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Preliminary analyses of PNA FAD tracking data from 2016 and 2017

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Executive Summary

This paper presents preliminary data analyses from the PNA's FAD tracking programme, investigating research areas such as FAD densities in time and space, beaching events, dynamics around the WCPO FAD closure and some initial FAD life-history information. The 'cleaned' dataset discussed in this paper contained 7.4 million transmissions from FADs between January 1st 2016 and May 11th 2017. A general increase in FAD transmissions over this time was detected, potentially reflecting higher rate of tracking data provision by fishing companies. Nevertheless, it is likely that this dataset represents a sub-set of deployed FADs, and has been modified by fishing companies prior to submission to the PNA.

Spatial locations of transmission are dispersed over most areas of the tropical WCPO, with higher FAD densities in the southern part of Nauru and Kiribati's EEZs and the Bismarck Sea in 2016, and Papua New Guinea's EEZ in 2017. These areas of higher FAD densities appear to match the main FAD fishing areas by month but no pattern with CPUE could be distinguished by tuna species or year.

Examining the 2016 FAD closure period, a peak in transmissions before and reduced transmission rates during the closure were found. A second transmission peak occurred at the end of the third closure month, with transmissions slowly increasing until the end of the fourth month. The number of unique FAD transmitting by day decreased during the 4-month closure period, potentially indicating that some FADs are not 'located' at all by fishers during the closure or that data were not provided to PNA.

Potential locations of beaching events were examined. 641 FADs (3.7% of FADs) 'beached', with relatively high occurrences in Kiribati, Tuvalu and Papua New Guinea. Preliminary investigation of historical tracks of those beached FADs indicated the potential to identify deployment areas, and drifting patterns once verified deployments could be identified.

Combining FAD tracking, logsheet and observer data may help studies of the dynamics of setting, deployment, recovery, appropriation and/or loaning/trading events of FADs. Using a data sub-set, fishing sets performed in the vicinity of transmitting FADs, multiple deployments of FADs by the same vessel, and FAD appropriations have been identified. However, additional data processing is needed before expanding analyses to the whole dataset. Identification of at-sea and on-board transmissions is essential. A first indicator of these is the speed between two transmissions. Most FAD speeds ranged between 0 and 5 km/h (74% of the data), which may correspond to a drifting speed. 6% of data indicated speeds between 5 and 30 km/h (2.7 to 16.2 knots) consistent with vessel cruising and slow speeds. However, speed alone may incorrectly classify a FAD as drifting when on a vessel that is setting, investigating a tuna school, or drifting at night.

This data set offers clear potential to enhance our understanding of the operational use of drifting FADs and the ecosystem interactions they drive, and provide useful advice to inform management.

We invite WCPFC-SC13 to:

- Note this preliminary PNA FAD tracking data analysis and the suggestions for further analyses.
- Note the importance of complete FAD tracking data to support scientific analyses and encourage their provision by fishing companies.
- Noting on-going WCPFC considerations, further discuss the importance of unique FAD and buoy marking and monitoring programmes to better identify and follow individual FADs.

Introduction

The use of drifting Fish Aggregating Devices (FADs) by tropical tuna purse seiners has increased globally in the last few decades, particularly with the arrival of new technological developments to track FADs such as satellite and echo-sounder buoys (Fonteneau et al., 2013; Lopez et al., 2014). In the Western and Central Pacific Ocean (WCPO) the number of FADs deployed was estimated at more than 30,000 per year in 2013 (Gershman et al., 2015) and considered likely to have increased every year since. The high capture of juvenile bigeye tuna on FAD associated sets (Harley et al., 2015) has led the Parties to the Nauru Agreement (PNA) and WCPFC to implement a three to four month FAD closure where all FAD-related activities (e.g. fishing, deployment) are prohibited (e.g. CMM-2016-01). However, the number of active buoys at any time and the precise number of FAD deployments per year is currently unknown.

The PNA initiated a FAD tracking trial in 2016, which tracked satellite buoys attached to drifting FADs associated with purse seine vessels, with an aim of improving the understanding of the use of FADs and their impacts. The objectives of the trial are:

a) improved understanding of the use of FADs,
b) better scientific information on the impacts of FADs and fishing on them,
c) enhanced compliance and control relating to FADs,
d) better understanding of the economics of FAD use, and
e) enhanced FAD management options.

This paper presents the first analysis of FAD satellite transmissions for the period 2016 into 2017, including position and time stamps, in the WCPO.

Satellite buoys are deployed by fishers on any floating object (drifting FAD or log) but may be activated from a few hours to several weeks before deployment (i.e. when leaving port). Once activated, the transmission time step is adjusted by fishers depending on the intended use of a FAD, and therefore varies between and within FADs. A buoy deployed on a FAD may be retrieved afterwards by the same vessel or another (appropriation from vessels of another company) and can be re-deployed several times, or if they drift out of productive areas their transmissions may be stopped. Tracks examined in this dataset reflect the life-history of a buoy, rather than the FAD on which it was initially deployed, but for the sake of simplicity the term 'FAD transmissions' is used for all of these in the rest of the paper. The objective of this preliminary study was to identify the data processing of the FAD transmission dataset required and to examine different aspects of FAD fishing and of FAD drifting behaviour at sea. It describes the data available, patterns of FAD density, and temporal dynamics around the 2016 FAD closure period, assesses the potential for the data to indicate FAD beaching events, examines whether the data can provide information on the life history of a FAD, and highlights some of the further work that may be undertaken.

Tracking data and pre-processing

The dataset presented and analysed in this paper comprises drifting FAD locations and time stamps from January 1st 2016 to May 11th 2017. In addition to location and time, the dataset includes the fishing company each FAD buoy belongs to, course direction, water temperature and drifting speed. Water temperature and speed data appear highly variable, and instrumentation may be inconsistently calibrated among vessels. These data are therefore felt unlikely to be informative in their current form.

Information on the vessel deploying the FAD is also missing. It should be noted that FAD transmissions data are reported to PNA with a delay (few days to several weeks).

The raw data contained a total of 8.3 million transmissions from 18,648 unique FADs. Transmissions from unique FADs (1301) associated to multiple fishing companies were removed as these may be due to entry or export errors or potentially reflect appropriation of FADs found drifting at sea by vessel from another fishing company. Such change in ownership of buoy and/or FAD requires further investigation.

The selected dataset contains transmissions from 17,347 FADs (7.4 million transmissions) from 159 fishing companies. A general increase in FAD transmission over time was detected (Figure 1), which may simply reflect higher rates of reporting. Peaks in transmissions at the end of several months are noted. This could reflect either real checking of FAD position by fishers or may be an artefact of the data. Data transmission rates are irregular and vary between and within FADs, depending on each vessel strategy at a given FAD (e.g. when approaching a FAD's location and performing a set the time step between transmissions may be shorter). Nevertheless, most transmission intervals were every hour or day (see Figure A1 in Appendix).

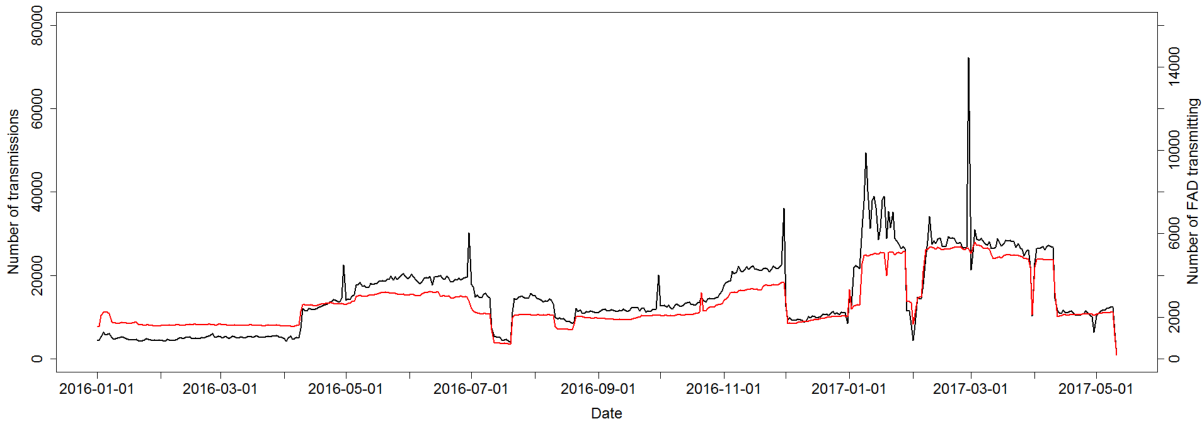

Figure 1. Number of transmission (black line) and unique FAD transmitting (red line) by day.

Spatial locations of transmissions are dispersed over most areas of the tropical WCPO (Figure 2). Note that in some areas the density of tracks appears low due to data being 'geo-fenced' by companies, with information outside specific EEZ boundaries being removed before data transmission (see Figure A2 for a FAD track with geo-fenced positions). This is especially the case for transmissions after March 2016. This editing of the data affects the geographic pattern of information, adding a bias in density analysis and makes it challenging to identify FAD deployments.

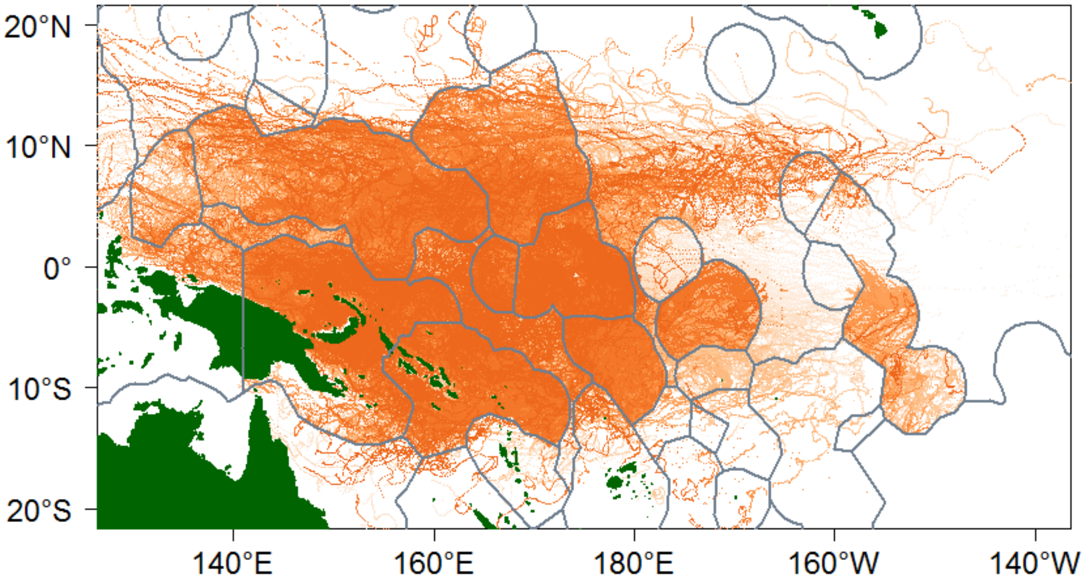

Figure 2. Position of unique FADs transmitting at least once per 1° degree grid cell during the study period. Colour of track provides an indication of the month of the track (from light orange in January and to the darkest shade in December).

FAD densities

Density maps of all unique FADs transmitting at least once per 1° grid cell were derived from the pre-processed dataset (Figure 3). Higher FAD densities are found in the southern part of the Nauru EEZ, Kiribati's Gilbert Islands EEZ, and in the Bismarck Sea in 2016, and in Papua New Guinea's EEZ in 2017. Transmissions from FADs on board vessels (at port or at sea) are however still present in this dataset, potentially adding noise to these density maps. Main areas of high FAD density match areas of higher number of associated sets (drifting FAD and log, see Figures A3 and A4) in 2016 (South of Nauru and Kiribati EEZ) but not in 2017. In addition, no pattern between FAD density and CPUE could be distinguished for each tuna species or year (Figures A5 and A6). Further analysis on CPUE and FAD density could be performed by month and area (i.e. EEZ). However, this will be more appropriate once transmission data have been processed further by identifying at-sea and on-board positions. Nevertheless FAD densities and associated sets by month already show some interesting matching patterns (Figures A7 and A8).

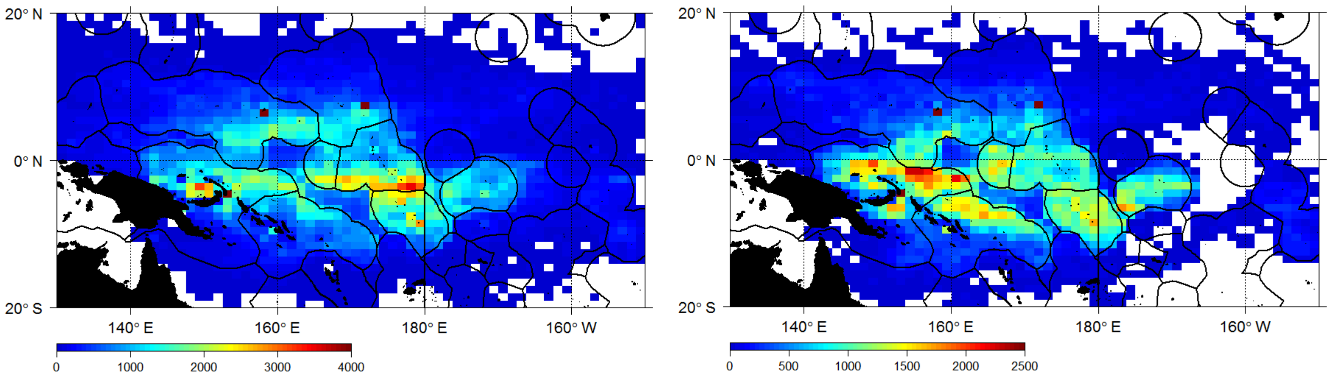

Figure 3. Density of FADs transmitting at least once per 1° degree grid cell during 2016 (left) and 2017 (right).

Temporal dynamics around the 2016 FAD closure period

Transmission activity for all FADs around the FAD-closure in 2016 shows some interesting patterns (Figure 4). First, a peak in transmission is detected on June 30th, as fishers may have wished to locate all their FADs before the closure. Second, two dips in FAD transmission occur mid-July and mid-August. Third, a second peak in transmission is detected at the end of September, at the end of the 3rd month of the closure period when fishers (potentially those who selected the 3-month closure and overall FAD set limit) locate all their FADs. Finally, the number of transmissions slowly increases through October (4th month of closure for some vessels) back to the pre-closure level at the beginning of November. The number of unique FADs transmitting by day drops to ~2000 at the beginning of the closure and increases again to the same previous level (~3500) at the end of the 4th month (the two dips mid-July and mid-August are also present here). This indicates that during the closure some FADs may have not been checked at all by fishers or that their transmission data during the closure was not provided to PNA, while others still transmitted regularly. This varies between fishing companies and FADs within the same company (e.g. a FAD only in the main fishing area may still be tracked by that company during the closure).

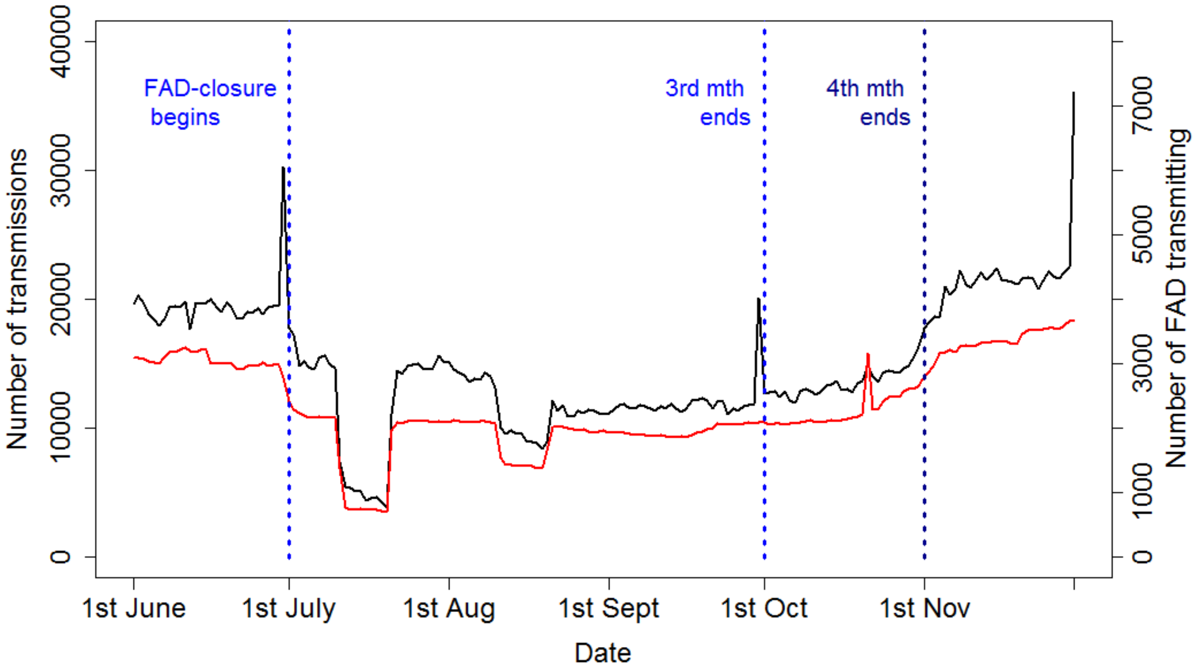

Figure 4. Number of transmissions (black line) and unique FAD transmitting (red line) by day around the FAD-closure period in 2016 (1st of June through 30th of November).

Potential beaching of FADs

Beaching events, where a FAD may have come into contact with the shoreline or offshore reef areas, were identified from the pre-processed dataset by i) removing positions located 10km from major ports, and ii) identifying FADs having at least their three last positions in the same location within 10 km of shore. The resulting data set represented 641 FADs, i.e. 3.7% of all FADs transmitting during the study period. Beaching occurred on most islands throughout the main purse-seine fishing grounds (Figure 5), but higher potential occurrences in 2016 and 2017 were located in Kiribati (mainly in the Gilbert Islands), Tuvalu and Papua New Guinea.

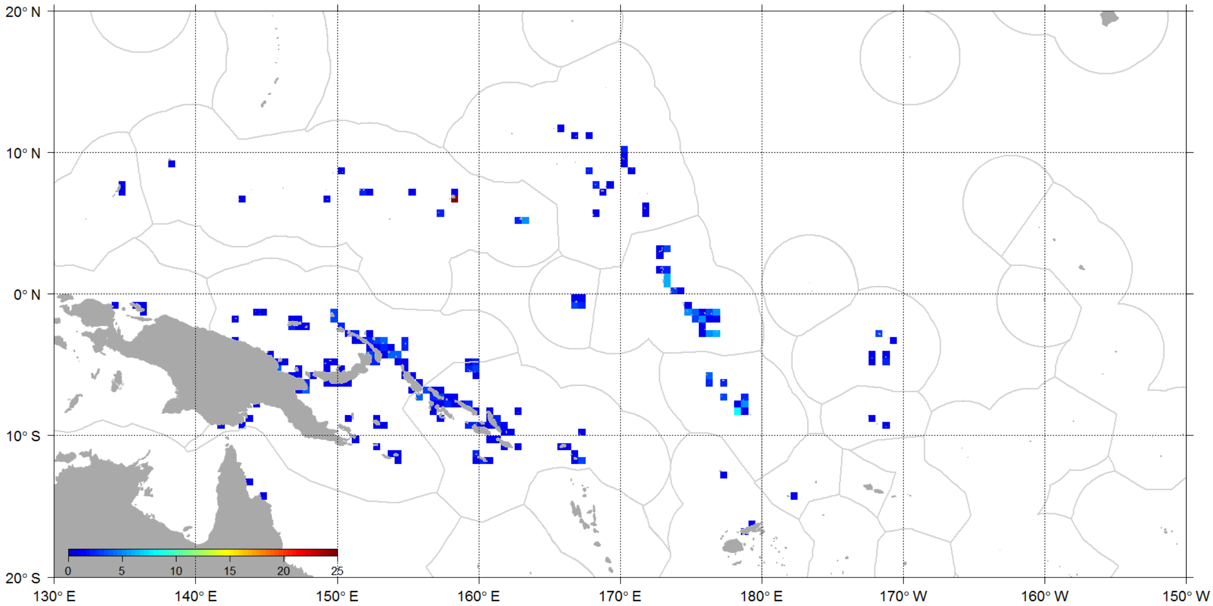

Figure 5. Density of FAD beaching (three last transmissions at the same position and within 10km of the shore) events by 1° grid cell over the study period.

Some individual tracks of FADs that may have beached are shown in Figure 6. The large gap in the track of the two first FAD tracks corresponds to the FAD closure (July to September), during which these FADs did not transmit. The position of the first FAD after the closure ended suggested that it was beached (Figure 6a), and this FAD only transmitted again for a few days before it may have been disabled or turned off. The FAD in Figure 6d was deployed in February 2016. The first few transmissions indicate that the FAD may have still been on-board (gaps between transmissions), followed by a clear shift in transmission locations when drifting at-sea (Figure 6d).

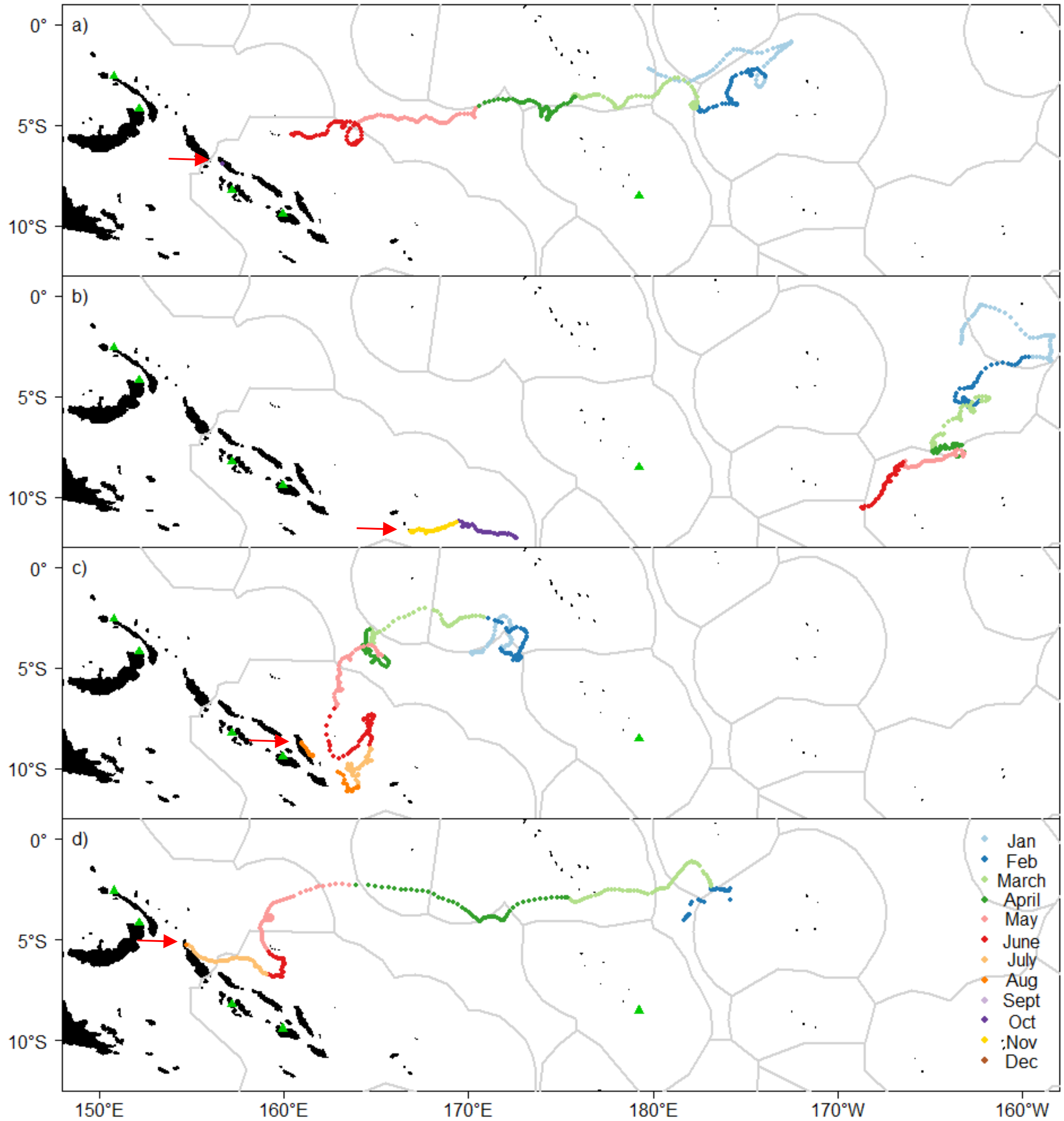

Figure 6. Track of four drifting FADs that transmitted from a) January to October 2016, b) January to November 2016, c) January to August 2016 and d) February to August 2016 and considered beached at the last position. Red arrows represent beaching positions, green triangles major ports.

Examining FAD life history

FAD life history was analysed through an assessment of the associated dynamics of setting, deployment, recovery, appropriation and/or loaning events by following a single buoy. This could be done by combining tracking data, logsheet data (fishing sets), observer data (vessel position for every recorded activity, FAD deployment and recovery) and VMS data. The key challenges remain:

- absence of vessel name in the FAD tracking data;
- lack of a unique identification on FADs that can be followed through time and associated with a setting event; and
- differences between the rate of FAD position transmission and the location and time of a fishing set.

To investigate the last challenge, we first matched FAD positions from the 'beaching analysis' data set with associated set positions (logsheet data) on the same date and used varying distances from a FAD location transmission. Exact matching positions were very rare (5 sets), but 400 associated sets were found within 2km of a recorded FAD position (145 unique FADs out of the 641 considered FADs, i.e. 23%). Secondly, for identified vessels that had completed that set, all positions recorded by observer, along with FAD deployments and recovery events within the corresponding trip were superimposed on the FAD transmission positions. An example of this is given in Figure 7. Several fishing sets were performed in the same area of the transmitting FAD, but looking at the FAD's track, it is clear that the FAD must have been on-board at the time of these sets (in February), then deployed at the beginning of March. Some FAD deployments from that vessel were also identified but did not match the first 'drifting position'. We also identified multiple deployments of FADs by the same vessel on one night (Figure A9), as well as a potential FAD appropriation (Figure A10). For this last type of event, we considered that where a FAD's and vessel's fishing company records matched, this represented a FAD owned by the vessel (or at least vessel having 'authorisation' to set on, and retrieve the FAD), while a mismatch between FAD fishing company and vessel fishing company represented an appropriation.

This in-depth analysis was only performed on the beached FAD data sub-set due to computation times, but represents an area that should be considered for further investigation. In addition we have linked FADs and vessels by fishing set positions and date, we could in future analyses potentially link deployments and recovery positions to a FAD's first and last positions, which could allow an investigation of FAD characteristics (e.g. design, main material, dimensions) recorded by observer.

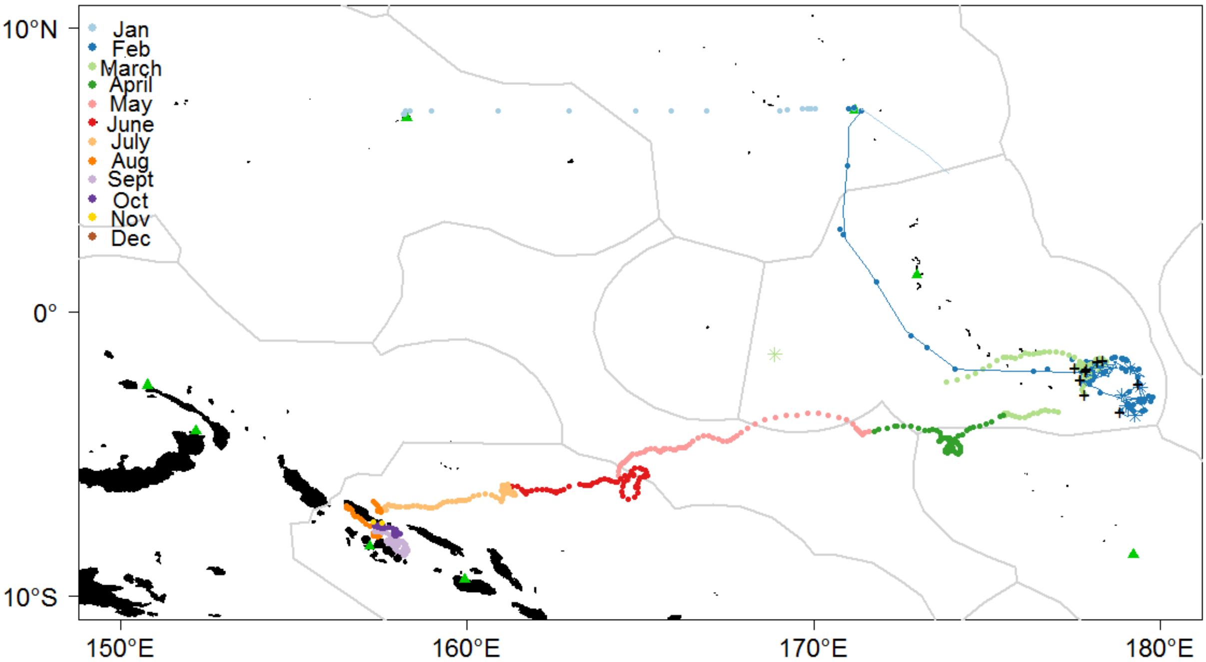

Figure 7. 'Life history' of an ultimately beached FAD (dots) and of the identified vessel from which it was presumably deployed (blue line). Black crosses represent shared positions between a fishing set and the FAD, stars represent deployment or retrieval of FADs by the vessel (as recorded by onboard observers) and green triangles are major ports. To simplify the figure, only the vessel track that was shared with the FAD is shown.

Additional data processing

From all the preliminary analysis performed, it is clear that additional data processing is needed. This includes identification of at-sea and on-board transmissions, as well as the identification of multiple deployments of the same FAD. The identification of at-sea and on-board position could be done using the calculated speed between two transmissions (Figure 8). Most inter-transmission intervals correspond to a speed below 5 km/h (Maufroy et al., 2015), and represent 74% of the data (Figure 8, Table 1). However, the distribution also presents a large tail with speeds between 5 and 30 km/h (2.7 to 16.2 knots). This speed range corresponds to vessel cruising speed and slow speed (e.g. investigating tuna schools, servicing FADs) and represents 6% of the data. It should be noted that almost 20% of the data corresponds to duplications (Table 1): double transmissions that should be removed, or consecutive transmissions at the same position (i.e. speed of 0, corresponding to beaching event or transmissions at port).

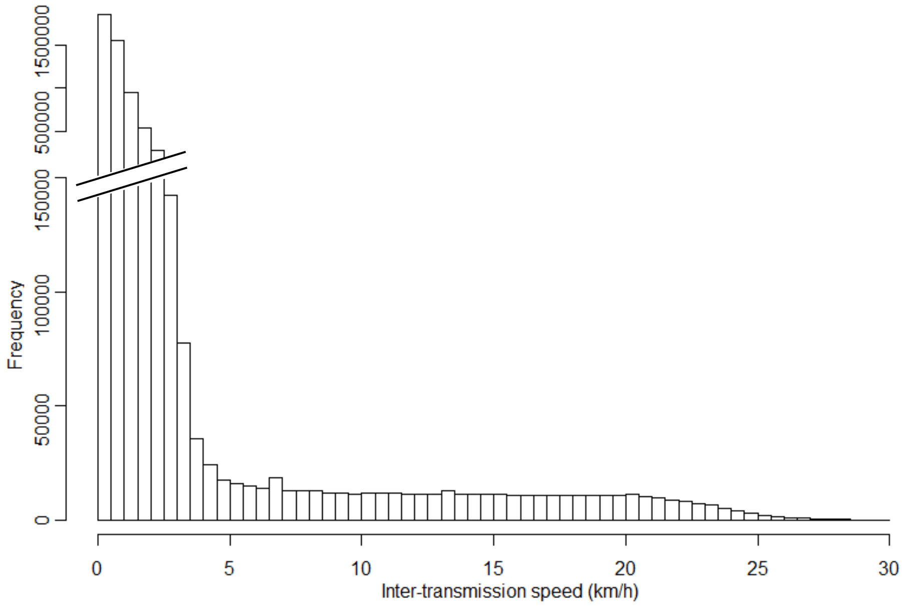

Figure 8. Frequency of inter-transmission speed (speed = 0 and >30km/h have been removed).

Table 1. Percentage of the data within each transmission speed class.

Inter-transmission speed	% of the data
Double transmissions at the same time	11.9
Consecutive transmissions at same position	8.0
Consecutive transmissions at speed 0-5 km/h	73.8
Consecutive transmissions at speed 5-30 km/h	6.0
Consecutive transmissions at speed >30 km/h	0.06

Similar analyses have been performed in the Atlantic and Indian Oceans, using various variables (speed, time interval, acceleration, heading change, etc.) to identify at-sea and on-board positions (Maufroy et al., 2015). Those authors found that 15.5% of their data (excluding double transmissions) consisted of on-board positions, highlighting the importance of separating at-sea and on-board positions before analysing patterns of FAD use. In our data, it is evident that more data processing is still needed, as not all on-board position have been correctly identified (Figure A11). For instance, FAD on-board transmissions when the vessel is fishing, investigating a tuna school or drifting at night may result in misclassification, as noticed by Maufroy et al., (2015). To overcome this, Maufroy et al. (2015) classified isolated at-sea transmissions (i.e. between two on-board transmissions) as on-board transmissions.

It should also be noted that a FAD may be deployed several times by the same or various vessels. Time gaps between transmissions may be used to identify these multiple deployments (Figure 9). However, currently the dataset is geo-fenced, which makes it difficult to identify deployments. Deployments may correspond to the first transmission of a series or could be hidden by geo-fencing. In this case, the use of deployment positions recorded in observer data, if available, could be useful, noting that observers may not see all deployments by a vessel, or only analysing the data from within a single EEZ.

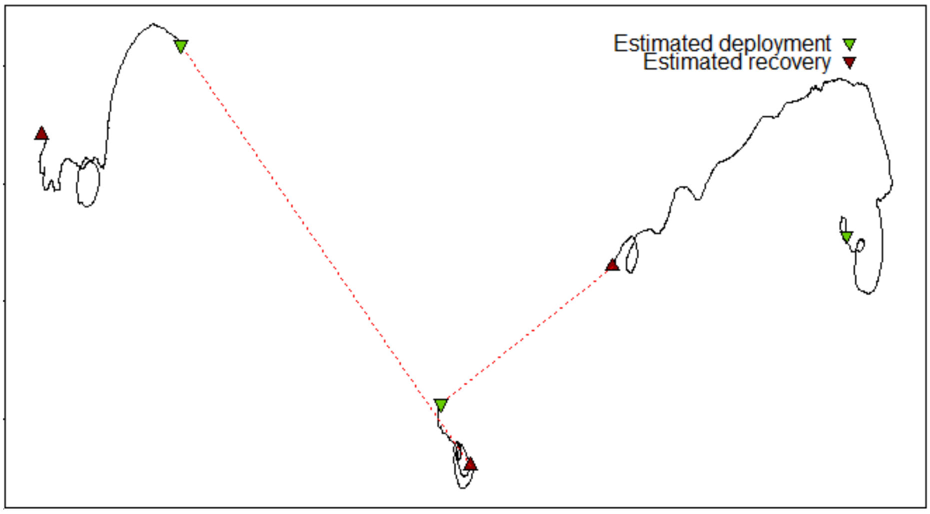

Figure 9. Recorded positions of a FAD with large temporal and spatial gaps in transmission, suggesting separate deployments.

Conclusion and potential next steps

This preliminary study of PNA FAD tracking data shows the spatial and temporal patterns of the data available for 2016 and 2017. It presents some of the analyses that could be performed using this valuable dataset: i) FAD density estimation related to CPUE and density of associated sets, ii) investigation of FAD dynamics around FAD closures, iii) estimation and distribution of beaching events and iv) exploration of FAD fishing dynamics through deployment, drifting, setting, recovery and appropriation events. It should be noted that these data are probably only a small sub-set of the actual number of FADs deployed in the WCPO (Gershman et al., 2015). Nevertheless, this dataset has clear potential to enhance our understanding of the operational use of drifting FADs and ecosystem interactions they drive, and also to be a useful tool to inform management. While the data still needs some processing, it could be used to investigate several research topics. The potential next steps include:

- Further process the data to identify at-sea and on-board positions and precise deployment positions. This could be done by examining additional variables (course direction, time interval, acceleration, etc.) or by comparing FAD speed to oceanic currents.
- Investigate change in ownership of buoys and/or FADs.
- Analyse patterns of deployments and drifting behaviour between areas/EEZs, seasonally, using multiple FAD deployments at the same position and time. Using knowledge on ocean

currents and known deployment trajectories may provide information on FAD connectivity between regions of interest. Comparing drifting behaviour with information on the FAD's dimensions, type of structure and depth of attachment could also potentially be done using both tracking and observer data.

- Further investigate FAD density related to CPUE and catch data. In particular, compare the size of the tuna school captured in areas of high and low FAD density to investigate tuna school fragmentation.
- Investigate change in transmission frequency, which may be linked to fishing events or to FADs leaving main fishing areas.
- Examine rates of FAD loss and emigration (FAD drifting outside fishing areas).
- Analyse the link between tuna catch on a FAD and time spent drifting, drift speed and ocean environment experienced throughout a trajectory.
- Further investigate beaching events and if possible, link them to areas of deployment and the influence of oceanographic conditions.
- Access information not recorded by observers (e.g. deployments by night), that could be recorded by vessel operators.
- Potentially, incorporate biomass data from sonar buoys within the analysis, where operational and FAD tracking data can be related. This could provide significant insights into purse seine vessel behaviour and potential implications for effort creep.

We invite WCPFC-SC13 to:

- Note this preliminary PNA FAD tracking data analysis and suggestions for further analyses.
- Note the importance of complete FAD tracking data to support scientific analyses and encourage their provision by fishing companies.
- Noting on-going WCPFC considerations, further discuss the importance of FAD marking and monitoring programmes to better identify and follow individual FADs.

Acknowledgments

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Appendix

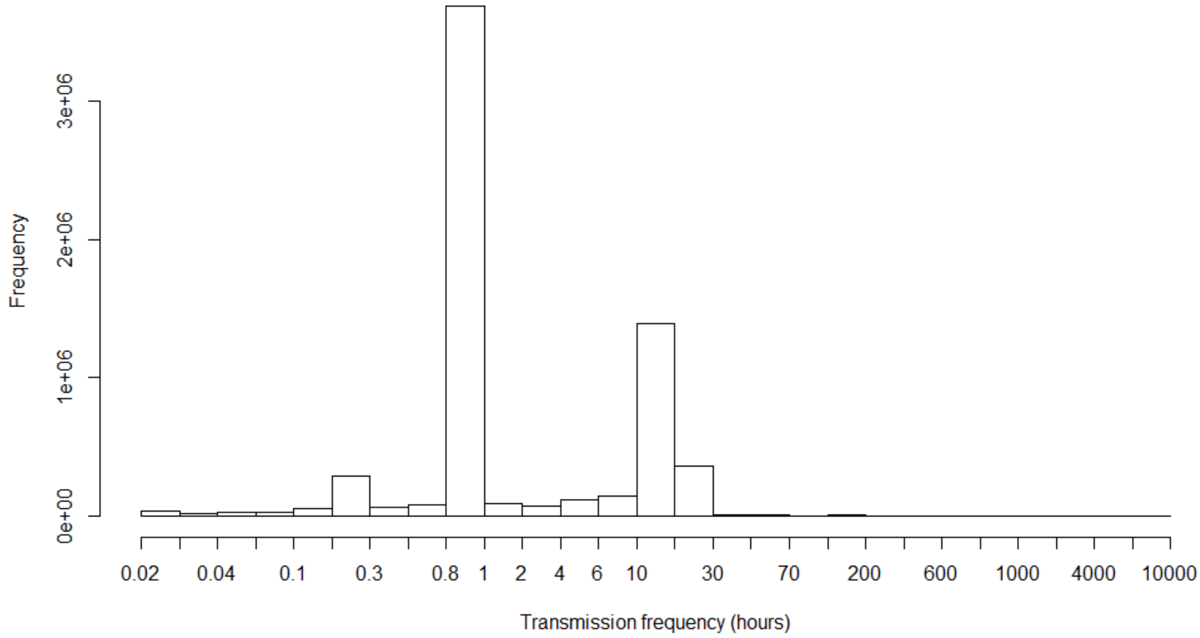

Figure A1. Frequency of transition intervals in hours for all records in the database.

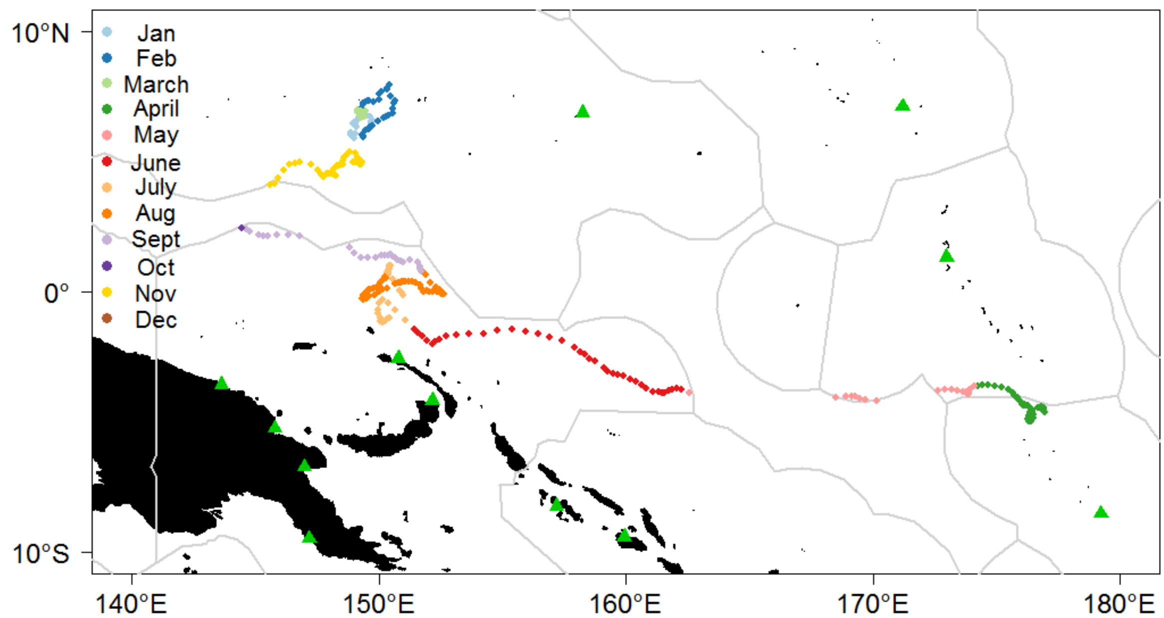

Figure A2. Track of a FAD deployed in April 2016 and transmitting until March 2017, showing clear geo-fencing patterns. Green triangles indicate major ports.

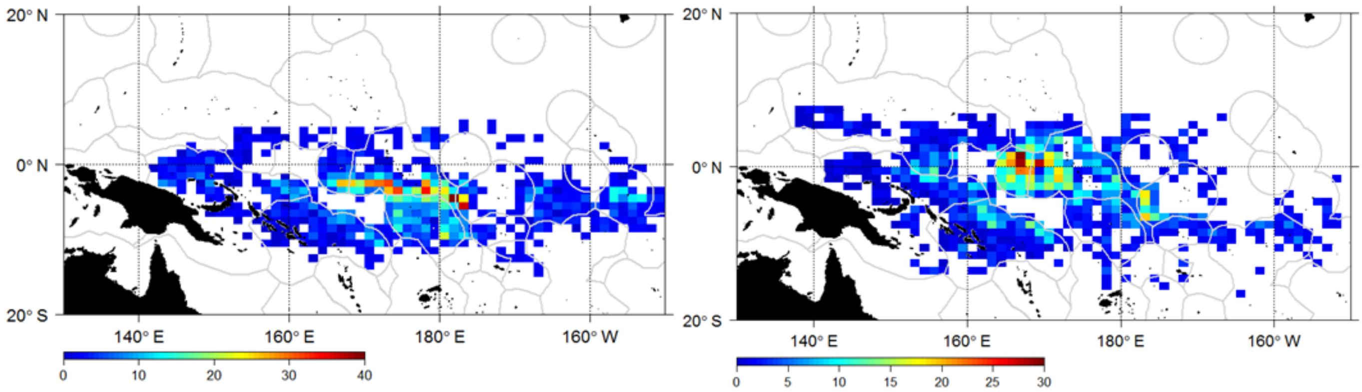

Figure A3. Number of associated set (drifting FAD and log) per 1° grid cell in 2016 (left) and 2017 (rigth) from logsheet data. Note that in 2017 only part of the data from January to May were available.

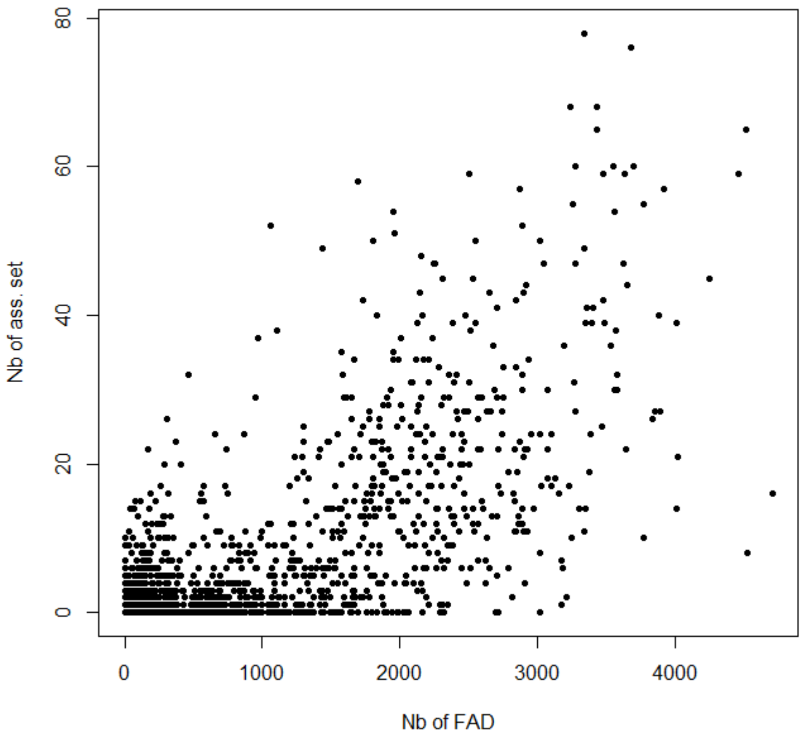

Figure A4. Number of associated sets (drifting FAD and log; logsheet data) function of number of associated set per 1° grid cell for 2016 and 2017.

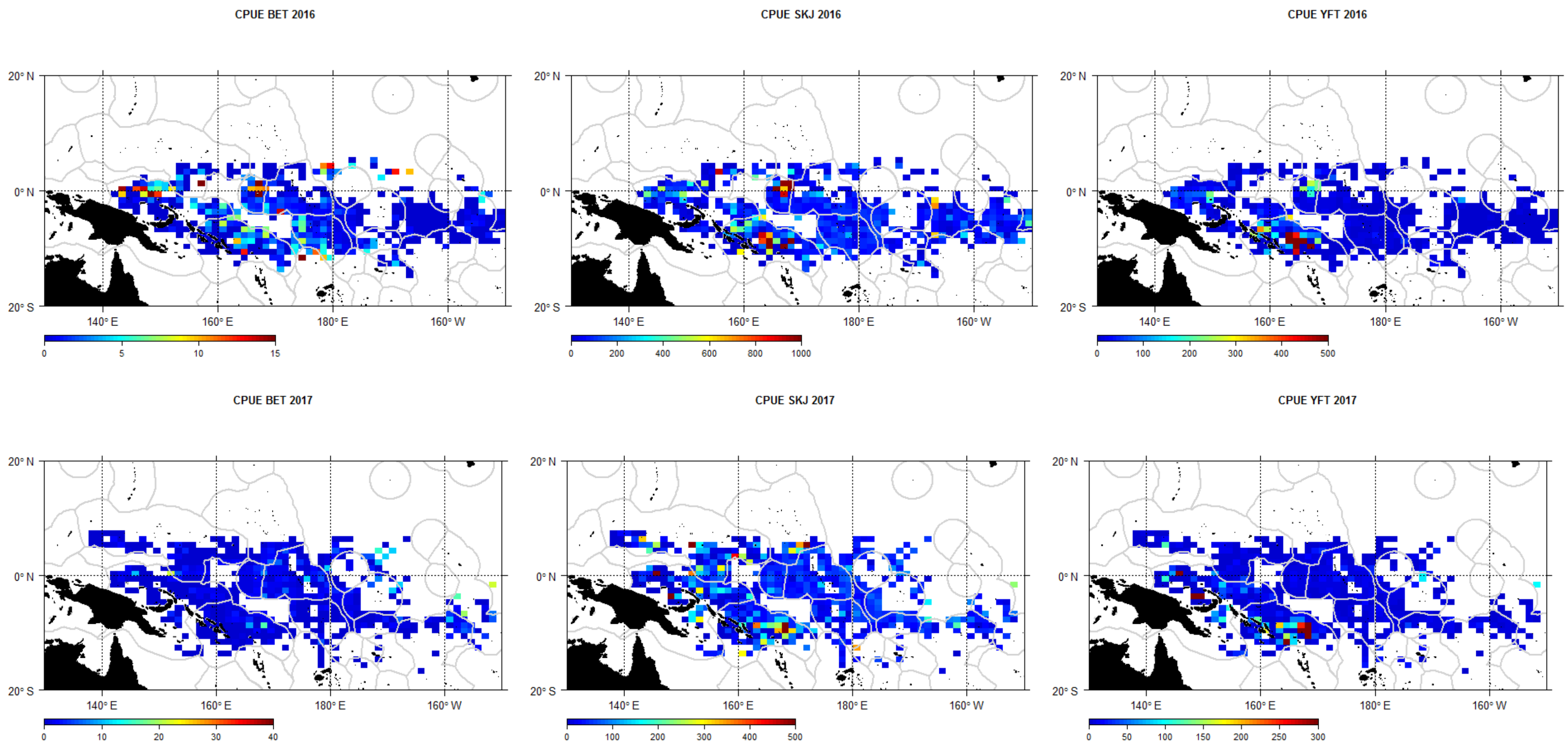

Figure A5. CPUE of each tuna species on associated set (drifting FAD and log) by 1° grid cell for 2016 (top) and 2017 (bottom) from logsheet data. Note that in 2017 only part of the data from January to May were available.

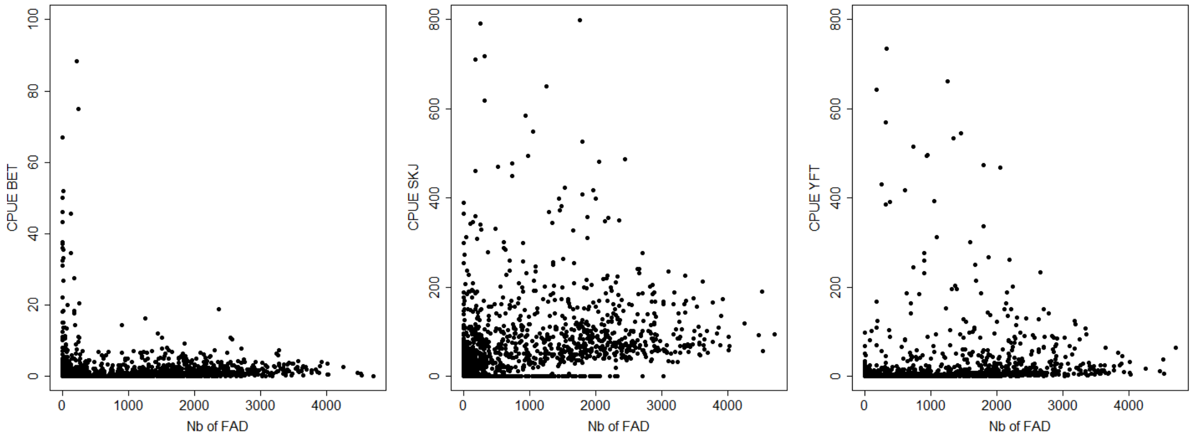

Figure A6. BET, SKJ and YFT CPUE on associated set (drifting FAD and log; logsheet data) function of number of associated set per 1° grid cell for 2016 and 2017.

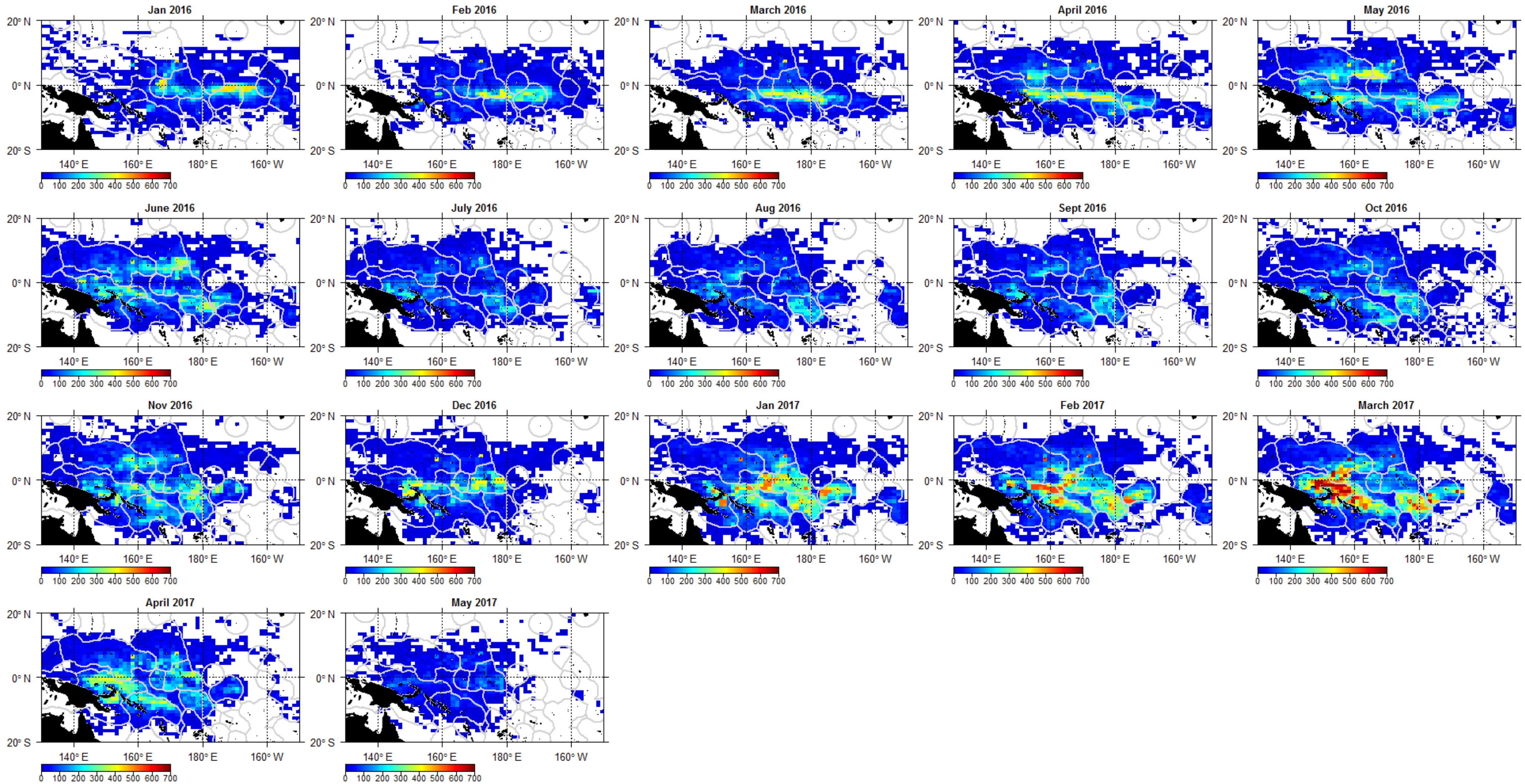

Figure A7. Density of unique FADs transmitting at least once per 1° grid cell each month during the studied period.

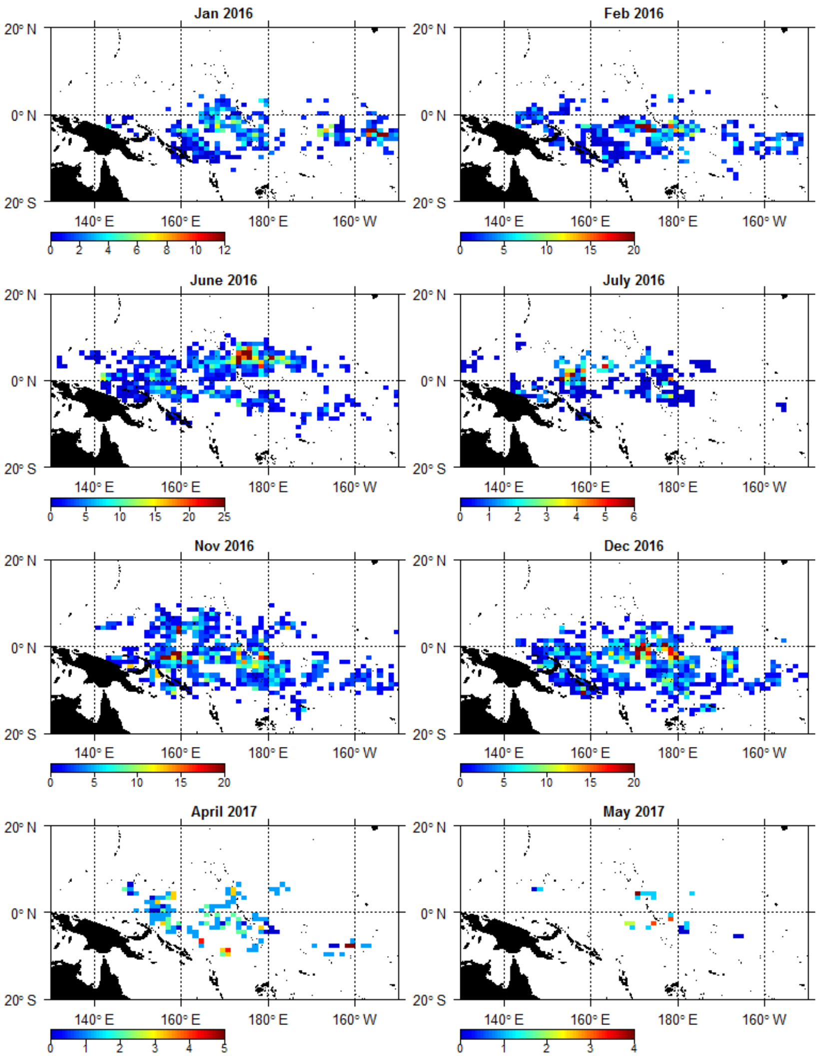

Figure A8. Number of associated set (drifting FAD and log) per 1° grid cell each month during the studied period from logsheet data.

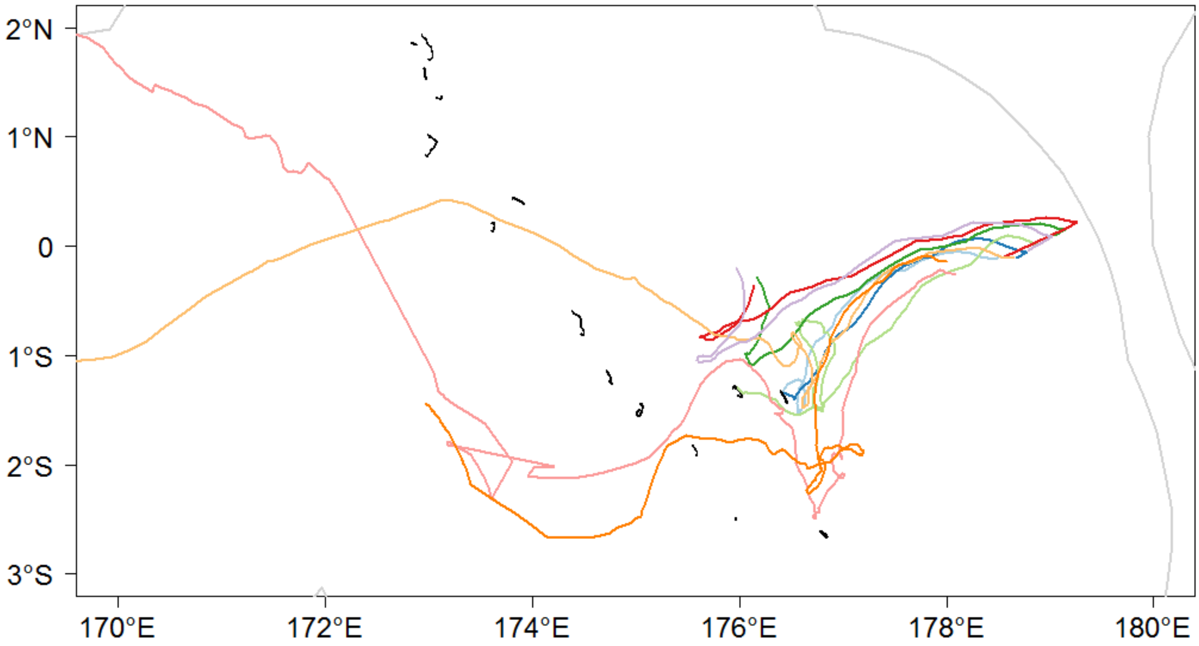

Figure A9. Multiple deployments of FADs by the same fishing company (presumably the same vessel) during the same night in the South-Eastern area of Kiribati's Gilbert Islands EEZ. Tracking periods presented varied between 2 and 4 months and have been cropped when the following position was too far to have been accomplished by a drifting FAD. Dark blue and yellow tracks show beaching events.

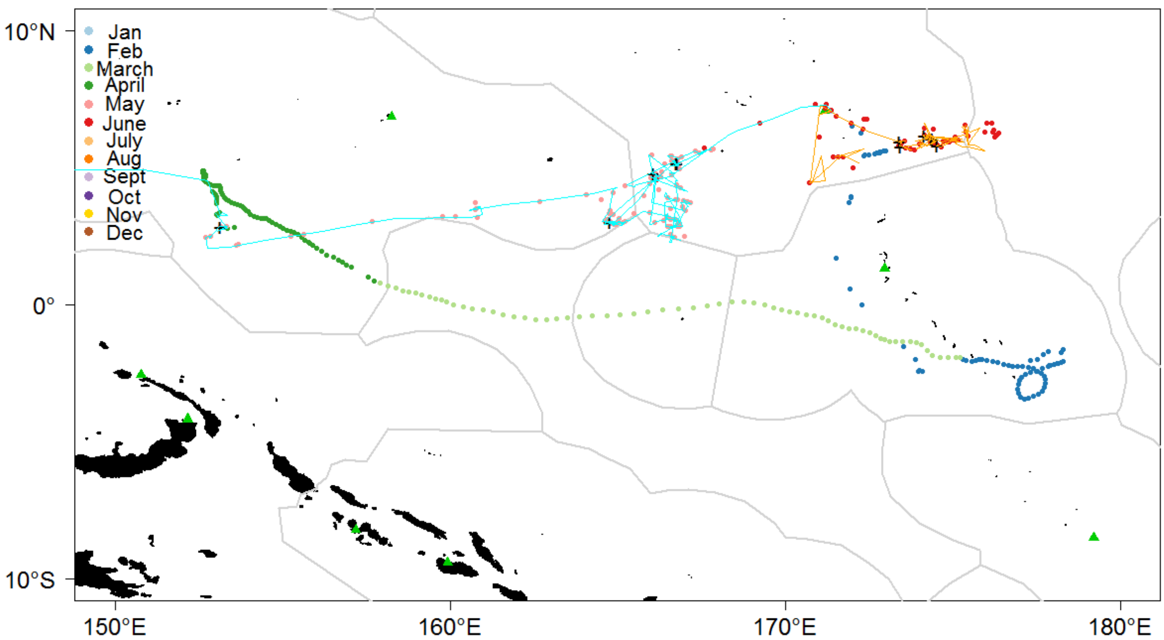

Figure A10. Track of a FAD (dots) and of two vessels that have possessed it for some time (orange and light blue line). Black crosses represent common position between a fishing set and the FAD and green triangles represent major ports. To simplify the figure, only the part of the vessels' tracks that was shared with the FAD represented. Note that the FAD must have been on-board another vessel in the beginning of February.

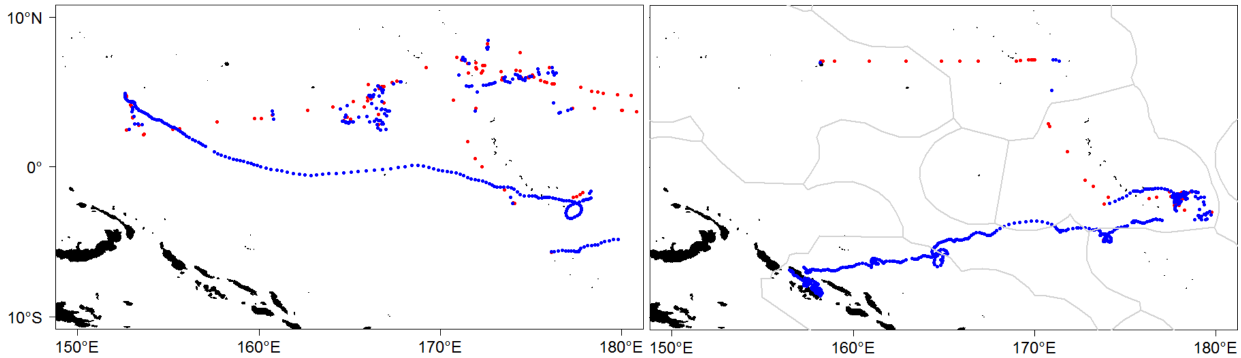

Figure A11. Tracks of two FADs with position classified as at-sea (blue) and on-board (red) based on speed classification.