SCIENTIFIC COMMITTEE

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Updates on Project 88: FAD acoustics analyses

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(Rev.01)

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Executive Summary

The deployment of satellite and echo-sounder buoys on drifting Fish Aggregating Devices (FADs) has dramatically increased their use by the purse seine fishery, with more than 30,000 FADs estimated to be deployed annually in the Western and Central Pacific Ocean (WCPO). This large volume of echo-sounder readings transmitted every day by buoys on FADs has the potential to be a useful source of information for scientific analysis that could help inform mitigation measures, enhance our understanding of fishery dynamics, and potentially provide independent data on tuna biomass for regional stock assessments. To this end, the WCPFC project 88 'FAD acoustics analyses', funded by the European Union, aimed at investigating fisheries echo-sounder data from satellite buoys deployed on FADs in view of the following objectives that might ultimately be addressed:

1) Whether acoustic buoys on drifting FADs could provide new fishery-independent data for stock assessments (e.g., indices of abundance);
2) Whether limiting sets to only those FADs that have a large estimated biomass beneath them could reduce the proportion of bigeye and yellowfin caught.

Following a scoping exercise last year, this report presents results from the first 6 months of project 88. The available data comprise 4.7 million acoustic transmissions from buoys deployed on FADs from US-based private sector firms Cape Fisheries and South Pacific Tuna Corporation and Solomon-based firm National Fisheries Developments in the WCPO in 2016–2018. This included data from three different satellite echo-sounder buoys: Satlink, Zunibal and Kato, which present different operational characteristics, such as biomass estimates, depth bins, transmission frequency.

Results presented in this report increased knowledge of biomass accumulation dynamics and of the signal captured by echo-sounder buoys. A subset of the dataset was selected, for which trajectory and fishing activities corresponded, with high confidence, to the same buoy attached to a FAD. Then, several parameters were compiled that could be used in further analyses performed on the dataset. For instance, models to study the influence of these parameters on the relationship between catch per set and estimated biomass; as well as characterisation of a relative index of abundance using trends and levels of biomass which would be compared to other sections of trajectories. The parameters compiled with the available data included: FAD soak time, drift speed, trends in biomass accumulation leading to a fishing set, biomass moving averages, biomass by depth, total catch or catch per species, moon phase, time of the set, and spatial areas.

We invite WCPFC-SC16 to:

- Note the preliminary results from Project 88 of acoustic data from echo-sounder buoys deployed on FADs, and note the proposal for future investigations.
- Note the potential, over the longer-term, to derive an index of abundance that could be used in stock assessments.
- Recommend the need for better labelling or identification of particular FAD buoys (e.g. via the buoy identification numbers) by commercial vessel operators or via observer reports.
- Endorse the continued cooperative relationship with the fishing community to obtain business confidential data for analysis by regional scientists, particularly with regard to FADs, and the fishing strategies involved in their use. Highlight the need for additional data covering the whole WCPFC convention area and encourage other industry partners to become involved in the project.

1. Introduction

The deployment of satellite and echo-sounder buoys on drifting Fish Aggregating Devices (FADs) by the purse seine vessel operators has dramatically increased over the last two decades in all ocean basins. In the Western and Central Pacific Ocean (WCPO), although the reported number of FAD sets has been relatively stable over recent years, the actual number of FADs now deployed are in the tens of thousands each year and this fishing mode corresponds to around 40% of the reported purse seine tuna catch (Williams et al., 2020). Satellite and echo-sounder buoys are a relatively new technological development that tracks a FAD and indicates the amount of tuna beneath it, which increases fishing efficiency (i.e., catch per unit effort - CPUE) dramatically (Lopez et al., 2014). They also have the potential to be a useful source of information for scientific investigations (Moreno et al., 2016). It has been estimated that more than 30,000 FADs with satellite buoys are deployed annually in the WCPO (Escalle et al., 2020b; Gershman et al., 2015) with the majority being deployed with an echo-sounder (97% in 2019, see Escalle et al. 2020). This represents a very rich and robust data source that has the potential to help inform mitigation approaches to addressing catches of small bigeye and yellowfin tuna, increase our understanding of fleet dynamics, and potentially provide a new source of fishery-independent data on tuna abundance for regional stock assessments. This source of information is believed to be particularly important for skipjack assessments, given the long-term reduction in pole and line fishing effort, the main source of informative CPUE trends for the models.

A preliminary analysis, as reported to this meeting identified that the format of available data, i.e., from single frequency echo-sounders, allowed some investigations to be performed (Escalle et al., 2019b). In particular it was determined, that acoustic FAD data and logsheet/observer set data could be linked (although assumptions are required) and some signals in the acoustic data could be related to catch levels, with notable variability.

This report presents results from the first 6 months of the WCPFC project 88 'FAD acoustics analyses'. This continues the work started last year during the scoping project (Escalle et al., 2019b), in collaboration with two US-based private sector firms Cape Fisheries and South Pacific Tuna Corporation (located in San Diego, California) and one Solomon-based firm National Fisheries Developments (NFD). The three firms have multiple large purse seine vessels that operate in the WCPO and represent a large expanse of the fishing grounds, along with operational characteristics that are representative of a large segment of the fishery. Results from evaluations performed within this project will be used to identify whether the following objectives might ultimately be addressed using fisheries echo-sounder data from satellite buoys deployed on FADs:

1) Whether acoustic buoys on drifting FADs can provide a novel and efficient source of fishery-independent data for stock assessments (e.g., indices of abundance);
2) Whether limiting sets to only those FADs that have a large estimated biomass beneath them could reduce the proportion of small bigeye and yellowfin caught.

2. General description of the data and processing methods

2.1 Structure of the datasets

Biomass estimates were independently provided to Cape Fisheries, NFD, and South Pacific Tuna Corporation by the three satellite echo-sounder buoy providers (Satlink, Zunibal and Kato), each with unique characteristics (Table 1). The data available for analysis comprised over 4.7 million transmissions of acoustic data from Satlink, Zunibal and Kato buoys deployed on FADs in the WCPO in 2016–2018 (Table 1). The volume of the available data provides the potential to compare the outputs between buoy brands, but specific characteristics of the corresponding data sets much first be understood.

Satlink buoys transmitted acoustic (echo-sounder readings) and position information separately, with generally two transmissions of position data and three acoustic readings (typically around sunrise) per day (Table 1). In order to access the position related to each acoustic transmission, we linearly interpolated the position dataset at those times. Hence, for each echo-sounder reading, we had access to estimated position, date/time, processed total biomass estimates (t) and biomass estimates at 11.2m depth intervals or bins from 3 to 115m.

Zunibal buoys transmitted every hour with data for both the position of the buoy and echo-sounder readings (Table 1). Transmissions included position, date/time and total estimated biomass (t). However, data received included fixed position per day (same latitude and longitude throughout the whole day, while normally one position per hour should be available), which led to very high and unrealistic drift speeds between days. In order to process the data (see following section), we therefore retained one transmission per day, corresponding to the highest biomass reading. For some of the data (provided by one of the fishing companies), transmission included raw echo-sounder data at 1.6m depth bins from 1.6 to 120m. Finally, Zunibal buoys present a sensor archiving in/out water position, allowing access to buoy deployment position, which was also available for a subset of the Zunibal data only.

Table 1. Summary of data parameters per echo-sounder buoy by commercial brand.

Brand	Satlink	Zunibal	Kato
Year	2016–2018	2016–2018	2017–2018
Frequency of echo-sounder readings	Generally 3 per day (range 0-4)	Generally 1 per hour with associated position	1 per day with associated position
Frequency of position transmission	Generally 2 per day	Generally 1 per hour with associated acoustic data	1 per day with associated acoustic data
Number of echo-sounder transmissions	2,591,000	2,030,000	62,000
Biomass estimates	Total estimates in tons	Total estimates in tons	No
Biomass estimates per depth bin	Yes 11.2m; from 3 to 115m	No	Raw data (strength of echosounder 6–100%)
Echo-sounder raw data	No	Occasionally by depth bin of 1.6m; from 1.6 to 120m	Yes, by depth bin of 10m; from 0 to 150m
Buoy deployment position	No	Occasionally	No

Kato buoys transmitted once per day with data for both the position of the buoy and echo-sounder readings at the same time (Table 1). Transmissions included position, date/time and a signal corresponding to the echo-sounder reading. This corresponds to the acoustic signal strength, with a relative index between 0 and 7 given for each 10m depth bin between 0 and 150m.

Generally, the different characteristics of each echo-sounder buoy brand affects the analyses performed on acoustic data. Therefore most of the analyses were performed separately. In addition, the fact that most of the Zunibal buoys did not present any precise hourly position nor the acoustic data per depth bin precluded some analyses. For Kato buoys, acoustic data only corresponded to a relative index per depth bins, which will need very specific investigations. For these reasons but also the fact that we have received a higher number of Satlink buoys, with a wider spatial distribution and access to biomass estimates per depth bin, most of the analyses presented in this paper were performed on Satlink data only.

2.2 Data processing

Consistent with the analysis of the Parties to the Nauru Agreement (PNA) FAD tracking dataset (Escalle et al., 2020a) and analyses performed previously on similar FAD echo-sounder datasets (Escalle et al., 2019b), the raw position and acoustic dataset included transmissions from active buoys drifting at-sea but also included data from some that were still on-board a vessel (before deployment, or following recovery). Therefore, data were processed by identifying at-sea and on-board positions following the approach of Maufroy et al. (2015). Random Forest models were calibrated using a learning dataset, then used to predict the class (at-sea or on-board) of positions in the echo-sounder dataset. Additional correction procedures were also performed to eliminate isolated or short at-sea or on-board sections surrounded by long on-board or at-sea positions (Escalle et al., 2019a). Each buoy trajectory with acoustic data then consisted of one or several drifting ('at-sea') segments, separated by 'on-board' positions. Deployment positions were identified as the first at-sea position.

Note that this data processing procedure was not needed for some of the Zunibal data (i.e., portion of the dataset from one fishing company), for which deployment positions and transmissions from being on-board a vessel were already known. As mentioned previously, only one position per day was kept for the majority of the Zunibal data.

For some analyses the data were separated into main areas of the WCPO : i) equator, between 5°S and 5°N; ii) southwest, south of 5° S and west of 175°E; iii) southeast, south of 5° S and east of 175°E; and iv) north, north of 5°N (Figure 1).

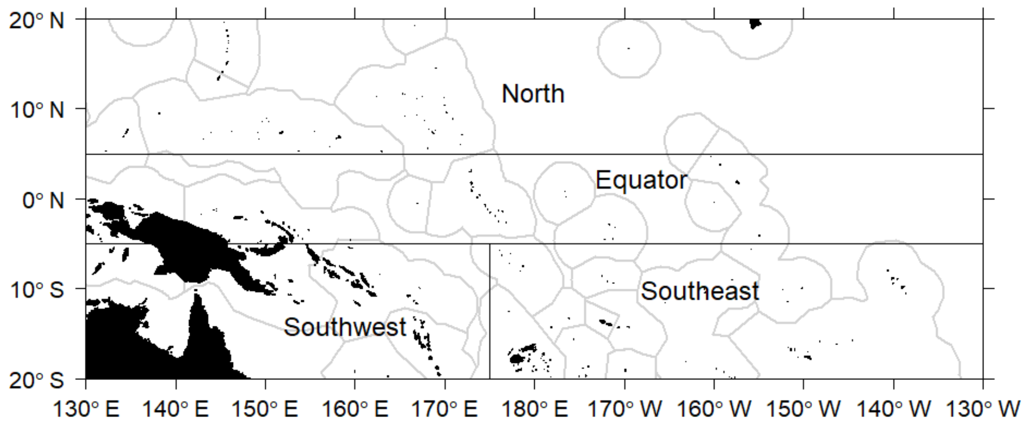

Figure 1. Map of the delineated areas of the WCPO used in the study.

2.3 Maximum estimated biomass and influence of the time of the day

The biomass estimated by Satlink and Zunibal echo-sounder buoys (no estimates in tons for Kato buoys) ranges from 0 to 350t (Figure 2). However, the profile of the distribution of maximum daily biomass estimates was different between Satlink and Zunibal buoys. For the majority of days, the maximum estimated value from Satlink buoys was between 1 and 5t. Note that when the echo-sounder estimated a biomass of less than 1t, no acoustic signal was sent, only a transmission of the position was received. The distribution of maximum daily biomass estimates decreases gradually from 5 to 100t. Zunibal buoys presented maximum daily estimated biomass mostly between 0 and 25t, then a gradual decrease in the distribution of maximum daily biomass from 30 to 100t was seen (Figure 2).

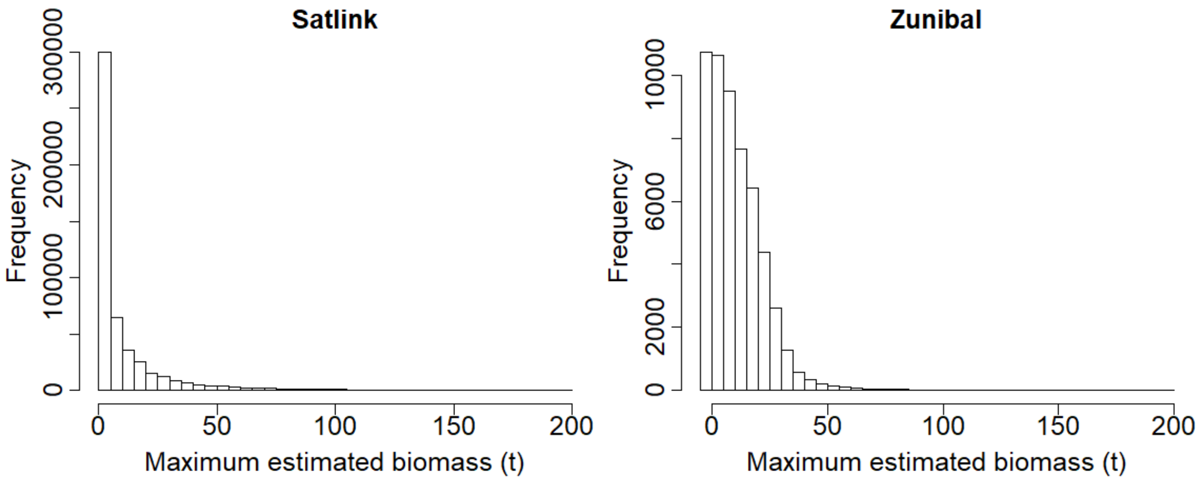

Figure 2. Maximum estimated biomass during the day for the Satlink and Zunibal echo-sounder buoys. Values above 200 t (0.4% of all values) were removed from the histogram to increase interpretability.

Higher numbers of biomass readings were found during the three hours before sunrise for the Satlink buoys (Figure 3). Similarly, the maximum daily biomass also most commonly corresponded to this period before sunrise (Figure 3). Zunibal and Kato buoys showed different patterns. Zunibal transmitted biomass regularly throughout the day, with a maximum daily biomass being typically just after sunrise (Figure 4). Kato buoys transmitted one biomass reading per day, hence explaining the similarity in the histograms between the biomass transmissions and the maximum daily biomass transmission (Figure 5). The maximum daily biomass was found from 3 to 5 hours after sunrise (Figure 5). However, it should be noted that for Kato buoys, no general estimate across the whole echo-sounder detection cone is given, but only some index by depth bin. Adding those indices might not therefore be relevant, and additional exploratory analyses are needed.

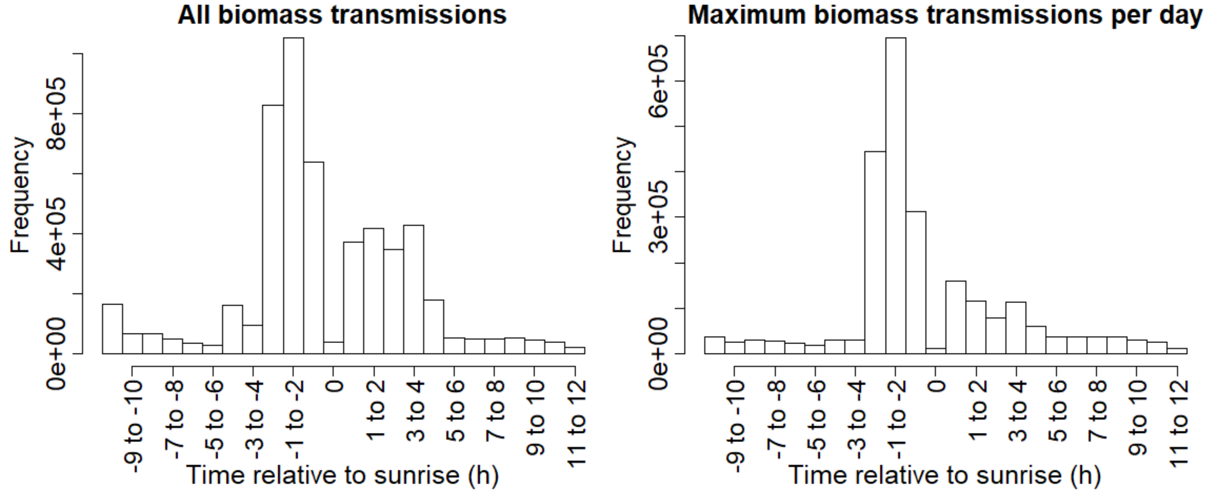

Figure 3. Time relative to sunrise of acoustic data transmission (left) and of the maximum biomass estimated during the day (right) for Satlink buoys.

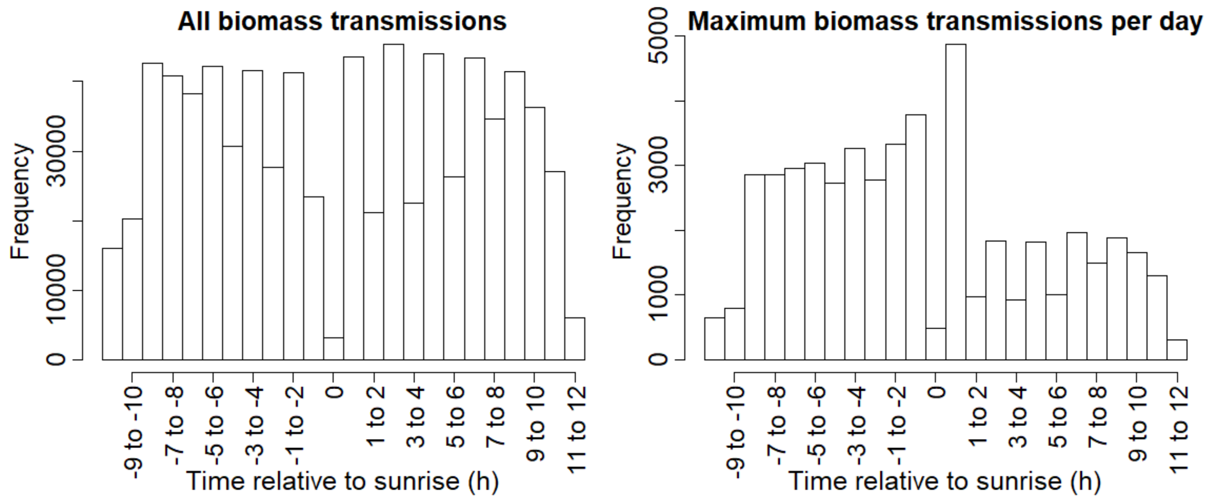

Figure 4. Time relative to sunrise of acoustic data transmission (left) and of the maximum biomass estimated during the day (right) for Zunibal buoys.

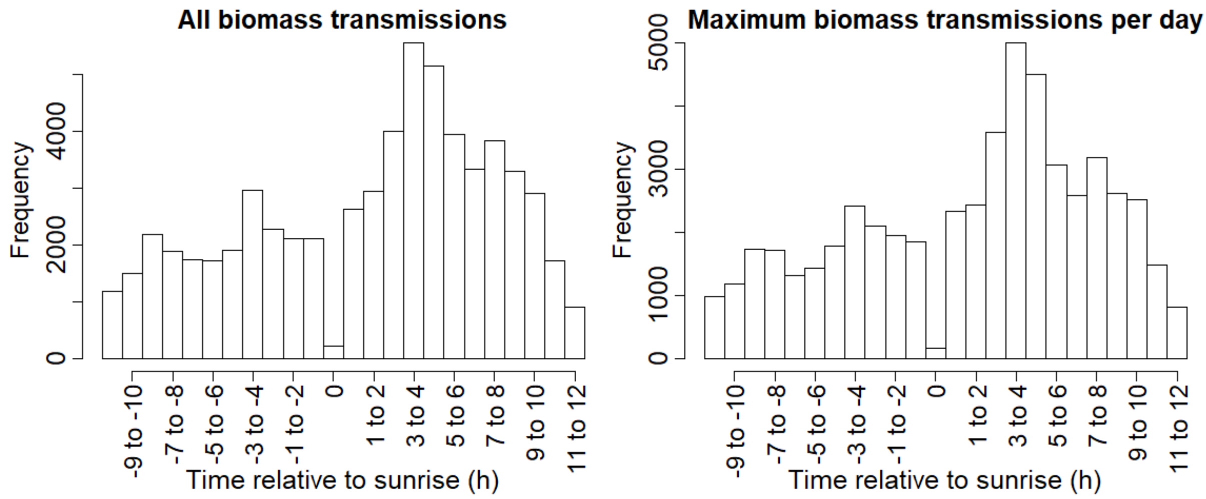

Figure 5. Time relative to sunrise of acoustic data transmission (left) and of the maximum biomass estimated during the day (right) for Kato buoys.

2.4 Identification of grouped deployments and precise FAD drifting duration

Buoy deployment positions were identified using the Random Forest algorithm previously described and defined as the first at-sea position of a trajectory or of an at-sea segment (if more than one deployment per buoy was detected). This allowed the compilation of buoy drift time. However, more importantly to study tuna aggregation processes or re-aggregation processes after a fishing set, the actual initial deployment of the FAD itself should also be identified. FAD and buoy initial deployments and hence drift time, might be different as buoys can be deployed or re-deployed on FADs found at-sea.

In the acoustic dataset received, there is no information regarding deployments and time drifting. Therefore, FAD deployments could be identified using records made by observers and matched to acoustic time series using buoy ID numbers. However, these identifiers remain rarely recorded. Another method to identify FAD deployments is to look at multiple buoy deployments around the same time and location ('grouped deployments'). Deployment of new FADs (vs buoys deployed on a FAD found at-sea) were therefore identified with certainty when several buoys were deployed in a row by a vessel (Figure 6). Grouped deployments were identified using time difference (2h) and distance (30km, considering maximum cruising speed of 15 knots) between different deployments of the same vessel.

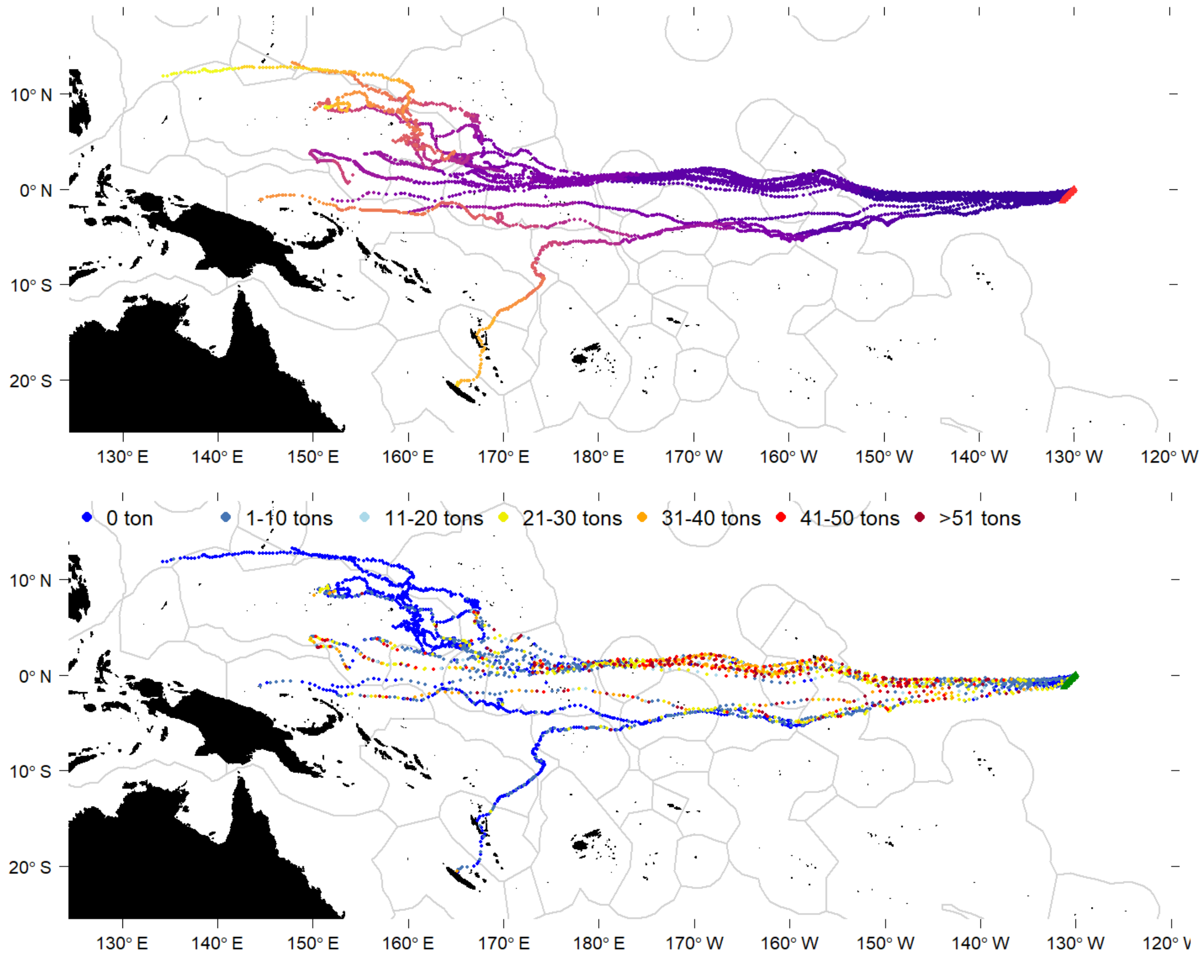

Figure 6. One example of grouped deployments, as identified using the distance and time difference between different buoy deployments, and related buoy trajectory. Colours indicate time since deployment in month (top) and biomass estimated by the echo-sounder (bottom).

A total of 2274 grouped deployments (from 2 to 45 buoys deployed in a row) were identified, most of them being the first deployment of the buoy (80% of grouped deployments identified). Temporal variability, in terms of time relative to sunrise, was investigated for all deployments (Figure 7). A peak was detected just before sunrise for deployment of a single buoy, corresponding to the time of FAD sets and therefore indicating the likely swap of buoys on a FAD that has just been found at-sea and set on. Grouped deployments occur throughout the day, with higher numbers at the end of the day (Figure 7).

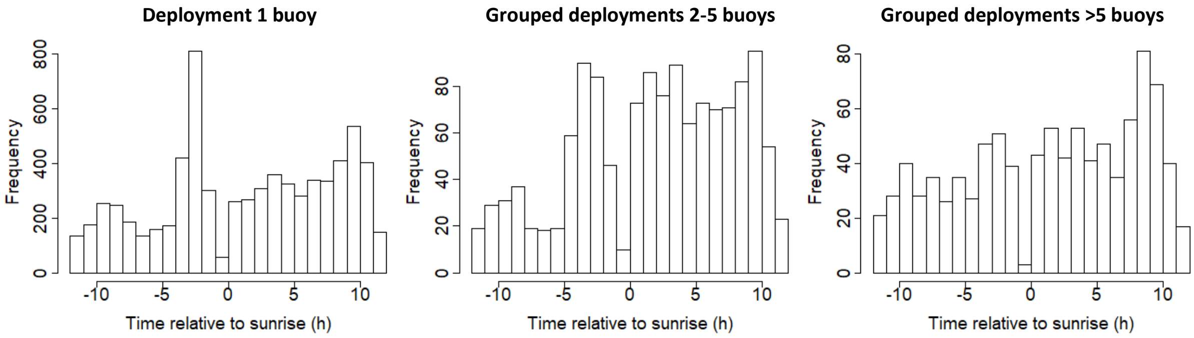

Figure 7. Time relative to sunrise of buoy deployments, separated between deployment of 1 buoy, grouped deployments of 2-5 buoys and grouped deployments of more than 5 buoys, as identified using the distance and time difference between different buoy deployments.

2.5 Sensitivity analyses in matching between echo-sounder buoy trajectories and fishery data

In order to access the sets and related catch made on the buoy attached to drifting FADs considered in this study, a match between the trajectory and the date and position of associated sets from logsheet and observer data was performed. Given that buoys rarely transmitted position every hour, even only one position per day for some buoys, a match was made on the same calendar day (UTC), with a distance varying between 0 and 10 km. Then sensitivity analyses were performed using observer data and recorded information about buoy owner (i.e. the vessel that initially deployed the FAD and is paying the buoy satellite fees) to make sure the buoy considered in the acoustic data was the same as the one attached to the FAD set on. Hence, distances and time difference between set information (observer) and acoustic transmission were compared for buoys: i) owned by a vessel of the same company as the vessel setting on the FAD; ii) owned by the vessel actually performing the set; or iii) with the same buoy ID as the one recorded by the observer. The latter corresponded to the most confident matching but resulted in a limited number as the buoy ID number remains rarely recorded by observers.

Most matching of buoys from the same company as the vessel making the set or of the same vessel were at 1–5km and 1–8 hours difference, and matching on the exact same buoy at 1–2 km and 1–3 hours difference (Figure 8 and Table 2). Overall 75% of matches on buoys set on by the owner vessel or one from the same fishing company and 90% of matches with same buoy IDs were found at a maximum distance of 5km and time difference of 8 hours (Figure 8 and Table 2). These distances and time differences were therefore considered for all matching between acoustic trajectories and logsheet or observer data (Table 3). This might underestimate all possible matches, but will allow selection of a subset of set and FAD-related activities from observer data for which we are almost certain that the buoy from the acoustic dataset corresponds to the one from the FAD set upon.

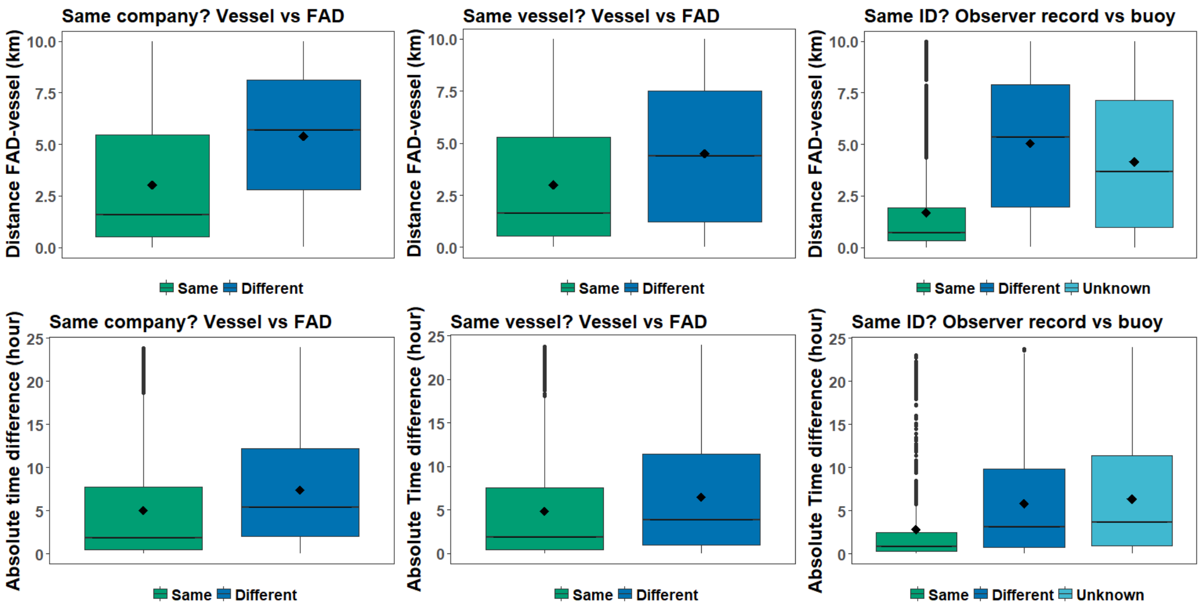

Figure 8. Distance and time difference between set and buoy transmission from the acoustic dataset, depending on the information recorded by the observer: the buoy is owned by a vessel of the same company as the vessel setting on the FAD (left); the buoy is owned by the vessel actually performing the set (middle); or the buoy ID is the same in the acoustic and observer dataset.

Table 2. Investigation of best distance and time difference between buoy trajectory and fishing set to correctly identify the same FAD on both the acoustic and observer datasets.

		All	Company		Vessel		FAD ID	
			Same	Different	Same	Different	Same	Different
Distance (km)	Quantile 75%	7.06	**5.49**	8.10	**5.32**	7.50	1.93	7.90
	Quantile 90%	8.88	8.10	9.27	8.05	9.08	**5.18**	9.22
	Quantile 95%	9.46	9.14	9.64	9.09	9.54	7.29	9.58
Time difference (h)	Quantile 75%	10.60	**7.84**	12.18	**7.65**	11.35	2.47	9.87
	Quantile 90%	16.34	16.08	16.59	15.17	16.69	**7.46**	16.21
	Quantile 95%	18.94	19.09	18.74	17.29	19.25	18.27	19.31

A total of 4,342 sets from the logsheet dataset and 2,769 sets from the observer dataset were matched with a buoy in the acoustic dataset (Table 3). If multiple buoys were matched to the same set, the closest one or the one with the same buoy ID (observer data only) were kept. If we also consider matching at <5km and ±8h, a total of 2,224 sets from the logsheet dataset and 1,339 sets from the observer dataset were selected.

Other FAD-related activities (deployments, visits, recoveries) from the observer data were also matched with acoustic trajectories (Table 4). In order to refine again the selection of sets and other activities matched with a buoy trajectory, we only selected those data where the observer's recorded buoy ID and that ID for the trajectory matched. All the other activities (e.g., fishing sets) recorded at the same time were considered to be made on the same FAD. This resulted in 661 sets in the logsheet data, 657 sets in observer data, 1,198 visits, 211 FAD deployments, 194 FAD retrievals, 462 buoy deployments and 458 buoy retrievals considered for further analyses (Tables 3 and 4).

Table 3. Matches between buoys in the acoustic dataset and sets in logsheets, or set and other FAD related activities in the observer data from vessels of the collaborating companies.

	Logsheet				Observer			
	All	%	<5 km ±8h	%	All	%	<5 km ±8h	%
Total number of sets	53,597				39,430			
Number of matching	4,342		2,378		2,769		1,403	
Unique set matched	3,935	7.3	2,224	4.2	2,531	6.4	1,339	3.4
Unique buoy trajectory with matching	2,344	34.5	1,596	23.5	1,674	24.6	1,008	14.8
Set with only 1 buoy matched	3,617	83.3	2,106	88.6	2,349	84.8	1,290	91.9
Set with >1 buoy matched	318		118	5.0	181	6.5	48	3.4
Average number of sets per buoy	2.8		2.5		2.5		1.8	
Number of buoys with grouped deployments	1006		489		604		271	
Selected matching			661				657	

Table 4. Other matchings made between trajectories and the observer database, at less than 5km and 8h difference, from vessels of the collaborating companies.

	Visits	FAD deployment	FAD retrieval	Buoy deployment	Buoy retrieval
Matching events	2,952	554	344	1,040	1,290
Unique buoy	1,586	458	299	976	755
Selected matching events	1,198	211	194	462	458

3. Relation between achieved catch and estimated biomass

Although independent estimates of biomass are not available to ground-truth the estimates derived from the echo-sounder buoys, the relationship between estimated biomass and resulting catch can be used to provide some useful information.

Following the sensitivity analyses previously performed using observer data, sets from logsheet operational data, as well as any set and other FAD-related activities from observer data, performed by vessels from the company owning the considered FADs were matched with the acoustic dataset using positions (≤ 5km) and date/time (±8h). Only sets or other FAD-related activities with the same buoy ID in observer and acoustic trajectory data were considered for analyses presented in this section.

3.1 FAD life history patterns and individual FAD accumulation processes before a set

Patterns of biomass estimates before and after a fishing set were investigated for some example FADs to better understand the variability between catch and biomass (Figures 9 and 10). Figures were generated to follow the 'life-history' of buoys, with the different fishing sets, as well as any other activities recorded by observers shown, as well as periods when that same buoy was on-board a vessel.

In general, there is an increasing trend in biomass detected before a fishing set. However, on a day to day basis, high variability is detected, making any catch/biomass relationship based on a given day or period of days prior to the set highly variable. After the fishing set, very low biomass is detected by the echo-sounder (Figure 9), or a fast biomass accumulation is detected again after a few days which may be followed by a second set shortly after (Figure 10).

High day to day variability in biomass estimates from the echo-sounder was previously highlighted (Escalle et al., 2019b), making a comparison with the reported catch per set difficult. Trends in biomass accumulation (using linear model) and smoothed biomass estimates over varying periods (i.e., moving average) were therefore used to capture levels and trends of aggregated biomass (Figure 9 and 10). From the data subset previously mentioned, and removing periods on-board a vessel or days before the previous set, linear regressions of the total maximum estimated biomass per day were compiled over several periods before a fishing set (40; 30; 20; 10 and 5 days prior to a set) to investigate the trend in biomass accumulation leading to a set (examples in Figures 9 and 10).

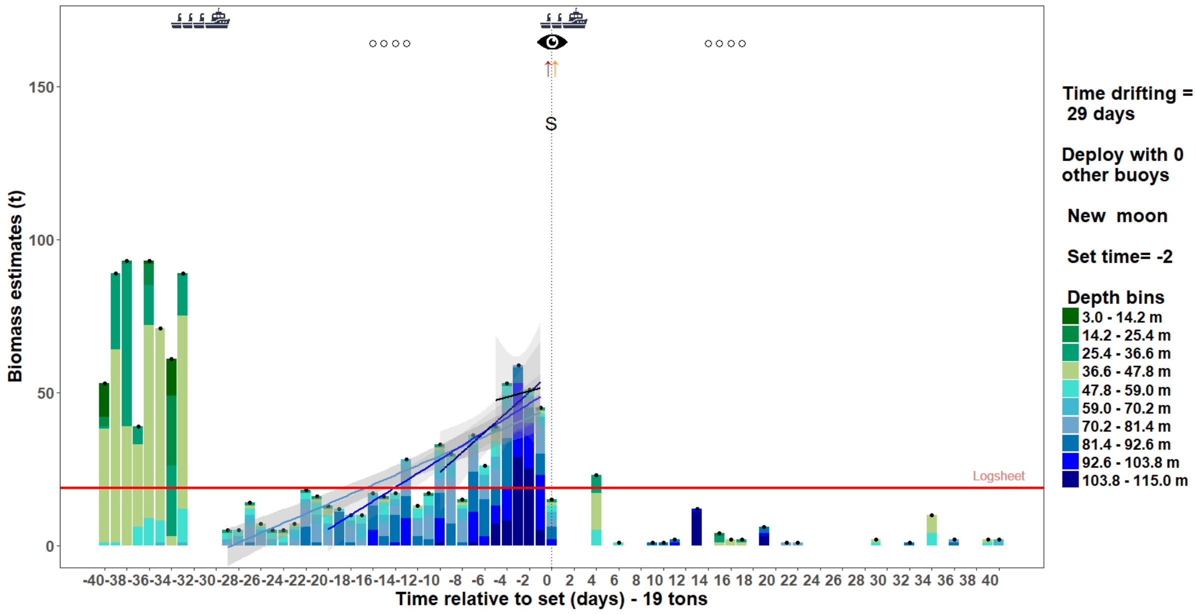

Figure 9. Example of biomass accumulation (t), from a Satlink buoy, before and after a fishing set. Color bars indicate the maximum biomass per day (40 days prior to and after a fishing set) and per depth bin, linear regression for 30-day, 20-day, 10-day and 5-day periods are shown as blue lines. On the right panel, time drifting, grouped deployments, moon phase (also indicated with circles on the graph for the full moon), time of the beginning of the set relative to sunrise and depth layers. Red horizontal line = total recorded catch of the set from logsheet data; S = day of a fishing set; top brown arrow = recovery of a FAD; top orange arrow = recovery of a buoy, vessel = buoy on-board; eye = visit of the FAD.

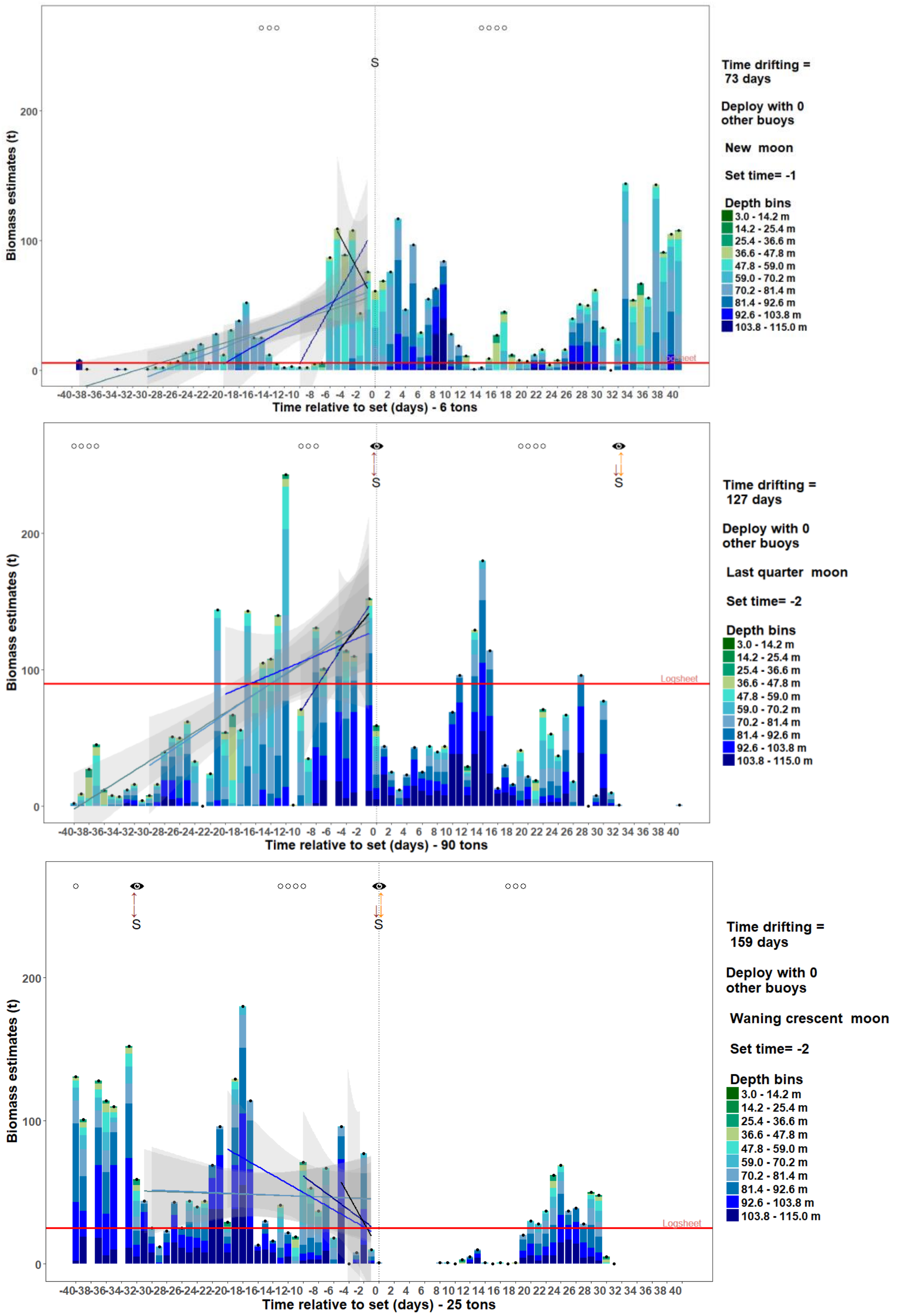

Figure 10. Examples of biomass accumulation (t), from a Satlink buoy, before and after a fishing set. Color bars indicate the maximum biomass per day (40 days prior to and after a fishing set) and per depth bin, linear regression for 30-day, 20-day, 10-day and 5-day periods are shown as blue lines. On the right panel, time drifting, grouped deployments, moon phase (also indicated with circles on the graph for the full moon), time of the beginning of the set relative to sunrise and depth layers. Red horizontal line = total recorded catch of the set from logsheet data; S = day of a fishing set; top/bottom brown arrows = recovery/deployment of a FAD; top/bottom orange arrow = recovery/deployment of a buoy, vessel = buoy on-board; eye = visit of the FAD.

3.3 Biomass accumulation before a set

The pattern of the maximum daily biomass before a fishing set was examined (Figure 11). The range of maximum biomass the day prior to a set was 0 to 140t, with most estimates being between 0 and 30t. An increase was detected through time, from 10 to 1 day before a set. Most buoys in the 3 days prior to a set had an estimated biomass between 25 and 60t (Figure 11). Similar patterns were found using the daily value and the 5 day moving average, although a more gradual increase leading to the fishing set was detected with moving averages (Figures 11 and S1).

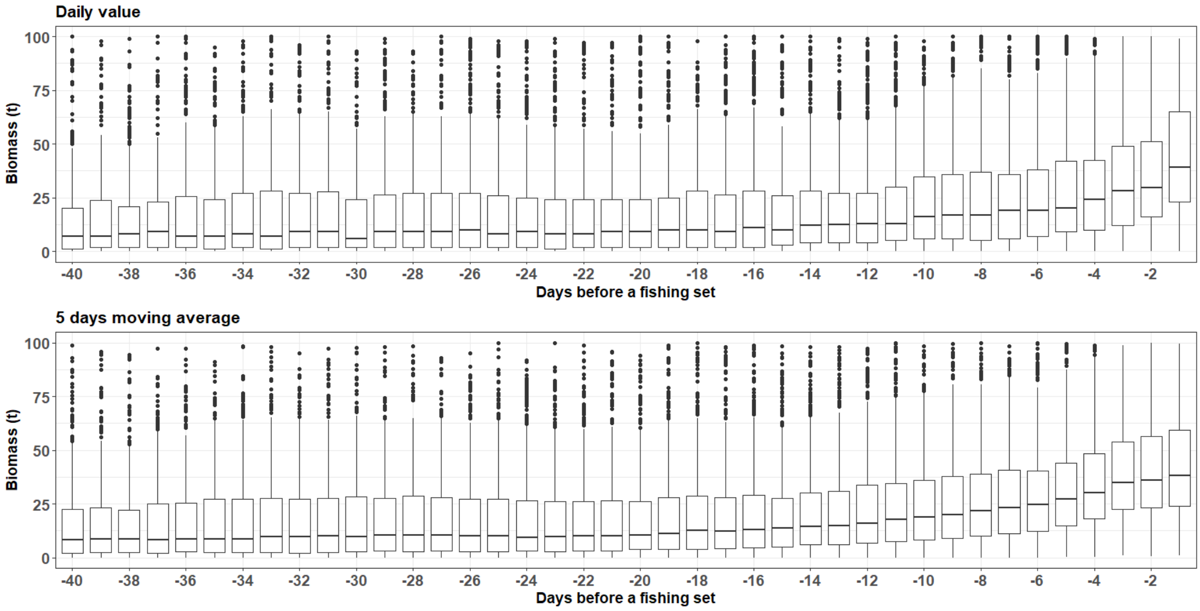

Figure 11. Evolution of the maximum daily biomass estimates (values >0.95 quantile not shown here, maximum of 340t) from Satlink echo-sounder buoys each day before a fishing set, using the daily value (top) or a 5-day moving average (bottom).

Slopes and intercepts from linear models of the estimated biomass per day over varying periods of time prior to the set were compiled (see linear regressions on Figures 9 and 10) over varying periods before a fishing set (40–2 days to the day before the set; Figure 12). This showed a general increasing trend in biomass before a set, except sometimes for periods just before the fishing set, when the slopes were sometimes negative. This could be due to overall high biomass levels already reached and some day-to-day variability. These parameters will be added, in addition to actual values of estimated biomass, to future models to further study the link between biomass and catch per set, as well as to characterize relative levels of biomass aggregated.

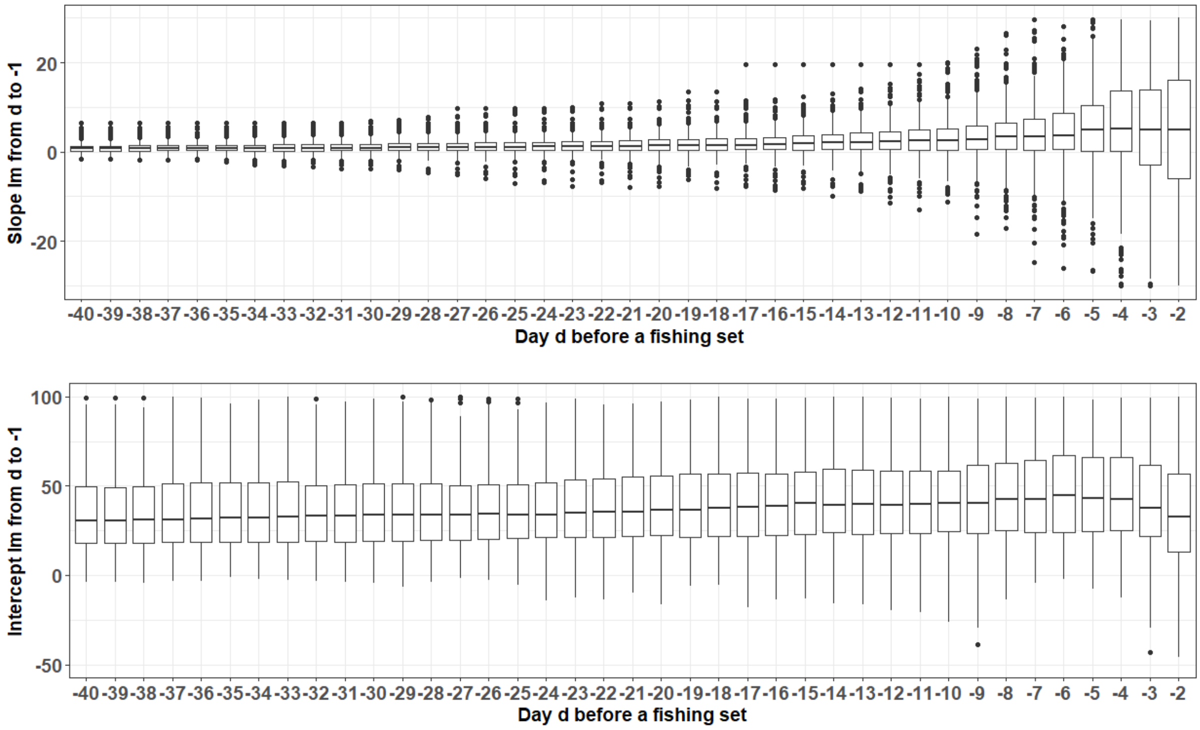

Figure 12. Slopes and intercepts from linear models of the maximum daily biomass estimates over varying periods prior to the set, depending on the period considered (40–2 days to the day before the set) from Satlink echo-sounder buoys.

When separating the dataset of buoys matched with a fishing set by large areas of the WCPO, aggregation patterns appear slightly different (Figure 13). In the north and southwest areas, aggregations before the fishing set appear gradual, with an increase over a 10-day period and an average daily biomass of 20–50t before the set. In the equator, the maximum daily biomass increases over a longer time-period prior to the fishing set and reaches higher level, between 25–60t (Figure 13).

Biomass accumulation prior to a set was also studied by depth layer, and showed that most biomass prior to a set would be located in the deeper layers, with a similar increasing trend as for the general estimated biomass (Figure 14). Adding bycatch per set would be interesting to better reflect the aggregated biomass levels estimated by the buoys at the different depth.

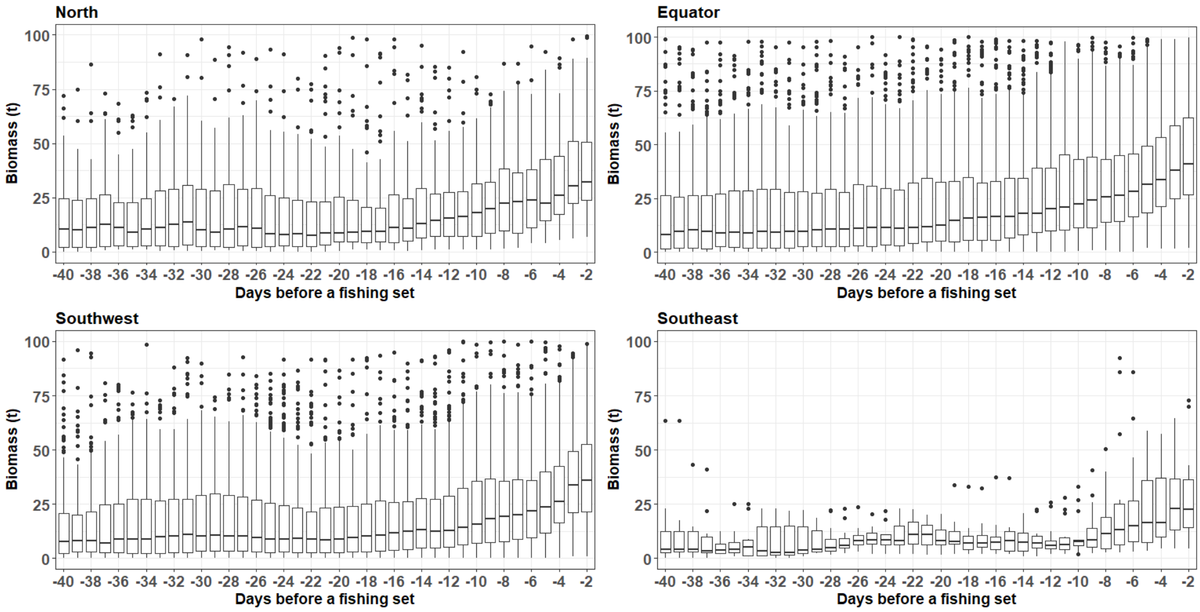

Figure 13. Evolution of the maximum daily biomass estimates from Satlink echo-sounder buoys each day before a fishing set using a 5-days moving average, per delineated areas of the WCPO.

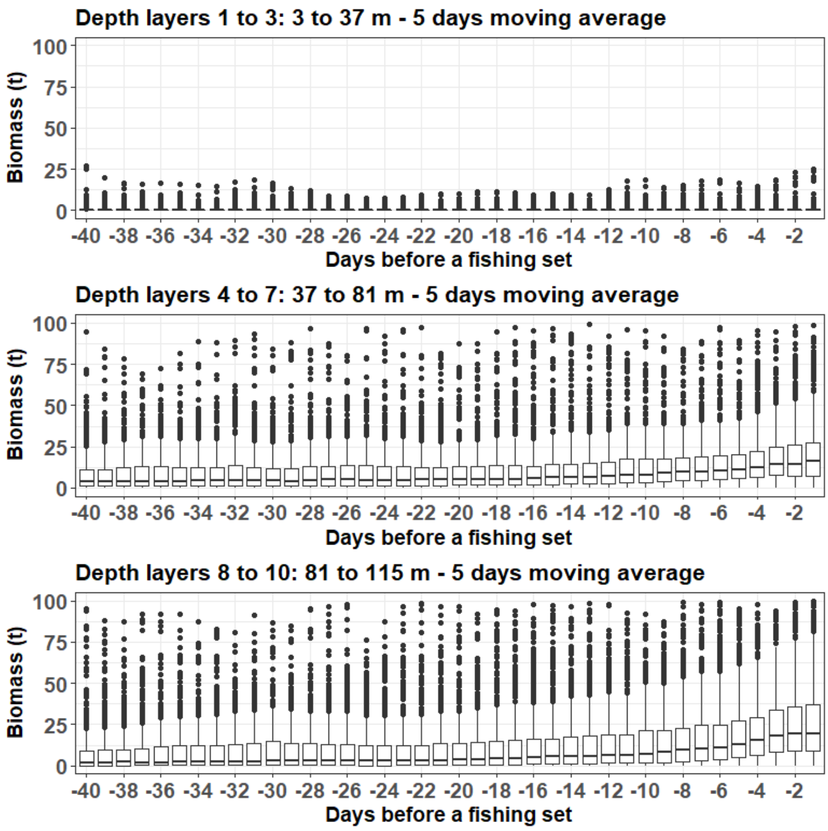

Figure 14. Evolution of the maximum daily biomass estimates from Satlink echo-sounder buoys each day before a fishing set, per depth layers using a 5-days moving average.

3.4 Relation between achieved catch and estimated biomass

Relationships between catch and 5-day moving average of biomass from echo-sounder buoys were compiled but no clear pattern could be identified (Figure 15). Preliminary investigation of biomass estimates per depth layer and total catch or catch per species were also performed (Figure 16). As mentioned previously, almost no biomass was detected for the shallower depth from 3 to 37m. For total catch and skipjack catch, higher biomass levels were detected for the largest sets, indicating that catch and estimated biomass could be related, at least for large aggregations. Biomass levels were higher in the 81–115m layer, except for very large sets where the 37–81m layer was of similar levels. For bigeye and yellowfin catch, higher biomass levels in the 91–115m layer were detected for intermediate catch (10 to 50t). No large yellowfin catches were included in the selected data set, while large bigeye catches corresponded to high biomass detected in the 37–81m layer (Figure 15).

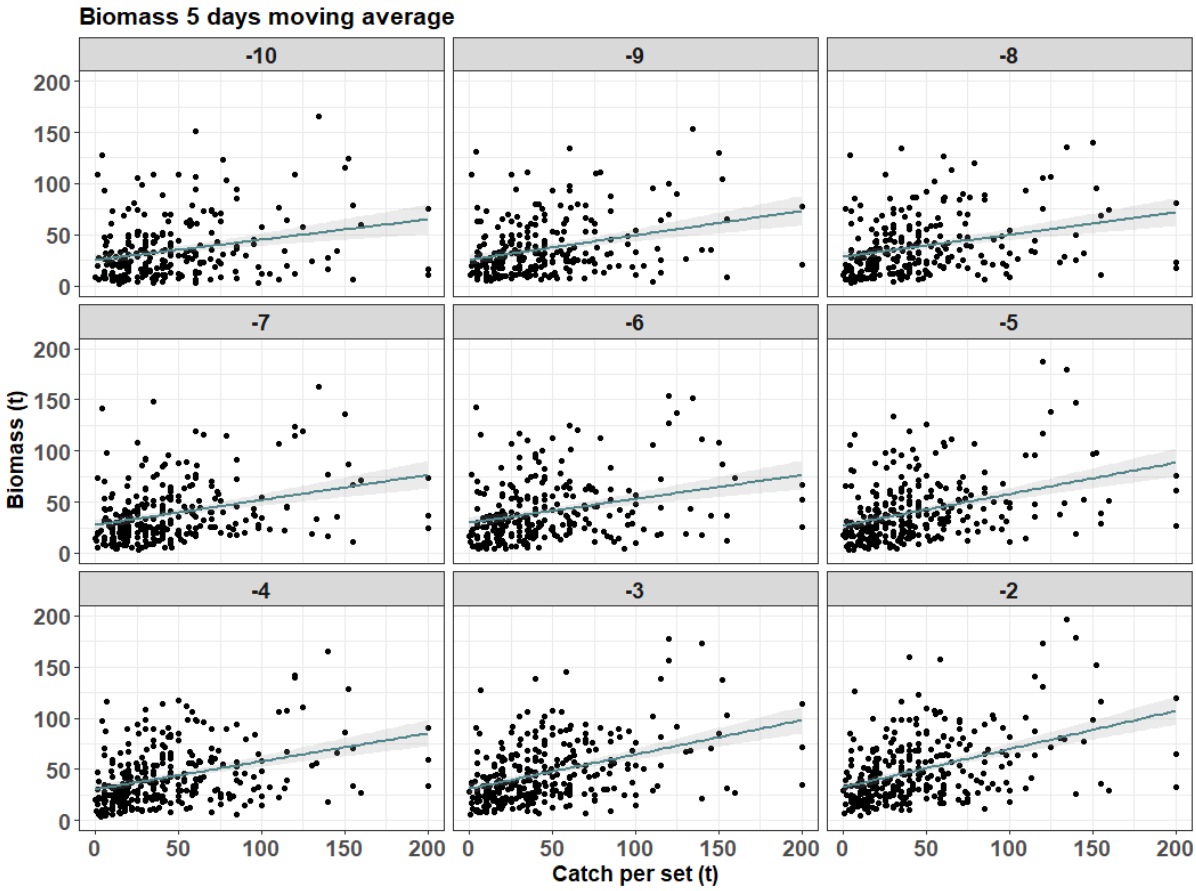

Figure 15. Relationship between catch per set (t) and the estimated biomass (t) from Satlink buoys over various periods preceding the set (note the low R^2, below 0.15 for all the regressions).

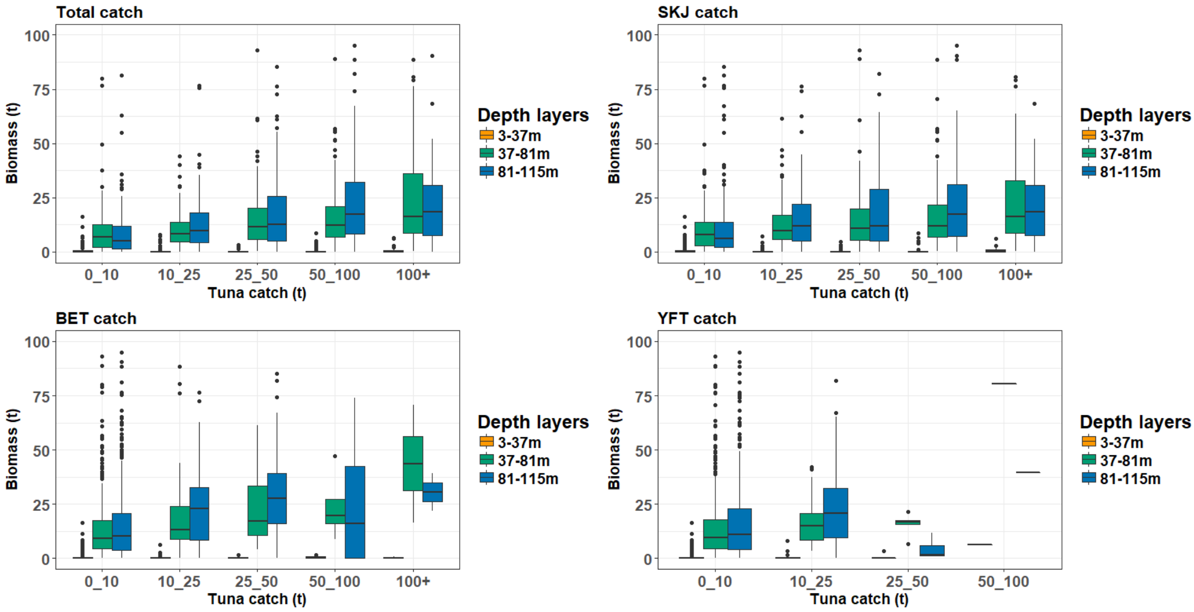

Figure 16. Daily biomass (t) estimated per depth layers over the 5 days prior to a fishing set function of total, skipjack, bigeye and yellowfin catch per set.

6. Discussion and Conclusion

This report presents data from over 4.7 million acoustic transmissions from echo-sounder buoys, from Satlink, Zunibal and Kato brands, deployed on FADs in the WCPO from 2016 to 2018 provided under a cooperative agreement with three commercial fishing companies. The three brands of echo-sounder buoys presented different characteristics, including the basic algorithm used to estimate total aggregated biomass, making inter-brand comparison difficult. Colonization and recolonization (i.e., after a fishing set) patterns were studied using echo-sounder and catch data (from logsheet and observer data). Refined analyses to more precisely identify sets and other FAD-related activities performed on buoys with available echo-sounder data allowed a FAD's 'life history' to be followed, and to better characterise biomass levels in relation to catch per set. Investigation of grouped or sequential deployments also allowed identification of newly deployed FADs. Biomass estimates in relation to total catch per set were investigated but the raw biomass estimates from echo-sounder data were highly variable on a day-to-day basis. The ability to accurately track a FADs 'life history' could have significant implications for integration of FAD associated information into regional stock assessments.

Many factors may influence both the echo-sounder estimated biomass and the catch per set. First, the whole school may either not be detected by the echo-sounder, much less caught during the set. Second, a mix of species will influence the echo-sounder readings; the algorithm for estimating biomass is programmed to estimate biomass for schools of skipjack only. In particular, bycatch species will also be detected by the echo-sounder, but will not appear in the logsheet catches.

As previously noted, this is an on-going analysis as scheduled within Project 88. In general, it would be relevant to study the catch/biomass relationships by large sub-areas of the WCPO, as they present different environmental characteristics. In particular, it is important to isolate analyses for the equatorial region in which higher current speeds are experienced that could lead to overestimates of the biomass by the echo-sounder. It is also important to account for the precise time relative to sunrise for both the echo-sounder data and the fishing set. For instance, if the set starts after sunrise the tuna school may have already started to leave the FAD, leading to a higher estimated biomass compared to the tuna catch. It would also be important to identify and separate the purely targeted FAD sets from the more opportunistic ones (set on a nearby FAD when cruising, or set on a FAD belonging to another vessel that was found at-sea). In order to more effectively account for all these parameters, access to a larger dataset covering all the different areas of the WCPO is needed.

This study continues to increase our knowledge of biomass accumulation dynamics and of the signal captured by echo-sounder buoys. A big challenge within this project relates to identifying with the most precision, fishing activities that are performed on the trajectories available. Although that information exists in the fishery data, identification of a precise record of buoy ID number remains a challenge. Accordingly a subset of the dataset was selected, for which trajectory and fishing activities corresponded, with high confidence, to the same buoy attached to a FAD. Several parameters were compiled here, that could be used in further analyses performed on the dataset. These parameters included: FAD soak time, drift speed, trends in biomass accumulation leading to a fishing set, biomass moving averages, biomass by depth, total catch or catch per species, moon phase, time of the set, and spatial areas. Bycatch per set, as well as tuna discards, as recorded by observers will also be added to better characterize the whole catch per set and compare it to the biomass estimated by the echo-sounder buoy.

Next steps in the project will use the data subset identified here and the parameters mentioned above to investigate the two main objectives of project 88:

1) Investigate the potential use of acoustic buoys on drifting FADs to provide new fishery-independent data, and in particular indices of abundance, for stock assessments;
2) Investigate the link between high aggregated biomass and the level of small of bigeye and yellowfin in the catch.

In particular, models to study the influence of the various parameters compiled on the relationship between catch per set and estimated biomass will be performed. The trends and levels of biomass, total or per depth layers, in the period before a fishing set will be used to attempt to characterise a relative index of abundance, which would then be compared to other sections of trajectories. Investigations using the raw acoustic data recorded by some buoy brands could also be performed. In particular to be able to compare the estimated biomass between the different satellite echo-sounder buoy brands.

We invite WCPFC-SC16 to:

- Note the preliminary results from Project 88 of acoustic data from echo-sounder buoys deployed on FADs, and note the proposal for future investigations.
- Note the potential, over the longer-term, to derive an index of abundance that could be used in stock assessments.
- Recommend the need for better labelling or identification of particular FAD buoys (e.g. via the buoy identification numbers) by commercial vessel operators or via observer reports.
- Endorse the continued cooperative relationship with the fishing community to obtain business confidential data for analysis by regional scientists, particularly with regard to FADs, and the fishing strategies involved in their use. Highlight the need for additional data covering the

whole WCPFC convention area and encourage other industry partners to become involved in the project.

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References

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

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

Escalle, L., Vanden Heuvel, B., Clarke, R., Brouwer, S., Pilling, G., 2019b. Report on preliminary analyses of FAD acoustic data. WCPFC Sci. Comm. WCPFC-SC15-2019/MI-WP-13.

Escalle, L., Vidal Cunningham, T., Hare, S., Hamer, P., Pilling, G., 2020b. Estimates of the number of FAD deployments and active FADs per vessel in the WCPO. WCPFC Sci. Comm. WCPFC-SC16-2020/MI-IP-13.

Gershman, D., Nickson, A., O'Toole, M., 2015. Estimating the use of FAD around the world, an updated analysis of the number of fish aggregating devices deployed in the ocean. Pew Environ. Gr. 1–24.

Lopez, J., Moreno, G., Sancristobal, I., Murua, J., 2014. Evolution and current state of the technology of echo-sounder buoys used by Spanish tropical tuna purse seiners in the Atlantic, Indian and Pacific Oceans. Fish. Res. 155, 127–137. https://doi.org/10.1016/j.fishres.2014.02.033

Maufroy, A., Chassot, E., Joo, R., Kaplan, D.M., 2015. Large-scale examination of spatio-temporal patterns of drifting fish aggregating devices (dFADs) from tropical tuna fisheries of the Indian and Atlantic Oceans. PLoS One 10, 1–21. https://doi.org/10.1371/journal.pone.0128023

Moreno, G., Dagorn, L., Capello, M., Lopez, J., Filmalter, J., Forget, F., Sancristobal, I., Holland, K., 2016. Fish aggregating devices (FADs) as scientific platforms. Fish. Res. 178, 122–129. https://doi.org/10.1016/J.FISHRES.2015.09.021

Williams, P., Reid, C., Ruaia, T., 2020. Overview of tuna fisheries in the WCPO, including economic conditions – 2019. WCPFC Sci. Comm. WCPFC-SC16-2020/GN-IP-01.

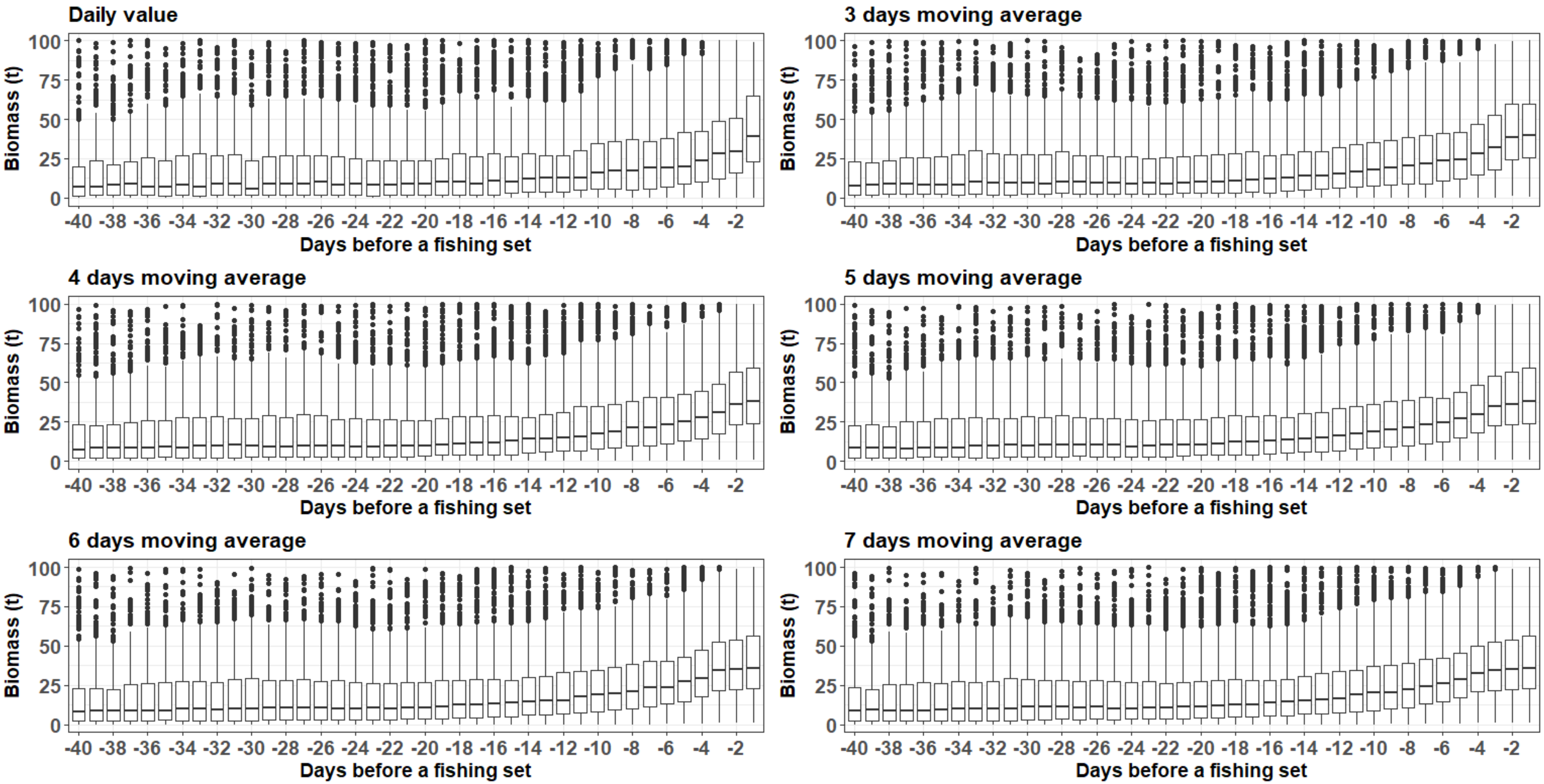

Figure S1. Evolution of the maximum daily biomass estimates from Satlink echo-sounder buoys each day before a fishing set, using the daily value or moving average over various periods from 3 to 7 days.