulatory framework (Conservation and Management Measures) supports some specific management measures aimed at regulating drifting FADs, which seek to limit the number of FADS to 350 per vessel (WCPFC, 2018); and operate a three-month closure, including prohibition of deploying, servicing or setting on FADs (WCPFC, 2018).

At the time of preparing this paper PNA had created a FAD Buoy Authorisation and Registration, Communication and Tracking scheme and were in the process of implementing a legally binding FAD buoy management instrument (PNA, 2019), due to be implemented from 2021.

Most PNA countries have specifically classified FADs as fishing gear, i.e. the *placing, searching for or recovering any fish aggregating device or associated equipment including radio beacons*; (e.g. Nauru Fisheries Act, 1997, FSM Marine Resources Act, 2002, and the Solomon Islands Fisheries Act 2015). Under these circumstances, a DFAD in waters under national jurisdiction constitutes fishing without authorisation and is an offence, which effectively means that vessels that are not licensed to fish in these waters under bilateral agreement or under the Federated States of Micronesia Agreement (FSMA) are committing an offence. The Republic of Palau specifically prohibits the use of FADs in its zone (Palau National Marine Sanctuary Ac, 2015).

Most Parties have also defined FADs within their legislation ''Fish aggregating device' means *any man-made or partly man-made floating or semi-submerged device, whether anchored or not, intended for the purpose of aggregating fish, and includes any natural floating object on which a device has been placed to facilitate its location'*. Furthermore, all Parties have legally binding articles that require them to incorporate WCPFC measures and to comply with treaties or arrangements to which they are a Party (e.g. Kiribati Amendment to the 2010 Fisheries Act, 2017). The proposed PNA Implementation Arrangement, once introduced would enable a Party to apply the definition of fishing more effectively than now.

Once fully implemented, national fishery acts or accompany regulations of license conditions will mean that:

- A FAD drifting in any closed area such as the Territorial Sea, a Closed Area around main Islands, or any other Closed Area is illegal fishing;
- A FAD drifting in a zone in which any vessel associated with the FAD is not licensed is illegal fishing; and
- For the PNA Vessel Day Scheme, a vessel with a FAD in the water anywhere is fishing, and a vessel would be considered as fishing in more than one EEZ at a time if it had FADs in the water in more than one EEZ.

Under the UN Law of the Sea Convention (Article 62(4)), Flag States are responsible for ensuring that their vessels are not fishing without authorization in any coastal state's EEZ, which in terms of the Convention or coastal state laws, extends to fishing gear. This would extend to application of flag state laws to non PNA countries into which FADs drift, notably Indonesia, Australia, Fiji, Vanuatu, Cook Islands, Guam and Samoa. All Pacific Island countries appear to have adopted legislation defining FADs as fishing gear and would classify the gear fishing without authorization when in zone (Maeva-Leigh Iro, Policy and Legal Officer, MMR Cook Islands). Indonesia applies its own FAD Registration and limit scheme (PER.30/MEN/2004; PER.08/MEN/2011 and PERMEN No. 26/PERMEN-KP/2014), where presumably any unauthorized FAD, if identified would be classed as fishing illegally. When the level of interaction is conceivably low, there is less likely to be a problem, but if the frequency of FADs in zone and beaching were to increase, fishing companies could find themselves vulnerable to prosecution.

8.2 Abandoned, Lost or otherwise discarded fishing gear

The International Convention for the Prevention of Pollution from Ships 1973/78 (MARPOL) is an international instrument that addresses marine pollution originating from ships under flag state control. Annex V) Prevention of Pollution by Garbage from Ships, covers the provisions related to fishing operations. Most UN member states are members of IMO. However, the Federated States of Micronesia, an island-nation in the Pacific Ocean, is also a non-member, as is Taiwan, a major Distant Water Fishing Nation, itself a non-member of the UN[7].

Whilst MARPOL excludes 'fishing gear released into the water with the intention for later retrieval' from its provisions concerning garbage or accidental loss (para 1.7.8.), the 2017 Guidelines for the Implementation of MARPOL note that fishing gear, once discharged come under the "accidental loss: provisions. This opens the possibility for PNA to shape international law by deciding that lost FADs are "accidental loss" in which case the relevant recording and reporting provisions apply. These guidelines also 'invite' members to take action to minimise the probability of loss, to record and report losses and to maximise recovery of lost gear. They encourage vessel operators, organisations and governments to undertake research and to develop technology and regulations as necessary. None of the PNA states or Flag States have implemented the guidelines to date.

If applying the guidelines, fishing vessel operators are required to record the discharge or loss of fishing gear in the Garbage Record Book or the ship's official log-book as specified in regulations 7.1 and 10.3.6 of MARPOL Annex V; and further required to report the accidental loss or discharge of fishing gear which poses a significant threat to the marine environment and navigation. Reports should be made to the flag state, and where appropriate, the coastal state in whose jurisdiction the loss of the fishing gear occurred, as specified in regulation 10.6 of MARPOL Annex V. The PNA draft FAD log sheet (PNA, 2019b) includes both provision for reporting the loss of a FAD and the loss in FAD buoy signals. These reports will be available to PNA coastal states, and potentially may be available to foreign flag states on request. Failure to report would be deemed an offence, but reclassifying the FAD as abandoned, lost or discarded, if still drifting would then fall into the bounds of fishing gear, which suggests that the FADs still need to be recovered.

[7] https://en.wikipedia.org/wiki/International_Maritime_Organization#Membership

When using the guidelines, flag states are also required to regulate the reporting of accidentally lost, discharged, or abandoned fishing gear that poses a significant risk to the marine environment or navigation. Both vessel owners and governments are required to report information on lost, discharged or abandoned fishing gear and share it with coastal states, under certain circumstances. Governments are also required to create communication frameworks to facilitate the reporting and sharing of information with coastal states. These provisions obligate flag states to regulate the fishing gear of their vessels, including monitoring and collecting information on the use, deployment, drifting, and retrieval phases of a drifting FAD to minimize marine pollution due to their loss.

The guidelines also stated that governments should give careful consideration to the impact of gear in sensitive areas, such as coral reefs, and in areas where interactions would have higher risks of detrimental impacts, such as foraging or breeding areas for protected species.

UNFSA, 1995 also requires that states are obliged, *inter alia*, to ‘minimize pollution ... [and] catch by lost or abandoned gear.’

8.3 Tampering with FADs

Some national laws (para 25 (3) Solomon Islands Fisheries Act, 2015) include reference to *No person shall destroy, damage or take any part of a fish aggregating device, artificial reef, mooring buoy, float, tray or other device which belongs to another person and has been authorised and deployed in accordance with this Act.* This terminology may need to be re-assessed for vessels removing old buoys and replacing with new, along with the issue of coastal fishers fishing on abandoned or lost FADs, once in territorial waters; and dismantling FADs in order to prevent damage to coral reefs.

9 Industry Views on Methods to Recover Fish Aggregating Devices

A survey of purse seine vessel companies to identify industry responses to Draft Guidelines for the Application of a System on the Marking of Fishing Gear (Gilman et al 2018) was carried out in 2017. The survey included fishers fishing in PNA zones, as well as fishers operating in other oceans. Some of the results of this work are relevant to the discussion in this report:

- Almost all respondents stated that the owner of a DFAD and responsibility for any damage caused by a DFAD should be the company that owns the satellite buoy that is currently attached to the DFAD. If a satellite buoy is not attached, then the company that last had their satellite buoy attached, if this can be determined, should be considered the DFAD's owner;
- The high at-sea operating cost for purse seine vessels makes it cost-prohibitive to retrieve distant DFADs. The expense for fuel and availability of vessels to retrieve DFADs over extensive areas would be the main costs for DFAD retrieval. Some respondents explained that when a DFAD that they are tracking drifts far from their fishing grounds, they monitor the buoy location and try to identify another vessel that can exchange buoys on the DFAD so that the vessel can return their satellite buoy. The cost to the purse seine sector of abandoning DFADs and replacing them with new ones is much lower than the cost of retrieving DFADs that drift out of range, especially if purse seine vessels conduct the retrieving.
- The environmental impacts from fuel required to be consumed to retrieve derelict DFADs would exceed the environmental costs of leaving derelict DFADs at sea.
- When a DFAD drifts out of their fishing grounds, some respondents direct their satellite buoy service provider to unsubscribe (stop the transmission of) the buoy attached to that DFAD, resulting in the DFAD being abandoned.
- Respondents explained that DFADs and components are very rarely discarded at sea. Fishers routinely refurbish DFADs, reusing old, worn-out components of the appendage and raft. A very small proportion of worn-out DFAD components cannot be reused. Some vessels modify DFADs by replacing unwanted components that have entangling designs with less or non-entangling designs. Most respondents retain unwanted synthetic materials from DFADs that cannot be reused. They either incinerate the unwanted synthetic components on board or dispose of it in port. However, some respondents reported that worn-out DFAD gear is also discarded at sea.
- When vessels exchange satellite buoys, fishers may let the old satellite buoy drift away after detaching it from the DFAD or may destroy the old satellite buoy and discard the debris at sea. The most common practice, however, is to retain the old buoy and return it to port so that it can be retrieved by the owner.
- When they replace worn-out biodegradable components of the DFAD raft, including reeds and bamboo, fishers discard these old components at sea.
- Some survey respondents commented that it is feasible to establish site-specific programmes that monitor DFAD satellite buoy data to determine when DFADs approach specific, sensitive sites so that the DFADs could be intercepted by locally-based vessels before running aground. For example, some respondents clarified that it would be feasible to retrieve derelict FADs in some hot spot areas.
- Some captains and vessel owners that operate in the Eastern Pacific explained that artisanal fishers recover satellite buoys from the derelict FADs in order to sell back to the owners.

- Some respondents commented that it is technically feasible for the purse seine sector to stop the practice of abandoning DFADs and instead retrieve them, and that these companies should adjust their annual operating budget to cover the costs to retrieve their fishing gear, which may require reducing the number of DFADs that they currently deploy.
- Other respondents suggested that management authorities should charge purse seine operators a per-DFAD fee to cover the costs incurred by managers to track and retrieve all DFADs deployed by vessels that they authorize to fish.
- Almost all respondents explained that they very infrequently dispose of synthetic DFAD components, either at sea or in port, but instead reuse them to refurbish DFADs. Furthermore, the reasons that fishers decide to abandon DFADs do not include issues with port disposal (availability, cost, practicality). Therefore, most respondents commented that incentivizing disposal of unwanted DFADs and components in port instead of discarding and abandoning at sea is not needed. However, a few respondents conversely stated that low or no-cost port disposal facilities that are practical to use might possibly increase the likelihood of vessels disposing unwanted DFAD components in port instead of discarding them at sea.
- Respondents recommended investing in technology research to develop self-navigable or remotely navigable DFADs to reduce or eliminate the current causes of abandonment and risk of grounding.
- Research to develop the technology to remotely sink biodegradable DFADs that are at risk of grounding on sensitive coastal habitat was another recommended research priority.

10 The costs of alternative DFAD recovery options

DFADs are purchased from service providers by the fishing vessel companies, the industry. Legal liability for the operation of the FAD falls to the industry. Any impact that these FADs may have on habitats falls to industry, and not the provider. This would include accounting for the habitat and economic impact from the materials and paying for the cost of recovery (materials and the FAD buoys).

Fleet Cost recovery options require two potential responses. Firstly, respondents (Gilman et al) stated that vessels could theoretically operate in different parts of the PNA EEZs, where some could be strategically placed to collect DFADs. This is not considered practical in the WCPO because of the El Niño–Southern Oscillation (ENSO) variations, which mean that vessels predominantly fish where the fish are, whilst the FADs drift across the range of the Ocean. In recent years, much of the fishing has been in the Eastern side of the WCPO, whereas FAD beachings are predominantly in the West.

Secondly vessels could steam to the FADs, which would be practical in cases where the FADs were close to the fishing grounds. Steaming from East to West (e.g. from Majuro to Rabaul, represents around 12,000 nautical miles, or 75 hours (4 days)) at 16 knots. The average fuel costs per day for a PNA purse seine vessel would be US$ 12,525 / day or potentially up to US$ 78,000 for the round trip (PNAO economic model, 2018) and a daily loss in fishing revenue of US$ 45,000/day. Assuming a rate of recovery four FADs per day, the opportunity cost would be US$ 11,250 per DFAD recovered.

Another recovery option that could be considered would be to use charter vessels. Indicative costs to hire a dedicated 2,000 GRT vessel, equivalent to the vessel used to support PC's tuna tagging programme has been around US$ 175,000/month, or US $ 5,800/day, including the cost of fuel (WCPFC, 2017). However, these costs were reported to have doubled to US$ 420,000, or US$ 14,000/day. Assuming a rate of recovery of four FADs per day, the opportunity cost would be US$ 3,500 per DFAD recovered.

It is reported that purse seine vessels have been using longliners to deploy FADs. The opportunity costs of a 200 GRT operational longline vessel (PNAO, 2018) assesses the cost of hiring a 200 GRT Pacific longliner could be calculated as loss in sales (~ US$ 1 million, less bait and fishing gear costs (US$ 165,000), all other costs, including fuel, crew and overheads being the same. Including fuel and full crew, deducting the operational costs of bait and fishing gear at US$ 835,000, would equal around US$ 3,340, or potentially with an overhead of 20%, at US$ 4,000/day. A Pacific based longline company, quoted a charter cost similar to that of US$ 125,000/month or US$ 5,000/day. From a range of US$ 4,000-US$ 5,000/day, assuming the recovery of 4 DFADs/day, the recovery costs would equate to US$ 1,125 per DFAD.

All of the above options would need to assume that each vessel would be able to locate 4 DFADs per day, and the option of companies sharing the costs of chartering a longline would need to be explored.

A third option would be to operate a lower scale industry NGO partnership recovery programme, following the example set up in the Seychelles, with the support of an industry funded FAD Watch programme (Zudaire et al., 2018) and national government. The system would be supported through adjustments to FIMS to provide DFAD trajectories. The FAD Watch programme used a 5.5 m fiberglass boat and skippers, as well as land-based resources such as tractors to move and store FADs once they were removed from the water. Logistical support requirements (resources and costs) were around US$ 100,000 per annum (Adam, pers com, 2018), representing a cost of US$ 4,166 per DFAD intercepted. Funding could be secured through a bond system linked to anticipated rates of recovery by Flag (Figure 4).

Noting that the economic impacts in hotspot countries (PNG, Solomon Islands and Kiribati) are in the range US$ 50 - US$ 76 / FAD (Table 15). All of these options illustrate a very high cost for recovery relative to the economic impact of FADs on coastal communities.

A final option would be to set up a recovery programme that incentivizes local fishers to recover FADs and FAD buoys. The system could send out details of FAD trajectories from the FIMS system to coastal communities. Fee rates could be based on the return of the FAD buoy, with the requirement that payment is made on a scale of the quantity of materials recovered along with the buoy. The buoy is likely to have a second-hand value and can be reused. Pacific Island subsistence fishers earn US$ 39 / day (15.6 kg fish caught (Gillett & Tauati, 2018) X US$ 2.8/kg (PC, 2017)) X 0.908% (Value added) (PC, 2017). A payment schedule, which includes the return of a FAD buoy, and photographic evidence of gear recovered and some form of independent verification (provincial fishery officer) would be worth exploring. The range of incentive would be between the opportunity cost of fishing US$ 39/day and the second-hand price of a FAD buoy, which is likely to be low. There was some evidence of informal exchanges of FAD buoys between Kiribati fishers and purse seiners (MFMRD, Kiribati, pers comm, September 2019), but the exchange was usually in-kind payments of fish, as opposed to a direct financial payment.

11 An assessment of recovery strategies

There are a number of possible ways to reduce the number of DFAD loss events on sensitive marine habitats. This includes 1) regulatory measures, which would be applied by PNA and its coastal state governments or WCPFC which would reduce the damaging impact of FADs; 2) development of appropriate recovery strategies, including penalties for non-recovery; 3) A reduction in the number of FADs; and 4) advances in DFAD design, which would seek to reduce and possibly eliminate some of the damaging environmental impact of FADs.

PNA has sought to avoid establishing two competing management instruments or rights. This is because the organisation sets its priorities for revenue earning capacity on the Vessel Day Scheme (VDS) (PNA 38, WP 386b) The PNA harbours no thoughts of utilising FAD management as an income earning opportunity, other than covering the costs of administering the FAD Registration Scheme, simply because it would detract from the VDS as the rent seeking vehicle. This follows the advice of MRAG, 2018, and largely removes the option of discussing economic and market incentives.

The PNA has specifically stated that the costs attributed to FAD recovery should be consistent with the polluter pays principle, whereby the party responsible for producing pollution, the vessels and vessel companies registered under the FAD Registration Scheme, are responsible for paying for the damage done to the natural environment, i.e. only to allow FAD fishing if they are adequately compensated for all environmental and economic risks (PNA 38, WP 386b).

11.1 Regulatory measures

The WCPFC Convention defines fishing very broadly to include engaging in any other activity which can reasonably be expected to result in *(iii) the locating, catching, taking or harvesting of fish for any purpose; and (iv) placing, searching for or recovering fish aggregating devices or associated electronic equipment such as radio beacons*.

Most national fishery acts may require an element of strengthening to fully take onboard these definitions, and thereafter ensure that they are incorporated into implementing regulations and license conditions. However, as it stands the collective interpretation of PNA country legislation is:

- A FAD drifting in any closed area such as the Territorial Sea, a Closed Area around main Islands, or any other Closed Area is regarded as illegal fishing;
- A FAD drifting in a zone in which any vessel associated with the FAD is not licensed is regarded as illegal fishing; and
- For the PNA Vessel Day Scheme, a vessel with a FAD in the water anywhere is fishing, and a vessel would be considered as fishing in more than one EEZ at a time if it had FADs in the water in more than one EEZ.

Under the PNA 4th implementation arrangement, vessels skippers will be obliged to report FAD deactivation. This does not preclude their vessels from their legal obligations. This means that there is an explicit requirement to recover gear if moving into an unauthorised zone (e.g. territorial waters or closed areas), unless there are concessions given by Parties. This could occur where, for example, FAD beachings are considered to be low or moderate risk (See CSA) or where advice that a FAD is entering a closed area but will not be fished on is acceptable as a defence to the charge of illegal fishing. However, where there are major risks of beaching events (Malaita, New Ireland, and the southern Gilbert Islands), individual Parties may look to create a FAD retrieval programme; and may also be more apt to support limits set on the number of FADs deployed. These issues are likely to be more relevant to Solomon

Islands, PNG and Kiribati. The MARPOL guidelines 'invite' members to take action to minimise the probability of loss, to record and report losses and to maximise recovery of lost gear. .

11.2. FAD recovery programmes

This report agrees with Industry that purse seine vessel FAD recovery programmes are prohibitively expensive to operate. However, it is not without reason to expect industry to pay recovery costs, and the current FIMS system can be adapted to model trajectories and allow for a recovery system.

There are a number of options that could be considered.

Recovery option 1:

The option of chartering longline vessels is financially feasible at US$ 125,000 / month, if the costs are shared (e.g. by bilateral partners), and when specific countries have a much higher FAD usage than others (Korea, Taiwan and Kiribati). Paying for the cost of recovery would potentially improve careful consideration to the number of DFAD deployed but would need to ensure that higher charges were levied on those FADs not recovered in order to ensure that the incentive to recovery existed.

A bond scheme could be considered to address issue of unrecovered beached FADs. The basis of the bond payments to each Party would be a fee rate higher than the equivalent cost of recovery, US$ 1,125 per beached? DFAD, under this option, combined with the economic impact (Table 15). These average US$ 55/FAD across the PNA but range from US$ 12 (Tuvalu) to US$ 427/FAD in Palau.

It is probably not practical to set up a bond structure for each party when the number of beachings are low. So there are stronger incentives for bond systems to apply for Solomon Islands, PNG, Kiribati and potentially Tuvalu, but equally there would need to be a structure that ensures that penalties are recoverable where there are fewer impacts, for example Palau, Nauru, FSM and RMI. Some of these countries, Palau and Nauru, are shown to have relatively higher economic impact costs.

Recovery option 2:

A more cost-effective option would be to set up a recovery system, on similar lines to the FAD Watch scheme in the Seychelles, but this will require the support of Government and a local NGO to implement the scheme.

FAD charges reflecting the 'economic impact' could added to the FAD buoy registration charge, and funds. distributed to each Party, and for each Party to implement a FAD Watch Scheme. A FAD Watch scheme would require the creation of a buffer zone and an effective alert system to coordinate fishers to intercept the DFADs, and some payment incentive to ensure that all materials, and not just the buoys are recovered. This system would ensure that those Parties most affected by the beachings, were the net beneficiaries of the funds – but equally, each Party would have to demonstrate that a recovery system was in place.

Table 17. Potential annual redistribution of economic impact if funds allocated to FAD Watch schemes based on 64,900 deployed FADs.

Country	US$	% share
Solomon Is	221,653	33%
PNG	187,575	28%
Kiribati	161,918	24%
Nauru	32,645	5%
FS Micronesia	18,525	3%
Palau	20,760	3%
Tuvalu	11,223	2%
Marshall Is	9,202	1%
Tokelau	1,618	0%
Total PNA	**665,118**	**100%**

Source: Extracted from Table 15

These recovery costs would have to be reviewed based on each of the different scenarios. The change to NER and BNER FADs (Table 4) would result on a much reduced requirement to recover FAD materials.

A buffer system allied to an automated financial penalty, such as a fee for the time the DFAD is in that zone, would incentivise recovery.

11.3 Overall reduction in DFAD numbers

Setting a limit on the number of DFADs that can be deployed per vessel in a given period (e.g. year, month) would directly restrict the number of DFADs entering the WCPO if it is set low enough to actually constrain the number of DFADs deployed. Compliance with such a measure would require an effective FAD buoy registration system, which PNA is developing, allied with the support of the satellite providers and an observer programme to prevent unregistered FAD buoys from being deployed.

A challenge to this system is to determine the number of active DFADs that could be deployed. (Lennert-Cody et al., 2018), examining rates of return per deployment for this fleet segment in the Eastern Pacific Ocean found that the greatest rate of return occurred at 200 DFAD deployments per vessel, whereas WCPFC CMM 2018-01 allows for 350 per vessel.

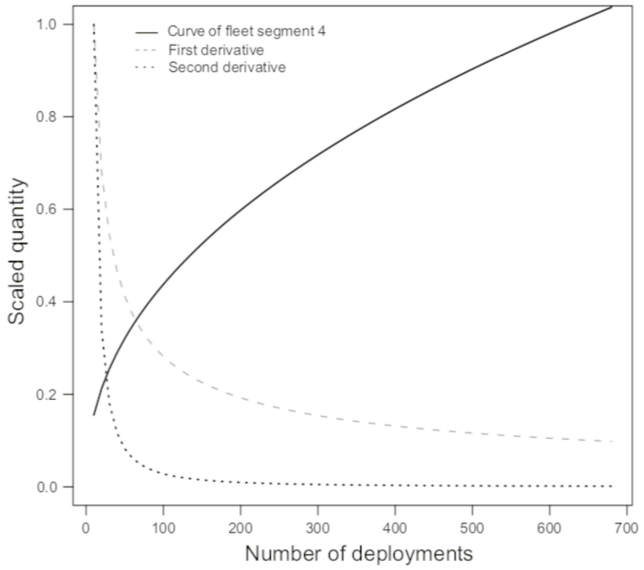


Figure 15. Rate of return per DFAD deployment.

Source: Lennert-Cody et al., 2018

Cabral et al (2014), modelling the impacts of fish aggregating devices (FADs) and their implications for managing small-scale fisheries, found that the optimal catches from FADs were found when distances between FADs were no less than 20 km, with a single FAD having an effective area of 400 square km. The area of the WCPO being 14.3 million m^2 divided by 400 m^2 would therefore suggest a maximum efficiency at 35,750 DFADS at any time in the water, which means about 140 FADs per vessel for the current number of vessels.

11.4. DFAD design

Evidence from the analysis on beaching events shows that there are two main issues associated with FAD loss; reef entanglement, causing loss in coral reef habitat; and animal entrapment. The main problem is caused by the impact of synthetic materials, largely netting and ropes and superstructures – metal or wooden frames. Other waste materials include the buoy and floats. There are no substitutes for floats and buoys, but there are substitutes for netting and heavy-duty frames. Evidence suggests that HER FADs have a significant impact on coral reef habitats and marine wildlife because of the use of netting. In the short run, wildlife entangling impacts are reduced with LER FADs, but the number of beachings and habitat impacts are expected to remain similar (when netting panels are used, the impact surface per FAD will still be large while for "sausage" designs, the coiled netting can unravel creating a large impact surface). In the long run, the netting used in LER FADs structure is likely to break and larger holes created can become entangling. For sunk FADs that are not retrieved, the impacts of LER FADs are still likely to be irreversible in areas where these FADs accumulate because the components are not degradable. The use of NER FADs would most likely eliminate the impact on wildlife because no netting is used in their structure. The use of canvas panels is still likely to have some impact on reef structures. If only ropes are used in the submerged structures, the overall impact area is likely to be lower. NER FAD floating structures, built of bamboo, may also become water-logged and are more likely to sink before hitting the reef thus, probably the rate of beaching will be lower. On this basis the use of NER FADS is likely to significantly reduce the impact on coral reef habitats, potentially to as low as 10% (see Appendix 5). BDNER FADs would appear to be a more palatable option, but the durability of these FADs appears to be short lived, and therefore could lead to a greater number of cumulative FADs deployed. They are also costlier to build. However, BDNER FADs are more likely to address concerns on the impact of sunk FADs, because the impacts will not be irreversible (all or most components will be biodegradable).

11.5 Abandoned, Lost or Otherwise Discarded Fishing Gear

The analysis has focused on assessing the impact of FAD beachings and not sunk FADs, which account for 66% of all losses. Measuring the environmental impacts of ALDFG on seamounts and abyssal plains are extremely difficult to determine, and as per coastal FADs, these impacts are likely to be localized. However, a precautionary approach would be to not deploy FADs that are associated with high levels of synthetic debris (HER and LER FADs); or to require FADs to be recovered within a more limited lifespan of 10-12 months (Table 1). In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall be not used as a reason for postponing cost-effective measures to prevent environmental degradation. NER FADs are highly likely to have a lower impact on coastal habitats. A change to BDNER FADs would are much more likely to reduce the impact on deepwater habitats, but the risks are that they are largely untested and less durable. If PNA were to apply the precautionary approach, which is consistent with all PNA country legislation, and the WCPFC Convention, the current timeline would need be reviewed by Parties in the context of first adopting NER FADs, with a view to moving to BDNER FADs, once more work has been completed on their effectiveness.

It is also noteworthy that some parties have adopted the ecosystem approach to fisheries management. These are explicit in the fisheries acts of Kiribati, FSM, RMI, Solomon Islands and Tuvalu. The ecosystem approach to fisheries strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries.

12 Conclusion and Recommendations

The assessment shows that over the coming 10 years there is a strong likelihood that the number of DFADs sunk or beached will be in the region of 514,000 to 711,000. An risk analysis of beached FADs suggests that these represent a medium risk to the coastal habitats where there are higher levels of beachings – Solomon Islands, PNG and Kiribati. The risks are much lower for other PNA coastal countries, but nevertheless add to localised impacts of coral mortalities.

The impact of sunk FADs is uncertain, but likely to have some impact on corals habitats on seamounts and deep-water biota.

The risks have been further quantified in terms of producer surplus and represent an annual economic impact of about US$ 700,000. This is against an annual income to PNA fisheries of around US$ 500 million.

Proposed recommendations for consideration to mitigate against DFAD loss are as follows:

Recommendation 1: Ensure that vessel owners are aware that DFADS constitute fishing activities and as such are liable sanctions for unauthorised fishing in unauthorised zones (EEZs where vessels have no access entitlement, territorial seas and closed areas). Hence, there is an emphasis on vessel owners in recovering FADs before entering these zones;

Recommendation 2: Recovery options should be implemented, especially where the prospects for beachings are high, and where the risks of environmental damage are high to medium – Solomon Islands, PNG and Kiribati; and such options can include two possibilities. Owner recovery is not likely to be cost effective, leaving the option of a domestic FAD Watch and recovery scheme to be applied in high risk areas. The FAD Watch system would require purse seine vessel owners partner with national fisheries departments, local NGOs and/or coastal fishers to recover DFADs;

Recommendation 3: In any area where DFADs fail to be recovered, individual countries should be in a position to implement sanctions so as to encourage improved FAD management. Such an option would be especially attractive where there are high impact from beachings, even where the numbers of beachings are quite small, for example Palau.

Recommendation 4: Alternative funding scenarios could be considered whereby management fees are generated from the FAD charging system to allow for the cost of recovery. These funds would be allocated to all Parties but distributed on the basis of historic beachings;

Recommendation 5: National government should set sanctions to deter beachings. It is recommended that these are based on a combination of a recovery cost along with the economic cost of the impact (US$ 1,250 + US$ 75), or in some cases higher, where FAD impacts are likely to have a higher economic impact, e.g. Palau;

Recommendation 6: The management authorities should therefore re-evaluate the limits set on the number of FADs to be carried. The figure of 350 FADs per vessel is not precautionary and is likely to significantly increase the impact of damage to coastal habitats, sea mounts and deep-water biota. Studies show that a realistic range for FAD numbers per vessel lies somewhere between 140 to 200 FADs per vessel.

Recommendation 7: A change from to LER to NER FADS in order to reduce the environmental impact. The assumption is that a further change to BNR FADs, if operational from a fishing perspective, will lessen the impact and are most likely to reduce the impact on both coastal and deep-sea habitats. A change to NER and BNER will eliminate the need for a FAD recovery programme.

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Appendix 1 Lost DFADs Projections to 2029

Scenario 1: HER FADs will continue to be used for the whole period

a) With constant number of deployments (see section 4 for method)

Year	New deployments /year	Cumulative deployments	Retrieved	Cumulatively retrieved	Beached and pre-beached	Cumulatively beached	Lost	Deactivated	Drifting and unexplained deactivation	Sunk	Cumulatively sunk
2020	64,900.00	64,900.00	7,094	7,094	7,574	7,574	33,657	9,086	7,489	0.00	0.00
2021	64,900.00	129,800.00	8,583	15,677	13,436	21,010	40,725	10,994	9,062	42,881	42,881
2022	64,900.00	194,700.00	8,583	24,260	13,436	34,446	40,725	10,994	9,062	42,881	85,762
2023	64,900.00	259,600.00	8,583	32,843	13,436	47,882	40,725	10,994	9,062	42,881	128,642
2024	64,900.00	324,500.00	8,583	41,426	13,436	61,318	40,725	10,994	9,062	42,881	171,523
2025	64,900.00	389,400.00	8,583	50,010	13,436	74,754	40,725	10,994	9,062	42,881	214,404
2026	64,900.00	454,300.00	8,583	58,593	13,436	88,190	40,725	10,994	9,062	42,881	257,285
2027	64,900.00	519,200.00	8,583	67,176	13,436	101,626	40,725	10,994	9,062	42,881	300,166
2028	64,900.00	584,100.00	8,583	75,759	13,436	115,062	40,725	10,994	9,062	42,881	343,046
2029	64,900.00	649,000.00	8,583	84,343	13,436	128,498	40,725	10,994	9,062	42,881	385,927
2030 residual from 2029			1,489	85,832	5,862	134,360				42,881	428,832

b) with 5% annual increase in deployments (see section 4 for method)

Year	New deployment s /year	Cumulative deployments	Retrieved	Cumulatively retrieved	Beached and pre-beached	Cumulatively beached	Lost	Deactivated	Drifting and unexplained deactivation	Sunk	Cumulatively sunk
2020	64,900	64,900	7,094	7,094	7,574	7,574	33,657	9,086	7,489	0.00	-
2021	68,145	133,045	8,938	6,031	13,815	21,388	42,408	1,448	9,437	42,881	42,881
2022	71,552	204,597	9,385	25,416	14,505	35,894	44,528	12,021	9,909	45,025	87,906
2023	75,130	279,727	9,854	35,270	15,231	51,125	46,755	12,622	10,404	47,276	135,182
2024	78,886	358,613	10,347	45,617	15,992	67,117	49,093	13,253	10,924	49,640	184,822
2025	82,831	441,444	10,864	56,481	16,792	83,909	51,547	13,916	11,470	52,122	236,944
2026	86,972	528,416	11,407	67,888	17,631	101,540	54,125	14,611	12,044	54,728	291,672
2027	91,321	619,737	11,978	79,866	18,513	120,053	56,831	15,342	2,646	57,464	349,136
2028	95,887	715,624	12,577	92,443	19,439	139,492	59,672	16,109	13,278	60,338	409,473
2029	100,681	816,305	13,205	105,648	20,411	159,902	62,656	16,914	13,942	63,354	472,828
2030 residual from 2029			11,004	116,652	11,749	171,651				66,522	539,791

Scenario 2: LER FADs for a three-year transition period and NER FAD thereafter

a) With constant number of deployments (see section 4 for method)

Year	New deployment s /year	Cumulative deployments	Retrieved	Cumulatively retrieved	Beached and pre-beached	Cumulativel y beached	Lost	Deactivated	Drifting and unexplained deactivation	Sunk	Cumulatively sunk
2020	64,900	64,900	7,094	7,094	7,574	7,574	33,657	9,086	7,489	0.00	0.00
2021	64,900	129,800	8,583	15,677	13,436	21,010	40,725	10,994	9,062	42,881	42881
2022	**64,900**	**194,700**	**8,583**	**24,260**	**13,436**	**34,446**	**40,725**	**10,994**	**9,062**	**42,881**	**85762**
2023	64,900	259,600	8,583	32,843	13,436	47,882	40,725	10,994	9,062	42,881	128642
2024	64,900	324,500	8,583	41,426	13,436	61,318	40,725	10,994	9,062	42,881	171523
2025	64,900	389,400	8,583	50,010	13,436	74,754	40,725	10,994	9,062	42,881	214404
2026	64,900	454,300	8,583	58,593	13,436	88,190	40,725	10,994	9,062	42,881	257285
2027	64,900	519,200	8,583	67,176	13,436	101,626	40,725	10,994	9,062	42,881	300166
2028	64,900	584,100	8,583	75,759	13,436	115,062	40,725	10,994	9,062	42,881	343046
2029	64,900	649,000	8,583	84,343	13,436	128,498	40,725	10,994	9,062	42,881	385927
	LER	**194,700**		**24,260**		**34,446**					**85762**
	NER	**454,300**		**60,083**		**94,052**					**300166**

b) with 5% annual increase in deployments (see section 4 for method).

Year	New deployments /year	Cumulative deployments	Retrieved	Cumulatively retrieved	Beached and pre-beached	Cumulatively beached	Lost	Deactivated	Drifting and unexplained deactivation	Sunk	Cumulatively sunk
2020	64,900	64,900	7,094	7,094	7,574	7,574	33,657	9,086	7,489	0.00	-
2021	68,145	133,045	8,938	16,031	13,815	21,388	42,408	11,448	9,437	42,881	42,881
2022	**71,552**	**204,597**	**9,385**	**25,416**	**14,505**	**35,894**	**44,528**	**12,021**	**9,909**	**45,025**	**87,906**
2023	75,130	279,727	9,854	35,270	15,231	51,125	46,755	12,622	10,404	47,276	135,182
2024	78,886	358,613	10,347	45,617	15,992	67,117	49,093	13,253	10,924	49,640	184,822
2025	82,831	441,444	10,864	56,481	16,792	83,909	51,547	13,916	11,470	52,122	236,944
2026	86,972	528,416	11,407	67,888	17,631	101,540	54,125	14,611	12,044	54,728	291,672
2027	91,321	619,737	11,978	79,866	18,513	120,053	56,831	15,342	12,646	57,464	349,136
2028	95,887	715,624	12,577	92,443	19,439	139,492	59,672	16,109	13,278	60,338	409,473
2029	100,681	816,305	13,205	105,648	20,411	159,902	62,656	16,914	13,942	63,354	472,828
	LER	**204,597.25**		**25,416**		**35,894**					**87,906**
	NER	**611,707.98**		**80,232**		**124,008**					**384,922**

Scenario 3. LER FADs for a three-year transition period and BNER FAD thereafter.

- Same rates of beaching and sinking were applied, although BNER FADs might have lower beaching rates

a) With constant number of deployments (see section 4 for method)

Year	New deployments /year	Cumulative deployments	Retrieved	Cumulatively retrieved	Beached and pre-beached	Cumulatively beached	Lost	Deactivated	Drifting and unexplained deactivation	Sunk	Cumulatively sunk
2020	64,900	64,900	7,094	7,094	7,574	7,574	33,657	9,086	7,489	0.00	0.00
2021	64,900	129,800	8,583	15,677	13,436	21,010	40,725	10,994	9,062	42,881	42881
2022	**64,900**	**194,700**	**8,583**	**24,260**	**13,436**	**34,446**	**40,725**	**10,994**	**9,062**	**42,881**	**85762**
2023	64,900	259,600	8,583	32,843	13,436	47,882	40,725	10,994	9,062	42,881	128642
2024	64,900	324,500	8,583	41,426	13,436	61,318	40,725	10,994	9,062	42,881	171523
2025	64,900	389,400	8,583	50,010	13,436	74,754	40,725	10,994	9,062	42,881	214404
2026	64,900	454,300	8,583	58,593	13,436	88,190	40,725	10,994	9,062	42,881	257285
2027	64,900	519,200	8,583	67,176	13,436	101,626	40,725	10,994	9,062	42,881	300166
2028	64,900	584,100	8,583	75,759	13,436	115,062	40,725	10,994	9,062	42,881	343046
2029	64,900	649,000	8,583	84,343	13,436	128,498	40,725	10,994	9,062	42,881	385927
	LER	**194,700**		**24,260**		**34,446**					**85762**
	BNER	**454,300**		**60,083**		**94,052**					**300166**

b) with 5% annual increase in deployments (see section 4 for method).

Year	New deployments /year	Cumulative deployments	Retrieved	Cumulatively retrieved	Beached and pre-beached	Cumulatively beached	Lost	Deactivated	Drifting and unexplained deactivation	Sunk	Cumulatively sunk
2020	64,900	64,900	7,094	7,094	7,574	7,574	33,657	9,086	7,489	0.00	-
2021	68,145	133,045	8,938	16,031	13,815	21,388	42,408	11,448	9,437	42,881	42,881
2022	**71,552**	**204,597**	**9,385**	**25,416**	**14,505**	**35,894**	**44,528**	**12,021**	**9,909**	**45,025**	**87,906**
2023	75,130	279,727	9,854	35,270	15,231	51,125	46,755	12,622	10,404	47,276	135,182
2024	78,886	358,613	10,347	45,617	15,992	67,117	49,093	13,253	10,924	49,640	184,822
2025	82,831	441,444	10,864	56,481	16,792	83,909	51,547	13,916	11,470	52,122	236,944
2026	86,972	528,416	11,407	67,888	17,631	101,540	54,125	14,611	12,044	54,728	291,672
2027	91,321	619,737	11,978	79,866	18,513	120,053	56,831	15,342	12,646	57,464	349,136
2028	95,887	715,624	12,577	92,443	19,439	139,492	59,672	16,109	13,278	60,338	409,473
2029	100,681	816,305	13,205	105,648	20,411	159,902	62,656	16,914	13,942	63,354	472,828
	LER	**204,597.25**		**25,416**		**35,894**					**87,906**
	NER	**611,707.98**		**80,232**		**124,008**					**384,922**

Scenario 4: LER FADs will be deployed for three years to allow transitioning to BNER FADs which will be used for the rest of the seven years but with a lower limit set on FAD numbers at 200. For BNER beaching rates might differ and beaching and sinking numbers were not calculated for this scenario.

Year	New deployments /year	Cumulative deployments	Retrieved	Cumulatively retrieved	Beached and pre-beached	Cumulatively beached	Lost	Deactivated	Drifting and unexplained deactivation	Sunk	Cumulatively sunk
2020	49,800	49,800	5,443	5,443	5,812	5,812	25,826	6,972	5,747	0.00	0.00
2021	49,800	99,600	6,586	12,029	11,674	17,485	31,250	8,436	6,954	32,904	32,904
2022	**49,800**	**149,400**	**6,586**	**18,616**	**11,674**	**29,159**	**31,250**	**8,436**	**6,954**	**32,904**	**65,808**
2023	49,800	199,200									
2024	49,800	249,000									
2025	49,800	298,800									
2026	49,800	348,600									
2027	49,800	398,400									
2028	49,800	448,200									
2029	**49,800**	**498,000**									
	LER	**149,400**		**18,616**		**29,159**					**65,808**
	BNER	**498,000**									

Appendix 2 Beaching Habitats

Gilbert Islands Hotspot

Beaching events distribution and habitat types affected as well as number of buoys collected by local population in Gilbert Islands hotspot, Kiribati, 2016-2018.

Hotspot	Beaching Location	Habitat type	No Beachings	Collected by locals
Gilbert Islands	Beru Atoll	Lagoonal reefs	1	0
		Reef flat, sediment dominated	6	6
		Seagrass meadows on back reef pavement	1	1
		Deep habitats (unknown)	5	0
		Unknown (FAD possibly still moving)	2	0
	Onotoa Atoll	Fore reef terrace/slope	1	1
		Lagoonal reefs	2	0
		Reef flat, sediment dominated	14	13
		Deep habitats (unknown)	2	0
		Unknown (5 possibly still moving, 1 beaching location cannot be identified)	6	1
	Tabiteuea	Lagoonal reefs	1	1
		Reef flat, sediment dominated	4	3
		Seagrass meadows on back reef pavement	1	1
		Deep habitats (unknown)	1	0
		Unknown (4 possibly still moving, 1 beaching location cannot be identified)	5	1
Total Gilbert Islands Hotspot	Beru, Onotoa and Tabiteuea (East)	Fore reef terrace/slope	1	1
		Lagoonal reefs	4	1
		Reef flat, sediment dominated	24	22
		Seagrass meadows on back reef pavement	2	2
		Deep habitats (unknown)	8	0
		Unknown (still moving or beaching site cannot be identified)	13	2
		Total	**52**	**28**

Source: FAD Tracking Program data analysed on high resolution Google Earth satellite imagery.

Solomon Islands Hotspots

Beaching events distribution and habitat types affected as well as number of buoys collected by local population in Solomon Islands hotspots, 2016-2018.

Hotspot	Beaching Location	Habitat type	No Beachings	Collected by locals
Ontong Java	Ontong Java Atoll	Fore reef terrace/slope	16	9
		Lagoonal reefs	11	10
		Reef flat, sediment dominated	14	11
		Multiple impact on various reef habitats	7	2
		Deep habitat (unknown)	2	1
Malaita North	Malaita North	Reef flat, sediment dominated	5	3
		Lagoonal reefs	5	3
		Unknown (still moving or beaching site cannot be identified)	17	14
		Mangroves	1	0
		Deep habitat (unknown)	4	0
	Leli Island	Fore reef terrace/slope	2	1
		Multiple impact on various reef habitats	5	2
		Reef flat, sediment dominated	1	0
	Manaoba Island	Fore reef terrace/slope	1	1
		Lagoonal reefs	3	2
		Reef flat, sediment dominated	1	1
		Multiple impact on various reef habitats	1	1
		Deep habitat (unknown)	2	0
	Mbathakana Island	Reef flat, sediment dominated	1	1
		Seagrass meadows on back reef pavement	1	1
	Mbokonimbeti Island	Reef flat, sediment dominated	1	1
	Ramos Island	Deep habitat (unknown)	1	1
Malaita South (including Ulava Island)	Malaita South	Fore reef terrace/slope	4	2
		Reef flat, sediment dominated	2	1
		Seagrass meadows on back reef pavement	1	1
		Mangroves	1	0
		Multiple impact on various reef habitats	3	2
		Unknown (still moving or beaching site cannot be identified)	1	1

Hotspot	Beaching Location	Habitat type	No Beachings	Collected by locals
		Deep habitat	3	1
	Maramasike Island	Fore reef terrace/slope	2	1
		Reef flat, sediment dominated	7	7
		Mangroves	1	1
		Multiple impact on various reef habitats	1	1
		Unknown (still moving or beaching site cannot be identified)	1	1
		Deep habitat (unknown)	1	0
	Ulava Island	Fore reef terrace/slope	8	6
		Reef flat, sediment dominated	8	6
		Seagrass meadows on back reef pavement	1	1
		Deep habitat (unknown)	2	0
		Soft sediment bay	1	0
	Fanalei Island	Multiple impact on various reef habitats	2	2
		Reef flat, sediment dominated	3	3
	Aiura Island	Multiple impact on various reef habitats	1	1
	Aio Island	Fore reef terrace/slope	1	0
		Reef flat, sediment dominated	1	0
	Ainuta Paina Island	Mangrove	1	0
	Walade Island	Fore reef terrace/slope	1	0
Total Solomon Islands Hotspots	Ontong Java, Malaita North and Malaita South	Fore reef terrace/slope	35	20
		Lagoonal reefs	19	15
		Reef flat, sediment dominated	44	34
		Multiple impact on various reef habitats	20	11
		Seagrass meadows on back reef pavement	3	3
		Mangrove	9	4
		Unknown (still moving or beaching site cannot be identified)	20	18
		Deep habitat (unknown)	15	2
		Total	**161**	**108**

Source: FAD Tracking Program data analysed on high resolution Google Earth satellite imagery.

Papua New Guinea

Beaching events distribution and habitat types affected as well as number of buoys collected by local population in Papua New Guinea hotspot 2016-2018.

Hotspot	Beaching Location	Habitat type	No Beachings	Collected by locals
New Ireland - Lihir	New Ireland - central area	Fore reef terrace/slope	8	5
		Reef flat, sediment dominated	11	8
		Multiple impact on various reef habitats	3	2
		Seagrass meadows on back reef pavement	3	3
		Mangroves	1	1
		Deep habitat (unknown)	1	0
		Unknown (still moving or beaching site cannot be identified)	3	1
	Lihir Island	Fore reef terrace/slope	1	1
		Reef flat, sediment dominated	4	4
		Seagrass meadows	2	2
		Mangroves	1	1
		Unknown (still moving or beaching site cannot be identified)	1	0
		Deep habitat (unknown)	1	0
	Mali Island	Fore reef terrace/slope	1	1
		Seagrass meadows on back reef pavement	3	3
	Masahet Island	Fore reef terrace/slope	1	1
	Sanambiet Island	Reef flat, sediment dominated	1	1
		Seagrass meadows on back reef pavement	2	2
Total PNG Hotspot	New Ireland-Lihir	Fore reef terrace/slope	11	8
		Reef flat, sediment dominated	16	12
		Multiple impact on various reef habitats	3	2
		Seagrass meadows on back reef pavement	8	8
		Seagrass meadows	2	2
		Mangroves	2	2
		Deep habitat (unknown)	2	0
		Unknown (still moving or beaching site cannot be identified)	4	1
		Total	**48**	**35**

Appendix 3 Scale, Intensity, Consequence, Analysis Scoring Methodology

Scoping

Component Identification

The risk assessment starts by identifying the components of the ecosystem to be analysed. In this assessment components affected by beaching are likely to be benthic habitats. Hobday et al. (2007) recommend that habitats should be described using sediment, geomorphology, and fauna (SGF). The MSC guidance suggest a more general description using sediment, geomorphology and biota (SGB) attributes which are used here. Habitat types affected by beaching, identified in section 6, are summarised in Table 18.

Table 18. Habitat components to be assessed at SICA.

Sub-biome/ reef zone	Feature	Habitat type (SGB)	Depth
Fore reef	Shallow slope	Biogenic reef, high relief, large erect dominated by corals	5-20m
Fore reef	Deep slope	Biogenic reef, high relief, large erect dominated by corals	>20m
Back reef	Reef flat	Coarse to fine sediment, low relief, small encrusting/burrowing	0-10m
Back reef	Back reef slope	Biogenic reef, high relief, large erect dominated by corals	5-20m
Back reef	Back reef bommies	Biogenic reef, high relief, large erect dominated by corals	5-30m
Lagoonal reefs	Lagoonal bommies and pinnacles	Biogenic reef, high relief, large erect dominated by corals	5-40m
Back reef	Back reef pavement	Fine sediment, low relief, seagrass dominated	<20m
Inner shelf	Shelf	Fine sediment, low relief, seagrass dominated	<20m
Coastal area	Shelf	Fine sediment, low relief, mangrove dominated	0-1m

Operational Objectives

Before proceeding with the assessment, operational objectives need to be set on what is the situation desired to be achieved, e.g. DFAD beachings do not continue to contribute to coral reef habitat reduction.

Table 19. Operational objectives and examples of indicators of risk.

Component	Core Objective	Sub-component	Operational objective	Indicators	Rationale
All from Table 17	Avoid negative impacts on the quality of the environment; Avoid reduction in the amount and quality of the habitat (Hobday et al., 2007)	Habitat type	Habitat range is not reduced (1)	Extent and area of habitat types, % cover, spatial pattern	Coral reef habitats most impacted, are already under a variety of negative stressors. Given the importance of coral reef for human lives, avoidable degradation should be avoided.
		Habitat structure and function	Size, shape and condition of habitat types does not vary outside acceptable bounds (2)	Size, structure, species composition and morphology of biotic habitats	Coral reef habitat was shown to recover after disturbance although the species composition might be altered, this changing the structure and function of the habitat and affecting the associated fauna species composition (Moritz et al., 2018)

Hazard Identification

Hazard identification in this case refers only to DFAD beaching which is one type of gear loss. The loss of gear results in the addition of non-biological material, this includes nets, buoys, floats, and other materials. These materials can smother and kill corals and other habitat forming biota.

Scale, Intensity Consequence Analysis (SICA)

SICA uses a “worst-case” scenario approach to screen out components at low risk. For this reason, the most vulnerable sub-component is selected to be assessed at Level 1.

The sub-component selected as most likely to be affected by DFAD beaching was the shallow slope/terrace portion of the reef because this habitat is likely to have the highest coral cover and biodiversity and contribute the most to the benefits from coral ecosystem services. The first operational objective was selected for assessment because there was insufficient information to assess objective 2.

Spatial scale of activity is scored from one to six, depending on the extent of the impact.

Table 20. Spatial scale of activity scores for ERAEF

<1 nm:	1-10 nm:	10-100 nm:	100-500 nm:	500-1000 nm:	>1000 nm:
1	2	3	4	5	6

Source: Hobday et al. (2007)

The spatial scale score is not used directly, but the analysis will be used in making judgments about level of intensity in a subsequent step.

Temporal scale of activity is scored function of frequency with which the identified hazard is occurring. It must be used for determining the temporal scale score for each identified hazard. If the fishing activity occurs daily, the temporal scale is scored as 6.

Table 21. Temporal scale of activity for ERAEF

Decadal (1 day every 10 years or so)	Every several years (1 day every several years)	Annual (1-100 days per year)	Quarterly (100-200 days per year)	Weekly (200-300 days per year)	Daily (300-365 days per year)
1	2	3	4	5	6

Source: Hobday et al. (2007)

The temporal scale score is not used directly, but the analysis is used in making judgments about level of intensity.

The intensity scale score considers the direct impacts in line with the category of hazard analysed (e.g. addition of non-biological material, disturbance to physical processes, external hazards). The intensity of the activity is judged based on the scale of the activity, its' nature and extent. Activities are scored as per intensity scores in Table 14.

Table 22. Intensity scale scores description for ERAEF

Level	Score	Description
Negligible	1	remote likelihood of detection at any spatial or temporal scale
Minor	2	occurs rarely or in few restricted locations and detectability even at these scales is rare
Moderate	3	moderate at broader spatial scale, or severe but local
Major	4	severe and occurs reasonably often at broad spatial scale
Severe	5	occasional but very severe and localized or less severe but widespread and frequent
Catastrophic	6	local to regional severity or continual and widespread

Source: Hobday et al. (2007)

The consequence scores the likelihood of not achieving the operational objective for the selected sub-component and unit of analysis. It considers the flow on effects of the direct impacts for the relevant indicator (e.g. beaching FADs continue to degrade coral reef habitat). Activities are scored as per consequence scores in Table 23.

Table 23. Consequence scores description for ERAEF

Level	Score	Description
Negligible	1	Impact unlikely to be detectable at the scale of the stock/habitat/community
Minor	2	Minimal impact on stock/habitat/community structure or dynamics
Moderate	3	Maximum impact that still meets an objective (e.g. ecosystem still delivers key ecosystem services)
Major	4	Wider and longer-term impacts (e.g. long-term decline in CPUE)
Severe	5	Very serious impacts now occurring, with relatively long time period likely to be needed to restore to an acceptable level (e.g. serious decline in spawning biomass limiting population increase).
Intolerable	6	Widespread and permanent/irreversible damage or loss will occur-unlikely to ever be fixed (e.g. extinction)

Source: Hobday et al. (2007)

Appendix 4 Market value calculations

Appendix 4.1: Fishing Market Values

Country	Coral Reef Area (km2) (1)	Inshore Commercial Fisheries (t) (2)	Subsistence (t) (2)	Inshore Commercial Fisheries @ $ 4/kg (2)	Subsistence @ $ 2.1/kg (2)	Inshore commercial -Net value added (3)	Subsistence -Net value added (3)	Total		
Source	Chin	Gillette	Gillette	Gillette	Gillette	SPC	SPC	Total value added	% of total	Value add/sq km
PNG	14,535	6,500	35,000	26,650,000	73,500,000	18,015,400	66,885,000	84,900,400	39.5%	5,841
Solomon Is	6,743	6,500	20,000	26,650,000	42,000,000	18,015,400	38,220,000	56,235,400	26.2%	8,340
Kiribati	3,041	7,600	11,400	31,160,000	23,940,000	21,064,160	21,785,400	42,849,560	19.9%	14,091
FS Micronesia	4,925	1,725	3,555	7,072,500	7,465,500	4,781,010	6,793,605	11,574,615	5.4%	2,350
Marshall Is	3,558	1,500	3,000	6,150,000	6,300,000	4,157,400	5,733,000	9,890,400	4.6%	2,780
Nauru	15	163	210	668,300	441,000	451,771	401,310	853,081	0.4%	56,872
Palau	966	865	1,250	3,546,500	2,625,000	2,397,434	2,388,750	4,786,184	2.2%	4,955
Tokelau	155	100	350	410,000	735,000	277,160	668,850	946,010	0.4%	6,103
Tuvalu	1,210	300	1,135	1,230,000	2,383,500	831,480	2,168,985	3,000,465	1.4%	2,480
Total PNA	***35,148***					***69,991,215***	***145,044,900***	***215,036,115***	***100%***	***6,118***
Australia (4)	348,000			-	-	-	-	342,483,000		984
Cook	528	150	276	615,000	579,600	415,740	527,436	943,176		1,786
Fiji	6,704	11,000	16,000	45,100,000	33,600,000	30,487,600	30,576,000	61,063,600		9,109
Guam	225	72	42	295,200	88,200	199,555	80,262	279,817		1,244
Indonesia (5)	-	-		-	-	-	-	-		-
Samoa	402	5,000	5,000	20,500,000	10,500,000	13,858,000	9,555,000	23,413,000		58,241
Vanuatu	1,803	1,106	2,800.00	4,534,600	5,880,000	3,065,390	5,350,800	8,416,190		4,668
Total non PNA	***382,662***	***2,179,093***	***24,118***	***71,044,800***	***50,647,800***	***48,026,285***	***46,089,498***	***436,598,783***	***-***	***1,068***

Source: (1) Chin et al (2011) (for Coral reef areas); (2) Gillette, R. and Tauati, M.I (2016) tonnages and prices; (3) P. James, SPC (2016) (value added); (4) Deloittes (2017) (Australia) (for calculation of Great Barrier Reef values for fishing, recreation and tourism); (5) no data available for Indonesia

Appendix 4.2: Tourism market values

Country	Coral Reef Area (km2) (1)	Reef used for tourism (2)	Reef used for marine tourism (2)	Assigned market value	Value added/sq km	% of total
PNG (5)	14,535	1,744	12%	56,563,916	3,892	31%
Solomon Is (3)	6,743	472	7%	15,800,000	2,343	9%
Kiribati (5)	3,041	61	2%	3,900,000	1,282	2%
FS Micronesia (2)	4,925	498	10%	16,150,000	3,279	9%
Marshall Is (2)	3,558	41	1%	346,000	97	0%
Nauru (5)	15	1	7%	8,439	563	0%
Palau (2)	966	407	42%	90,978,000	94,180	49%
Tokelau (5)	155	0	0%	-	-	0%
Tuvalu (5)	1,210	36	3%	306,337	253	0%
Total PNA	35,148	3,260	9%	184,052,691	5,237	100%
					-	
Australia (4)	348,000	243,600	70%	3,842,000,000	11,040	
Cook (5)	528	95.04	18%	21,244,592	40,236	
Fiji (3)	6,704	2,011.	30%	574,000,000	85,621	
Guam (2)	225	112	50%	3,632,129	16,143	
Indonesia (5)	25,000	5,000	20%	639,907,221	25,596	
Samoa (5)	402	60.30	15%	13,479,050.12	33,530	
Vanuatu (3)	1,803	270.45	15%	12,310,000.00	6,828	

Source: (1) Chin et al (2011) (for Coral reef areas), (2) http://maps.oceanwealth.org/# for estimates of tourism values (Palau, FS Micronesia, Marshall Is and Guam) (3) MACBIO, 2015 (for Solomon Islands, Kiribati, Fiji and Vanuatu estimates of fishing, tourism and coastal protection values), (4) Deloittes (2017) (Australia) (for calculation of Great Barrier Reef values for fishing, recreation and tourism) (5) Non specified values (PNG, Kiribati, Nauru, Tokelau, Tuvalu, Cook Is, Indonesia and Samoa) extracted from similar country attributes.

Appendix 4.3: Coastal protection market values

Country	Coral Reef Area (km2) (1)	Built capital protected	Value added/sq km
PNG	14,535	26,171,580	1800.59
Solomon Is (2)	6,743	18,804,520	2788.75
Kiribati	3,041	7,055,460	2320.11
FS Micronesia	4,925	0	0.00
Marshall Is	3,558	5,859,000	1646.71
Nauru	15	0	0.00
Palau	966	0	0.00
Tokelau	155	1,149,197	7414.17
Tuvalu	1,210	0	0.00
Total PNA	**35,148**	**59,039,757**	1679.75
Australia	348,000	31,889,010	91.64
Cook	528	53,070	100.51
Fiji (2)	6,704	8,485,000	1265.66
Guam	225	267,670	1189.64
Indonesia	No data	No data	0.00
Samoa	402	0	0.00
Vanuatu (2)	1,803	18,370,000	10188.57
Total Non-PNA	**357,662**	**59,064,750**	165.14

Source: (1) Chin et al (2011) (for Coral reef areas), (2) MACBIO, 2015 (for Solomon Islands, Kiribati, Fiji), (3) TNC estimates of built capital protected by coral reef (annual benefits expected per km^2 reefs for flood protection predicted if keeping corals intact) maps.oceanwealth.org

Appendix 5 Cost of Damage to Coral Reefs from FAD beachings in WCPO

- **when traditional FADs are used**

(Net Present Value (NPV) by beaching EEZ and per FAD)

a) For 64,900 deployments per year and 3.5% discount rate (costs are in US dollars)

Year	Solomon	PNG	Kiribati	Tuvalu	Micronesia	Marshall	Nauru	Australia	Vanuatu	Palau	Fiji	Tokelau	Guam	Cook	Samoa	Total PNA	Total Non PNA
0	25,751	21,792	18,811	1,304	2,152	1,069	3,793	463	678	2,412	1,585	188	65	439	319	77,270	3,549
1	24,880	21,055	18,175	1,260	2,079	1,033	3,664	448	655	2,330	1,531	182	62	424	308	74,657	3,429
2	24,038	20,343	17,560	1,217	2,009	998	3,540	432	633	2,251	1,479	175	60	410	298	72,133	3,313
3	23,226	19,655	16,966	1,176	1,941	964	3,421	418	612	2,175	1,429	169	58	396	288	69,693	3,201
4	22,440	18,990	16,393	1,136	1,875	932	3,305	404	591	2,102	1,381	164	56	383	278	67,337	3,092
5	21,681	18,348	15,838	1,098	1,812	900	3,193	390	571	2,031	1,334	158	54	370	269	65,059	2,988
6	20,948	17,727	15,303	1,061	1,751	870	3,085	377	552	1,962	1,289	153	53	357	259	62,859	2,887
7	20,240	17,128	14,785	1,025	1,692	840	2,981	364	533	1,896	1,245	148	51	345	251	60,734	2,789
8	19,555	16,549	14,285	990	1,634	812	2,880	352	515	1,832	1,203	143	49	334	242	58,680	2,695
9	18,894	15,989	13,802	957	1,579	784	2,783	340	498	1,770	1,163	138	47	322	235	56,696	2,604
NPV	**221,653**	**187,575**	**161,918**	**11,223**	**18,525**	**9,202**	**32,645**	**3,987**	**5,838**	**20,760**	**13,639**	**1,618**	**556**	**3,780**	**2,746**	**665,118**	**30,546**
NPV/FAD	**58**	**50**	**76**	**12**	**24**	**19**	**247**	**52**	**93**	**427**	**413**	**58**	**80**	**181**	**395**	**55**	**148**

Total cost: $ 695,664

b) For 44,700 deployments per year and discount rate of 3.5% (costs are in US dollars)

Year	Solomon	PNG	Kiribati	Tuvalu	Micronesia	Marshall	Nauru	Australia	Vanuatu	Palau	Fiji	Tokelau	Guam	Cook	Samoa	Total PNA	Total Non PNA
0	17,736	15,009	12,956	898	1,482	736	2,612	319	467	1,661	1,091	129	44	302	220	53,220	2,444
1	17,136	14,501	12,518	868	1,432	711	2,524	308	451	1,605	1,054	125	43	292	212	51,420	2,361
2	16,556	14,011	12,094	838	1,384	687	2,438	298	436	1,551	1,019	121	42	282	205	49,681	2,282
3	15,997	13,537	11,685	810	1,337	664	2,356	288	421	1,498	984	117	40	273	198	48,001	2,204
4	15,456	13,079	11,290	783	1,292	642	2,276	278	407	1,448	951	113	39	264	191	46,378	2,130
5	14,933	12,637	10,909	756	1,248	620	2,199	269	393	1,399	919	109	37	255	185	44,809	2,058
6	14,428	12,210	10,540	731	1,206	599	2,125	260	380	1,351	888	105	36	246	179	43,294	1,988
7	13,940	11,797	10,183	706	1,165	579	2,053	251	367	1,306	858	102	35	238	173	41,830	1,921
8	13,469	11,398	9,839	682	1,126	559	1,984	242	355	1,261	829	98	34	230	167	40,416	1,856
9	13,013	11,012	9,506	659	1,088	540	1,917	234	343	1,219	801	95	33	222	161	39,049	1,793
NPV	**152,663**	**129,191**	**111,520**	**7,730**	**12,759**	**6,338**	**22,484**	**2,746**	**4,021**	**14,298**	**9,394**	**1,114**	**383**	**2,604**	**1,891**	**458,098**	**21,038**
NPV/FAD	**58**	**50**	**76**	**12**	**24**	**19**	**247**	**52**	**93**	**427**	**413**	**58**	**80**	**181**	**395**	**55**	**148**

Total cost: $479,136

- **when NER FADs are used**
  (Net Present Value (NPV) by beaching EEZ and per FAD)

c) For 64,900 deployments per year and 3.5% discount rate (costs are in US dollars)

Year	Solomon	PNG	Kiribati	Tuvalu	Micronesia	Marshall	Nauru	Australia	Vanuatu	Palau	Fiji	Tokelau	Guam	Cook	Samoa	Total PNA	Total Non PNA
0	2575	2179	1881	130	215	107	379	46	68	241	158	19	6	44	32	7727	355
1	2488	2105	1817	126	208	103	366	45	66	233	153	18	6	42	31	7466	343
2	2404	2034	1756	122	201	100	354	43	63	225	148	18	6	41	30	7213	331
3	2323	1965	1697	118	194	96	342	42	61	218	143	17	6	40	29	6969	320
4	2244	1899	1639	114	188	93	331	40	59	210	138	16	6	38	28	6734	309
5	2168	1835	1584	110	181	90	319	39	57	203	133	16	5	37	27	6506	299
6	2095	1773	1530	106	175	87	309	38	55	196	129	15	5	36	26	6286	289
7	2024	1713	1479	102	169	84	298	36	53	190	125	15	5	35	25	6073	279
8	1956	1655	1429	99	163	81	288	35	52	183	120	14	5	33	24	5868	269
9	1889	1599	1380	96	158	78	278	34	50	177	116	14	5	32	23	5670	260
NPV	22165	18757	16192	1122	1852	920	3265	399	584	2076	1364	162	56	378	275	66512	3055
NPV/FAD	6	5	8	1	2	2	25	5	9	43	41	6	8	18	39	8	21

Total cost: $ 69,566

d) For 44,700 deployments per year and discount rate of 3.5% (costs are in US dollars)

Year	Solomon	PNG	Kiribati	Tuvalu	Micronesia	Marshall	Nauru	Australia	Vanuatu	Palau	Fiji	Tokelau	Guam	Cook	Samoa	Total PNA	TotalNonPNA
0	1,774	1,501	1,296	90	148	74	261	32	47	166	109	13	4	30	22	5,322	244
1	1,714	1,450	1,252	87	143	71	252	31	45	160	105	13	4	29	21	5,142	236
2	1,656	1,401	1,209	84	138	69	244	30	44	155	102	12	4	28	21	4,968	228
3	1,600	1,354	1,169	81	134	66	236	29	42	150	98	12	4	27	20	4,800	220
4	1,546	1,308	1,129	78	129	64	228	28	41	145	95	11	4	26	19	4,638	213
5	1,493	1,264	1,091	76	125	62	220	27	39	140	92	11	4	25	19	4,481	206
6	1,443	1,221	1,054	73	121	60	213	26	38	135	89	11	4	25	18	4,329	199
7	1,394	1,180	1,018	71	117	58	205	25	37	131	86	10	3	24	17	4,183	192
8	1,347	1,140	984	68	113	56	198	24	35	126	83	10	3	23	17	4,042	186
9	1,301	1,101	951	66	109	54	192	23	34	122	80	10	3	22	16	3,905	179
NPV	15,266	12,919	11,152	773	1,276	634	2,248	275	402	1,430	939	111	38	260	189	45,810	2,104
NPV/FAD	6	5	8	1	2	2	25	5	9	43	41	6	8	18	39	5	15

Total cost:$47,914

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