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Pacific dFAD retrieval feasibility study

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Executive Summary

This report presents a study, in partnership with fishing companies, satellite buoy providers, and funded by The Nature Conservancy (TNC), to identify and evaluate options for reducing drifting Fish Aggregating Devices (dFADs) loss, thereby reducing associated ecosystem impacts. The study investigates the spatial and temporal dynamics of dFAD use and fate, specifically when drifting out of fishing areas, using historical buoy tracking data extending over 10 years (2010–2019) and encompassing both the Western and Central Pacific Ocean (WCPO) and the Eastern Pacific Ocean (EPO). These data were made available by 19 vessels that participated in the study. These vessels shared operational and geographical characteristics that are not reflective of the entire WCPFC convention area. While this study was able to identify several potential options to reduce dFAD loss, an expanded study with greatly increased vessel participation and geographic scope would allow more complete characterization of the identified options.

Areas with higher dFAD deployments, dFAD density, and four categories of dFAD fate (adrift, lost, recovered and beached), specific to the partner fishing companies, were identified. Different potential options to limit the number of dFADs lost or beached were considered based on the patterns detected. Firstly, deployments could be limited in areas where deployments lead to higher rates of dFAD beaching and deactivation adrift events, potentially leading to a small reduction in dFAD loss and beaching. Secondly, nine spatial boxes surrounding certain islands and with higher rates of beaching and signal loss were identified. Recovering all dFADs transiting through these spatial boxes could lead to a larger reduction in dFAD beaching and a moderate reduction in deactivation adrift events. Thirdly, recovering all dFADs transiting through hotspots of dFAD deactivation, outside main fishing areas, could lead to a larger reduction in both beaching and deactivation adrift events. Finally, recovering dFADs in an area that overlaps the hotspot of deactivation and extended dFAD density area could lead to a moderate reduction in beaching and a low reduction in deactivation adrift events. It should, however, be noted that the number of dFADs entering the fishing grounds after transiting through the potential recovery areas needs to be considered, as well as the number of dFADs transiting per day or month. Follow-up work based on the results from this study could explore the economic feasibility of the dFAD recovery options identified.

Patterns detected in this study correspond to the fishing patterns and distribution of the partner fishing companies, and their operational regions. Hence, this analysis would need to be extended into a feasibility analysis for a broader regional dFAD recovery programme, which would significantly change the economic viability of different mitigation approaches. This study is the first of its kind in terms of the type and scale of data analysed, and the time period investigated. It should therefore be considered as an example of the types of potential investigations that could be carried out at the scale of the WCPO or the whole Pacific which could be promoted by Regional Fisheries Management Organisations.

We invite WCPFC-SC17 to:

- Note this Pacific dFAD retrieval feasibility study, in partnership between SPC, fishing companies, satellite buoy providers and TNC.
- Note the type of data needed and the methods used to consider different potential options to reduce dFAD loss and beaching in the Pacific Ocean.
- Encourage the participation of other WCPFC members in similar dFAD retrieval feasibility studies to identify ways to reduce dFAD loss and beaching at a regional scale.

1. Introduction

The use of drifting Fish Aggregating Devices (dFADs) by industrial purse seiners has raised several concerns linked to the capture of small bigeye and yellowfin tuna, as well as higher bycatch rates than on free schools (Dagorn et al., 2013). Recently, there has also been an increasing focus on the ecosystem impacts of the expanding use of dFADs including marine pollution, ghost fishing and habitat damage through "beaching" of dFADs on the shores and coral reefs of Pacific Island Countries and Territories (PICTs) (Filmalter *et al.*, 2013; Balderson and Martin, 2015; Escalle *et al.*, 2020a). Recent work has estimated that 20,000 to 40,000 dFADs are deployed annually in the Western and Central Pacific Ocean (WCPO) (Escalle et al., 2021a). In addition, some work based upon the position information provided by dFAD satellite buoys (hereafter referred to as "dFADs" in this document) has suggested that only 10% of dFADs are recovered, while at least 7% are beached (Escalle et al., 2021b; Escalle et al., 2019). The growing focus on the issue of marine pollution, beaching and entanglement of Species of Special Interest (SSI) has led to the implementation of management measures regarding the use of low-entanglement risk dFADs and encouragement of the use of biodegradable dFADs (CMM-2018-01). These concerns highlight the need to consider the potential for dFAD retrieval activities to reduce environmental impacts linked to the extensive use of dFADs. However, the practical and economic feasibility of such a programme needs to be evaluated.

This study, in partnership with fishing companies, buoy service providers (Satlink and Marine Instruments) and The Nature Conservancy (TNC), has the objective of evaluating the practical and economic feasibility of retrieving dFADs that have drifted outside areas of normal dFAD fishing activities, with a particular focus on those that have the potential to become beached. This study uses a unique data set of anonymised historical buoy tracking data, from 19 vessels of partner fishing companies in the WCPO and the Eastern Pacific Ocean (EPO), over the last 10 years to identify and evaluate options to reduce dFAD loss and associated ecosystem impacts. This is, therefore, the first study of its kind, in terms of the scale of data analysed (Pacific-wide, complete trajectories), the time period (10-year) and the type of data transmitted (position during active time of each dFAD, date of manual switch off and date of satellite transmission deactivation). It allowed for a better definition of dFAD fates and an evaluation of different options to reduce dFAD loss and beaching. The method presented in this paper provide an example of the types of potential investigations that could be carried out at the scale of the WCPO or the whole Pacific Ocean to explore options to reduce dFAD loss and beaching.

2. Method

The methods used in this study involved three-steps. Firstly, similar to any analyses using dFAD trajectory data (Escalle et al., 2021b), a filtering and processing stage was implemented. Secondly, a spatial and temporal analysis of the data was performed to inform on the patterns of dFAD use, drifting dynamics and fate for the partner fishing companies. Results from this second stage were then used to explore several options to reduce dFAD loss and beaching.

2.1 Data filtering and processing

Ten years of anonymised historical satellite buoy data were received from two satellite buoy providers: Satlink and Marine Instruments. Zunibal, the third buoy brand used by the partner fishing companies, withdrew from the project due to limitations resulting from the Covid-19 pandemic. Updated data received corresponded to all buoys deactivated between 2010 and 2019.

The initial filtering further consisted of:

- removal of buoys activated for short periods to verify functioning and avoid bias in the analyses due to very short overall active time;
- the removal of buoys with less than 10 transmissions;
- removal of buoys active for less than seven days, and;
- removal of buoys with transmissions from a single position.

A Random Forest model was performed to identify on-board and at-sea position and hence identify deployment positions (see method in Escalle *et al.*, 2019). For the sake of simplicity, "dFAD" will be used when referring to the buoys deployed on dFADs in this report.

2.2 Spatial and temporal description of the data

2.2.1 Deployment areas

The spatial distribution of deployment/re-deployment of all dFADs in the available dataset was compiled across the whole Pacific Ocean. Annual and monthly variability was also explored.

2.2.2 DFAD density

DFAD density in the Pacific Ocean across all years and dFADs (individual dFADs were only counted once per 1° cell) was also examined, as well as the annual and monthly variability.

2.2.3 Signal loss

Locations of the last transmissions of individual dFADs, referred to hereafter as "signal loss", were investigated. These were identified as: i) last position of a trajectory if the signal loss occurred while the dFAD was drifting at-sea (as identified by the Random Forest model mentioned above); or ii) last recorded at-sea position of the trajectory if the signal loss was recorded on-board a vessel (i.e., location of the dFAD immediately before being picked up by a vessel).

A focus was then placed on 1° cells (~12,321 km^2 or 3,600 nm^2 at the equator) having higher rates of signal loss (i.e., > 0.9 quantile). Spatial boxes representing higher numbers of signal loss were then defined, with the objective to cover all the high signal loss cells in one specific area, but to maintain the smallest possible area. Temporal variability in signal loss was investigated at different scales.

2.2.4 Fate of dFADs

DFAD positions at the end of their trajectories were investigated to study the fate of dFADs. The end of a trajectory (i.e., last position recorded) was classified as: i) beached if the last position was "at-sea" and within 10 km of shore (excluding positions located at less than 10 km from major ports) and at least the last three positions were at 0 m, <10 m, or <100 m from each other; ii) recovered if the last position was "on-board"; iii) still at-sea.

To further investigate the fate of dFADs identified as still drifting at-sea at the end of their trajectories, additional information was used to differentiate dFADs remotely deactivated while still adrift (hereafter, "deactivated adrift" event) from dFADs that were simply lost (i.e., unintentional loss of signal). The latter category would include the appropriation of the dFAD by another vessel, the sinking of the dFAD, or buoy malfunction. It could also include the recovery of the dFADs with the buoy rapidly switched off, which would be reclassified as recovered. While the study could not determine the percentage of lost dFADs that were actually appropriated by another vessel, this is expected to be higher than sinking or buoy malfunction events. Ultimately, the fate of dFADs after deactivation remains uncertain, as they may be picked up, sink or beach. We also note that, in this study, it was not possible to determine whether the buoy was still attached to a dFAD when deactivated. In particular, when encountered by non-owner vessels, buoys are commonly detached from dFADs and set adrift, while the dFADs are normally repurposed, by replacing the buoy, reusing materials, or redeploying in other areas.

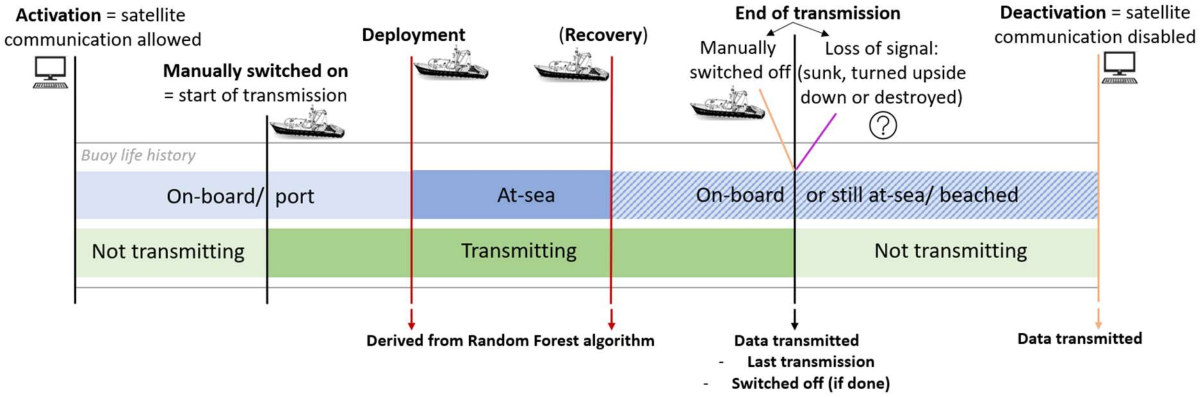

Figure 1. Visual representation of the life-history of a buoy, from activation to deactivation, with an emphasis on time spent at-sea or on-board (blue) and spent transmitting or not (green).

For the Satlink buoys, the date of satellite transmission deactivation and the date of manual switch off, if it occurred, were available (Figure 1). For Marine Instruments buoys, only the date of satellite transmission deactivation was available. If a date of manual switch off was available, the dFAD was considered as recovered. If no manual switch off date was available and the date of satellite transmission deactivation was within five days of the last known position, the dFAD was considered to have been deactivated and left adrift by fishers. Finally, if the date of satellite transmission deactivation was more than five days from the last known position, it was considered that fishers had lost communication with the buoy, for an unintentional reason, and therefore was classified as lost.

At the scale of the Pacific Ocean, most dFADs (80.9%) were still drifting at-sea at the end of their trajectories, with 46.5% of dFADs classified as lost and 34.4% as deactivated adrift events (Table 1). 12.2% of dFADs were recovered and 6.9% beached. Some differences were detected between the WCPO and the EPO, as shown in Table 1.

Table 1. Fate of dFADs in the WCPO and EPO, as indicated by the position of the dFAD last transmitted position.

	WCPO (%)	EPO (%)	Total (%)
Deactivated adrift	40.0	14.4	34.4
Lost	39.8	70.6	46.5
Recovered	12.4	11.6	12.2
Beached	7.9	3.4	6.9

2.3 Potential options to reduce dFAD loss and beaching

Based on the results obtained from the spatial and temporal description of the 10-year data set across the whole Pacific Ocean, several options were considered to reduce dFAD loss and beaching:

1. **Areas where deployments may lead to higher rates of dFAD loss and beaching events were explored.**

The spatial distribution of deployments/re-deployments from dFADs found beached in the WCPO and EPO, and from dFADs transiting in spatial boxes with higher rates of signal loss was explored.

2. **Recoveries in areas close to shore where high rates of beaching and signal loss were detected were also considered.**

The spatial boxes with higher rates of signal loss previously identified were considered as potential dFAD recovery areas close to shore.

3. **Oceanic areas linked to high rates of dFAD deactivation were considered for inclusion in a regional dFAD recovery programme.**

Given the limited number of final dFAD positions in the current dataset and the large spatial extent, the spatial distribution of the daily positions of each dFAD one month before remote deactivation was considered to further identify spatial hotspots of dFAD deactivation adrift events, and was compared to the extended dFAD density hotspot.

4. **Recovery of dFADs by purse seiners at the edge of the main fishing areas, before they are remotely deactivated was also considered.**

The overlap area between the dFAD deactivation adrift hotspots and the extended dFAD density hotspot was considered as a potential purse seiner recovery area.

For each area identified under these four options, the size of each area was calculated. The percentage of dFADs deployed or transiting in each area was compiled, as well as the percentage of dFADs deployed or transiting through each area that later entered the extended dFAD density hotpsot, as an indication of the use of these dFADs by fishing vessels. The potential reduction in dFAD beaching and deactivation adrift events, if no deployment was performed or if all dFADs transiting through the identified areas were recovered, was then calculated.

3. Summary results from potential options to reduce dFAD loss and beaching investigated

Several limitations were linked to the options considered: i) the sample size is currently too small (limited number of vessels and geographic distribution) to be representative of the Pacific Ocean dFAD fishery; and ii) each option is optimistic, representing the best-case scenario for each. In addition, additional analyses regarding economics and practicality need to be performed. Theoretical percentages of dFAD loss and beaching reduction for each recovery scenario were compiled, but given the limitation mentioned, the confidential nature of the data and the lack of study, to date, regarding practicality and economics of the options considered, these are not shown in this report. Preliminary results are therefore presented as relative importance (*; ** or ***) of reduction of potential beaching and deactivation adrift events.

The results presented here are indicative of potential areas in which further study using expanded data could help to refine and put forward as potential options moving forward for the region.

3.1.1 Reduce deployments in some areas

Three areas where dFAD deployments or redeployments lead to higher rates of beaching and deactivation adrift events were identified. Two were in the WCPO and one in the EPO. 0.9% to 3.7%

of dFAD were deployed in these areas(Table 2). However, most dFADs deployed in the one area entered the dFAD density hotspot (71.3%) and would likely be used by fishers (Table 2).

Table 2. Percentage of dFAD deployments in the deployment spatial boxes and potential reduction in beaching and deactivation adrift events if deployment is reduced in these zones.

Deployment spatial boxes	Area covered (nm^2)	% of all deployments/ re-deployments made in each area	Potential beaching reduction	Potential reduction in deactivation adrift events	% of deployed dFADs entering the dFAD density hotspot
WCPO 1[1]	215,536	3.7%	*	*	71.3%
WCPO 2[1]	215,536	0.9%	*	*	17.2%
EPO 1[1]	1,005,836	2.0%	*	*	17.6%

[1]Based on the total number of signal loss, beaching and deactivation adrift events in the whole Pacific. Note that the percentages per spatial boxe are non-additive.

3.1.2 Recoveries close to shore

Nine spatial boxes with higher signal loss events were detected, all in the WCPO. 29.5% of all dFADs in this study transited at least once through any of these spatial boxes (Table 3). Two spatial boxes had 35.0% and 15.2% of dFADs transiting through that later drifted into the extended dFAD density hotspot, while for the others this represented less than 1.5% (Table 3). Most dFADs transited the boxes within a few days up to three weeks, with a few areas showing longer transit times.

Table 3. Percentage of dFADs transiting in the identified high signal loss spatial boxes and potential reduction of dFAD beaching and deactivation adrift events if all dFADs transiting in these zones were recovered.

High signal loss spatial boxes	Area covered (nm^2)	% of all dFADs that transited in the area	Potential beaching reduction	Potential reduction in deactivation adrift events	% of transiting dFADs returning to dFAD density hotspot
Box 1[1]	14,369	8.3%	*	*	35.0%
Box 2[1]	43,107	7.4%	*	*	1.3%
Box 3[1]	43,107	6.6%	*	*	15.2%
Box 4[1]	28,738	4.2%	*	*	0.4%
Box 5[1]	53,884	4.1%	*	*	0.7%
Box 6[1]	43,107	3.6%	*	*	3.3%
Box 7[1]	14,369	3.4%	*	*	2.2%
Box 8[1]	3,592	3.0%	*	*	0.9%
Box 9[1]	86,215	2.7%	*	*	0.0%

[1]Based on the total number of signal losses, beachings and deactivation adrift events in the WCPO only. Note that the percentages per spatial boxe are non-additive.

3.1.3 Oceanic recoveries outside fishing areas

Two large hotspots of dFAD deactivation adrift events were identified, one in the southern WCPO and a second in the north straddling the WCPO and the EPO. A total of 41.3% and 9% of dFADs transited the southern and the northern hotspots (Table 4). 7.1% and 1.5% of these dFADs then re-entered the extended dFAD density hotspot, highlighting the fact that the vast majority of them are already lost to the fishery when transiting the hotspots of deactivation adrift events.

Table 4. Percentage of dFADs transiting the identified hotspots of dFAD deactivation adrift events and potential reduction of dFAD beaching and deactivation adrift events if all dFADs transiting in these zones were recovered.

Hotspot region	Area covered (nm^2)	% of all dFADs that transited in the area	Potential beaching reduction	Potential reduction in deactivation adrift events	% of transiting dFADs returning to dFAD density hotspot
Southern hotspot[1]	2,069,148	41.3%	***	***	7.1%
Northern hotspot[2]	772,338	9.0%	*	**	1.5%

Using the number of signal losses, beachings and deactivation adrift events in [1] the WCPO only and [2] the whole Pacific. Note that the percentages per region are non-additive.

3.1.4 Oceanic recoveries within fishing area

A potential purse seiner recovery area was considered covering the overlapping area between the southern hotspot of dFAD deactivation adrift events and the extended dFAD density hotspot. 34.1% of all dFADs in this study transited through this area, with 38.0% of them re-entering the dFAD density hotspot (Table 5). While dFADs in this area could be recovered after a fishing set, if recovery occurred during time spent in transit, it was noted that this would infer a fishing day under current regional management limits.

Table 5. Percentage of dFADs transiting in the potential purse seiner recovery area and potential reduction of beaching and deactivation adrift events if all dFADs transiting in this area were recovered.

Recovery area	Area covered (nm^2)	% of all dFADs that transited in the area	Potential beaching reduction	Potential reduction in deactivation adrift events	% of transiting dFADs returning to dFAD density hotspot
PS recovery area[1]	574,763	34.1%	***	**	38.0%

[1] Using the number of signal loss, beaching and deactivation adrift events in the whole Pacific.

4. Conclusion and potential next steps

This paper describes the method implemented in a recent study in partnership between SPC, fishing companies, satellite buoy companies and TNC, to evaluate the feasibility of a dFAD recovery programme. The availability of a unique and complete 10-year buoy position dataset from 19 vessels allowed a detailed spatial and temporal analysis of dFAD movement dynamics. In addition, access to additional information, such as the date of manual switch off and date of satellite transmission deactivation, allowed better determination of dFAD fate and, in particular, a discrimination between dFAD loss and dFADs remotely deactivated while adrift. Areas with higher dFAD deployments, dFAD density, and each category of dFAD fate (deactivation adrift, loss, recovery, and beaching) were identified. Purposefully, the patterns identified in the study were not described in detail in this report, respecting the confidential nature of the data used. However, based on the patterns detected, different potential options to limit dFAD loss and beaching were considered. Given the limitations mentioned previously of a small sample size and best-case scenario considered for each option, theoretical percentages of dFAD loss and beaching reduction were not presented here. In addition, additional analyses regarding economics and practicality need to be performed.

Multiple approaches may be needed to limit dFAD loss and beaching while also limiting the impact on the fishing operations and dFAD use. While some options could be considered by the partner fishing companies, others would need to be considered at a regional scale (WCPFC Convention Area or whole Pacific Ocean). The patterns detected here correspond to the fishing patterns and vessel distribution of the partner fishing companies. A more complete portrayal of dFAD movement dynamics and a refined feasibility analysis for a regional dFAD recovery programme would result from the contribution of a larger number of fishing companies and more comprehensive buoy dataset. A similar approach with data from multiple fleets across the region would allow better characterisation of the potential efficacy of measures that might be implemented to reduce dFAD loss and beaching, while allowing a more realistic evaluation of their feasibility.

A first option considered is to limit deployments in three areas that led to higher rates of dFAD beaching and deactivation adrift events. A second option is to recover dFADs transiting nine spatial boxes close to shore where high rates of beaching and signal loss were detected. A third option considered is the recovery of dFADs that have drifted outside the main fishing areas but are still in oceanic waters. The last examined option was for purse seiners to recover dFADs at the edge of their fishing grounds; in one area overlapping a hotspot of dFAD deactivation adrift events and the dFAD density hotspot. The comparison in terms of size, potential reduction in beaching and deactivation adrift events, cost and potential implementation are shown in Table 6.

Table 6. Summary table with area covered and potential reduction in beaching and deactivation adrift events for the different potential options considered.

Option	Area	Potential reduction in		Cost	Partners	Implementation
		beaching	deactivation adrift events			(position sharing)
Deployment reduction in 3 areas	**	*	*	Null	0	-
DFAD recovery in 9 coastal areas	*	***	**	**	In PICTs	DFADs entering boxes
DFAD recovery in 2 oceanic areas	***	***	***	***	Independent organization	DFADs outside fishing grounds
Purse seiners recovery area	*	***	**	*	Fishing companies	DFADs Lost or deactivated adrift

These potential options considered here included modification in fishing activities and dFAD recovery programs. Modification of fishing activities could include reducing or avoiding deployments in some areas or the recovery of dFADs by purse seiners, if possible, under the current regional management regime, at the edge of their fishing grounds. Fishing companies should encourage fishers to recover dFADs that will likely drift outside fishing grounds, after a fishing set for instance. To make such recovery more effective, positions of dFADs that will drift outside fishing grounds could be shared amongst different fishing companies, so that the closest vessel could recover it. Some additional analysis could assess whether information on individual dFAD deployment history and current position could be used by companies to direct vessels to recover dFADs likely to soon drift out of the fishing grounds as they set on them or when they are close by.

DFAD recovery options, that include non-purse seiners, could also be considered but likely at a regional scale only. This could either include some kind of “dFAD watch” system to recover dFADs close to shore, or other vessels recovering dFADs in oceanic areas. DFAD watches in several countries would be expensive and complicated, hence involvement by fishing companies could be considered essential for such a system to work. It should also be noted that for some PICTs, the recovery might only be possible very close to shore, depending on the type of vessels available. Recovery of dFADs in large oceanic areas would also be expensive; such a recovery programme would therefore need to be considered at a regional scale to be cost effective. However, this may require an independent organisation having access to positions of dFADs entering an area or considered by vessels as lost or outside fishing grounds. Regional organisations could be considered to play this role. Other vessels operating in the region, such as longliners, could potentially be involved by matching in real-time, Vessel Monitoring Systems (VMS) position and trajectories of dFAD's outside fishing areas, and developing an automated process of alerting skippers. In both the dFAD watch and oceanic recovery programmes, the recovered buoys could be returned to the owner, as a cost recovery option.

Additional investigations are needed to identify the possibilities for dFAD retrieval efforts. This could include the capacity of PICTs, including the potential partners, available vessels, reception facilities, and opportunities for dFAD recycling and disposal in proximity of ports. In addition, economic analyses are needed to investigate the preliminary cost estimate for a recovery project and explore cost recovery options such as resale of dFAD buoys, sale of recovered dFAD material to recyclers, and surcharges on dFAD buoy sales and services. Practicality of dFAD recovery by purse seiners or other vessels should also be considered, in terms of number of vessels present, distance, time and fuel needed. This would allow for refined estimates of the reduction in dFAD beaching and deactivation adrift for each option considered, that could be compared to the optimistic case assessed in this study. It should be noted that the number of dFADs entering the fishing grounds after transiting through the potential recovery areas needs to be considered, as well as the number of dFADs transiting per day or month. Increased participation by a broader group of vessels as well as follow-up work based on the results from this study could further refine the practicalities of implementing such measures.

Finally, additional data collection and analyses could also be considered. First, some of the dFAD deactivations considered in this study might include dFADs transferred to another vessel from non-partner fishing companies. Second, better determination when a buoy is adrift without an associated dFAD is needed. This could be identified through a comparison of drift speed and drift pattern between known cases where a buoy is alone and where a buoy attached to a dFAD. As events where the buoy is known to have become unattached may be a reason for deactivating a buoy, a questionnaire for vessel captains could be developed to gain a better understanding of how they make a decision to deactivate a buoy. Third, accessing buoy position data of dFADs after the time that they would normally be deactivated by fishers would complement the analyses performed in this study, by ground-truthing the patterns identified here using the historical data, and allowing identification of final dFAD fate, after deactivation at-sea.

An expansion of the current study to the whole WCPFC Convention Area or, ideally, the whole Pacific Ocean, with a larger and more comprehensive dataset from multiple fleets, should be promoted. While many dFAD recovery options will not be feasible with only a limited number of fishing companies, the analyses and method described in the paper could be extended to study the feasibility of different options to reduce dFAD loss and beaching at a regional scale.

We invite WCPFC-SC17 to:

- Note this Pacific dFAD retrieval feasibility study, in partnership between SPC, fishing companies, satellite buoy providers and TNC.
- Note the type of data needed and the methods used to consider different potential options to reduce dFAD loss and beaching in the Pacific Ocean.
- Encourage the participation of other WCPFC members in similar dFAD retrieval feasibility studies to identify ways to reduce dFAD loss and beaching at a regional scale.

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