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Analysis of purse seine set times and school association using observer data

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1 Introduction

The Western and Central Pacific Fisheries Commission (WCPFC) has developed a number of Conservation and Management Measures (CMMs) aimed at managing the bigeye, yellowfin and skipjack tuna stocks in the Western and Central Pacific Ocean (WCPO) (CMM2008-01; CMM2009-02; CMM2011-01; CMM2012-01; CMM2013-01; CMM2014-01; and CMM2015-01). An important part of this management strategy is the reduction of fishing mortality on bigeye tuna from the purse seine fleet. This includes seasonal prohibitions on the setting on fish schools associated with fish aggregating devices (FADs) (known as the FAD closure periods), as these sets have a higher proportion of small bigeye and yellowfin tuna, than sets made on free swimming fish. The WCPFC has defined a Fish Aggregation Device (FAD) in paragraph 3 of CMM2009-02 to includes "*any object or group of objects, of any size, that has or has not been deployed, that is living or non-living, including but not limited to buoys, floats, netting, webbing, plastics, bamboo, logs and whale sharks floating on or near the surface of the water that fish may associate with*" (WCPFC, 2009)

The FAD closure was initially two months long in 2009, it was extended to three months for 2010-2012 and four months from 2013 onwards. There are some exemptions to the closure for domestic vessels; and the 4^{th} month does not apply to some fleets that choose an annual FAD set limit. Therefore, some FAD sets are made legally during the FAD closure.

For FAD closures to succeed, the management authority needs to be confident that they are being adhered to. Whilst this FAD closure does not allow the servicing or deployment of FADs, it does not require that all FADs be removed from the water prior to the closure. Therefore, during the closure, FADs will be in the water aggregating fish.

In 2009, the Pacific Community (SPC) was requested to undertake an analysis in to assess whether the time of day could be used to determine whether or not a purse seine set was a FAD set (Harley et al., 2009). FAD sets are usually made pre-sunrise while free school sets tend to be made during daylight hours when fish are visible at the surface. Harley et al. (2009) used vessel logsheets to assess the time of day at which the set took place, specifically the time relative to local sunrise, to assess whether a set was associated with a FAD or not. That analysis required the exclusion of approximately 76% of logsheet records as they could not be sure of the set time. As a result they recommended undertaking a similar analysis using observer data where it is hoped that recording may be more standardised. This paper repeats the analysis undertaken by Harley et al. (2009) but uses observer data and includes the species composition of the catch to assess set type.

2 Methods

2.1 Data

The analysis was based on observer recorded catch and effort data, held by the SPC, from January 2010 to December 2015 covering the area of application of the FAD closure (20^oN to 20^oS). The WCPFC/IATTC overlap area (1,409 records) and archipelagic waters were excluded (11,982 records), leaving 114,218 sets for the remaining analyses. This period was chosen as it covers the most recent period when there has been 100% observer coverage on the tropical purse seine fishery and the FAD closure is at least three months long. Observers record FAD set types as shown in Table 1, these groupings were used to define unassociated and associated sets are shown, other set types were analysed separately.

To consistently estimate the time of local sunrise, a standard time is required (e.g. GMT). This is because not all vessel captains set ships' time to the local time zone, some use time at port of origin, time at home port or simply don't re-set the ships clock when they change time zones. Therefore, as the goal of the analysis was to calculate set time relative to local sunrise, we use the observer logsheets where the observer records their start of the work day in both GMT and the ships time. The difference between the two was then used to convert the ships time into GMT for each set. The set time, in GMT, was then converted to local time using the GMT, latitude and longitude with the R Package *XML* (R Core Team, 2015).

The next step was to calculate the time at official sunrise. This is defined as the time when the sun's zenith is at 90^o to the horizon. Official sunrise differs from civil, nautical and astronomical sunrise, which refer to sunrise as the time when the sun is at 6^o, 12^o and 12^o-18^o below the horizon respectively. This calculation was made using the US navy database of estimated sunrise times at each latitude and day of the year (Teets, 2003), date, latitude and longitude and the *suncalc* function in the R Package *RAtmosphere* (R Core Team, 2015). Finally, the difference between set time and sunrise was calculated. The records were then grouped into associated and unassociated sets and analysed by flag and set type. This was examined for the whole year, and inside and outside the FAD closure period.

Table 1: SPC observer logsheet code, FAD set type and groupings used to define unassociated and associated sets for this analysis.

Set-type	Description	Group
1	Unassociated	Unassociated
2	Feeding on baitfish	Unassociated
3	Drifting log	Associated
4	Drifting FAD	Associated
5	Anchored FAD	Associated
6	Live whale	
7	Live whale shark	
8	Other	

2.2 Clustering

The species composition was assessed for each set to assess if FAD and free school groups could be distinguished. For the cluster analysis the main tuna species were retained. As over 350 different bycatch species have been recorded by observers, all other species were grouped into three groups. Using the data presented in Peatman et al. (2017) these groups were chosen as: 1) those species most likely to be associated with a FAD; 2) those most likely to be associated with a free school; and 3) a range of other species that occur both in free school and FAD sets as well as all other bycatch species. The first bycatch group consisted of species often associated with FADs: rainbow runner (*Elagatis bipinnulata*); triggerfish (Balistidae); and mackerel scad (*Decapturus macarellus*). The second group consisted of bycatch species often associated with free school sets: all marlin species (Istiophoridae); and manta and mobulid rays (Myliobatidae). The third group was made up of all other species. The proportion of each species and species group was then determined for each set. Clustering was performed on the species proportions in R (R Core Team, 2015) using a k-means, which aims to partition the points into k groups such that the sum of squares from points to the assigned cluster centres is minimized.

3 Results and Discussion

The results presented here are similar to those of Harley et al. (2009). There are clear patterns in set time relative to local sunrise for the different ungrouped school associations (Figure 1). Sets on free schools (unassociated) and sets on free schools feeding on bait fish are broadly similar and mostly made in daylight hours. Anchored FADs are set on slightly earlier than drifting FADs which are set on closer to sunrise (Figure 1). The data indicate that some unassociated sets are made prior to sunrise; this may be due to the definition of sunrise used here, and the fact that some light will be available prior to the sun appearing on the horizon. No attempt was made to estimate first light as it would change seasonally relative to sunrise, but it could be up to an hour and a half before sunrise. The logsheet data analysed by Harley et al. (2009) showed that for anchored FADs there was a second peak about eight hours after sunrise. This was not apparent in the observer data analysed here and may have occurred in the Harley et al. (2009) analysis through non-GMT time reporting by some vessels (from Papua New Guinea and the Philippines).

Few sets were made on whales and whale sharks and these were almost always during daylight, and both show a trend for more sets later in the afternoon or early evening (about 11 hours after sunrise). Although some of these may not have been directed at whale sharks, as it has been noted in other reports (Tremblay-Boyer and Brouwer, 2016) that small whale sharks may get inadvertently caught in unassociated purse seine sets as they are not seen by the vessel prior to setting, in some cases these may then be recorded by the observer as a whale shark set.

There were marked similarities between the set times on unassociated and bait fish sets so these were grouped as unassociated; and log, drifting FAD and anchored FADs were similar and were grouped as associated sets for the remaining analyses. Overall in the analysis dataset there were more unassociated sets observed (Figure 2). Unassociated sets are undertaken predominantly (90%) in daylight hours and the associated sets are predominantly(90%) made prior to sunrise.

The cluster analysis revealed five main groups: two target species groups where sets consisted mostly of either skipjack or yellowfin tuna; a bigeye tuna cluster; and two bycatch clusters one associated with FADs; and another associated with free schools. The "all other bycatch group" was not influential in the analysis and was identified as a seperate cluster by the k-means test. The analysis revealed that the skipjack and yellowfin groups were the predominant group for all set types. However, the bigeye and FAD-bycatch groups made up about one third of the FAD sets prior to sunrise.

Sets declared as unassociated more than 1 hr before sunrise are likely to be erroneous, and something to be clarified during observer debriefing and data quality checking. Therefore, some unassociated sets prior to sunrise may be misclassified. From the species composition, some sets declared as unassociated 2h and 15 minutes before sunrise appear to be FAD-like and the timing suggests that they could be sets on anchored FADs. However, the proportions of these sets at this time of day is very low. More rigorous clustering such as the random forest analysis undertaken by Hare et al. (2015), which could include other factors such as fish size and vessel flag, could be explored in future to strengthen the designation of sets as associated or unassociated.

Outside of the FAD closure periods, 90% of associated sets were made prior to sunrise while 92% of unassociated sets were made during daylight hours. During the FAD closure periods the number of FAD sets was substantially reduced, but of the FAD sets that were made, 79% were made prior to sunrise, while 92% of unassociated sets were made during daylight hours. These proportions seem to be fairly consistent across fleets (see Appendix I). While the proportion of associated sets before sunrise is similar to Harley et al. (2009), who analysed vessel logsheets, the observer data showed slightly more unassociated sets before sunrise; Harley et al. (2009) found just 3%. The reasons for this difference are unclear but may relate to variation of perceivable light relative to sunrise (see below).

More sets are made outside of the FAD closure period than during the closure, simply as a result of the shorter time for the latter, nevertheless there appears to be evidence of FAD setting during the closure period which is allowed in some circumstances (Figure 3). These trends are not consistent across fleets (Appendix 1), with some fleets having similar trends inside and outside the FAD closure period, with strong peaks prior to sunrise, while others have very different fishing patterns during and outside the FAD closure. For these fleets it is clear that they rely on FADs outside the FAD closure but then switch to free school fishing during the closure months (e.g. the USA) (Figure A16).

While there are strong peaks for FAD fishing prior to sunrise not all FAD sets occur at this time and not all sets made before sunrise are FAD sets. Some of this variation is related to latitude. Close to the equator there are more sets and a higher proportion of associated sets and few unassociated sets (Figure 4). As you move further away from the equator the proportion of unassociated sets increases. Furthermore, as you move further away from the equator the number of unassociated sets at or before sunrise increases (Figure 4), this is likely to be related to the amount of perceivable light prior to sunrise, the closer to the equator you are the closer to sunrise light becomes visible, while in higher latitudes light becomes visible earlier relative to sunrise.

Therefore, using the time of day in relatin to sunrise to estimate set type will have some error associated with it, and in the next iteration of this work first light (Nautical Dawn) will be used instead of sunrise. There are clear differences reported in the juvenile bigeye and yellowfin tuna catch from the different set types (Lawson 2013, Pallarés et al. 2003). It may therefore be useful to estimate set type more accurately by adding species composition information (by EEZ) to set time relative to sunrise in future. In addition, any analysis assessing set types during the FAD closure period will also need to take latitude into account. Alternatively, we could consider set time relative to the first perceivable light.

Acknowledgements

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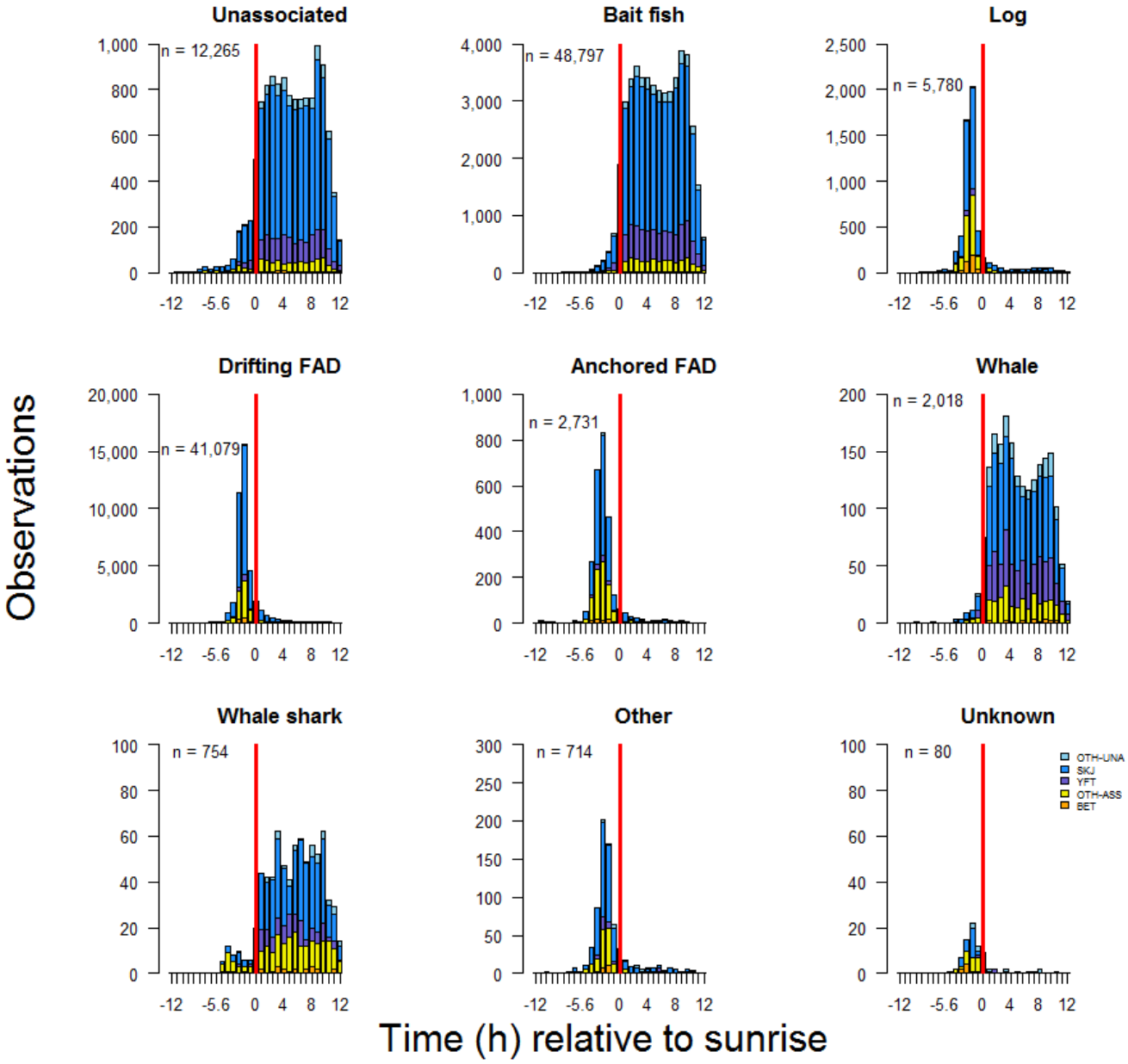

Figure 1: Set time relative to local sunrise where time = 0 (red line), in 48 minute time bins, for all fleets by school association. Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.

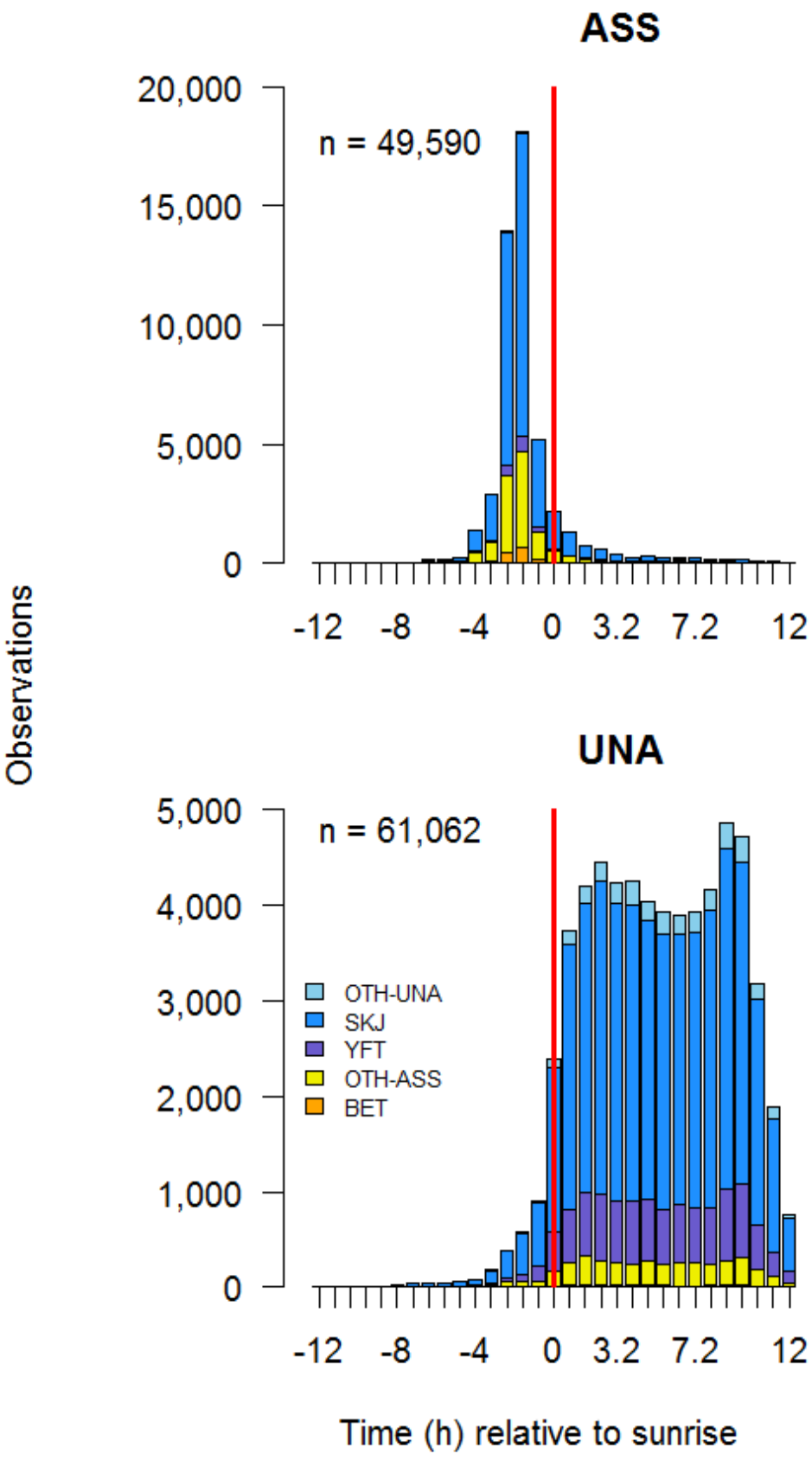

Figure 2: Number of sets relative to sunrise where time = 0 (red line), in 48 minute time bins, for associated (top) and unassociated (bottom) set types from 2010-2015. Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.

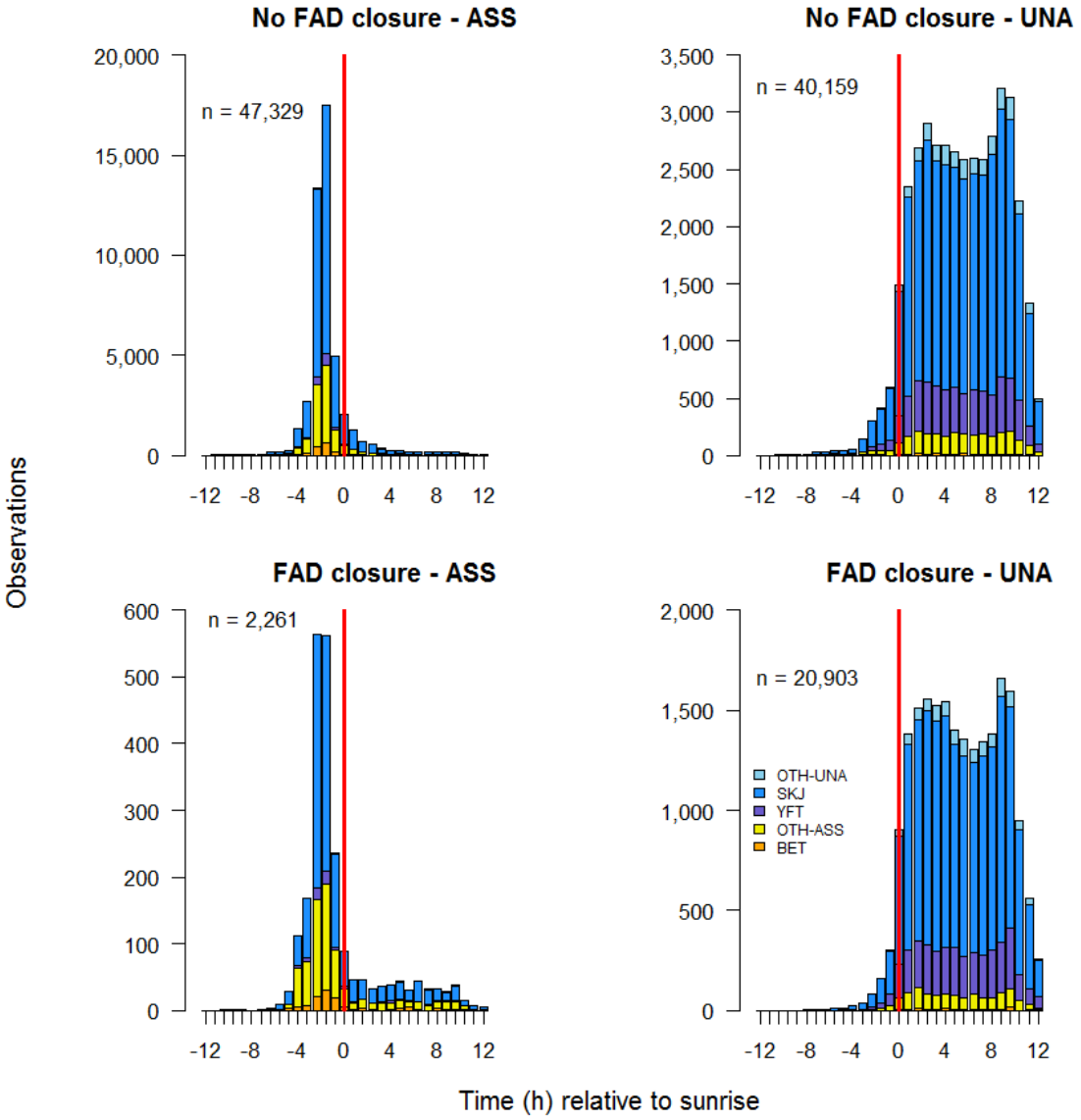

Figure 3: Purse seine set times relative to sunrise where time = 0 (red line), in 48 minute time bins, during the non-FAD closure period and the FAD closure periods in the WCPO from 2010-2015. Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.

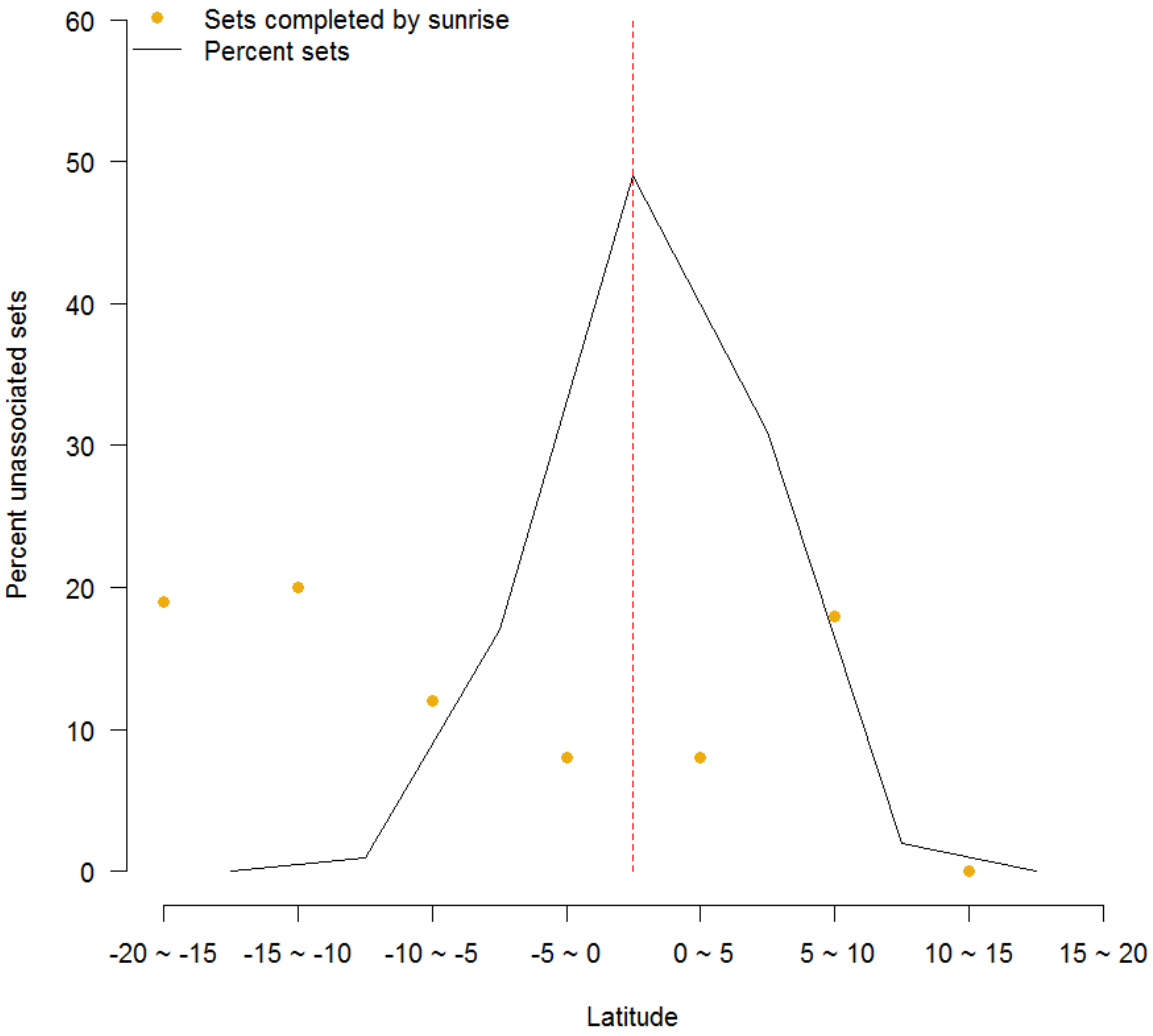

Figure 4: The proportion of unassociated sets by latitude prior to sunrise (gold points), and the proportion of sets by latitudinal band between 2010-2015. The red vertical line represents the equator

4 Appendix I

Below we present specific data for each country by set type and inside and outside the FAD closure. Note that some flaggesd vessels fishing in particular countries waters and in some years, may have been able to set on FADs legally during the FAD closure. These allowances have been made through exemptions to the Conservation amd Management Measure for tropical tunas (WCPFC, 2015). Noting the comment above that the data indicate that some unassociated sets are made prior to sunrise, which may be due to the definition of sunrise used here, and the fact that some light will be available prior to the sun appearing on the horizon. While no attempt was made to estimate first light as it changes seasonally relative to sunrise, it could be up to 100 minutes prior to sunrise. In this case if the red bar in the plots below was to represent first light, it would shift the bar up to three bins to the left in the plots presented here. In order to get some indication as to how this may impact the results Table A1 shows the percentage of associated and unassociated sets made prior to specific times before sunrise, representing first light occuring one hour or one and a half hours prior to sunrise.

Table A1: Percentage of sets of each type made between 12 hours prior to official sunrise and: official sunrise; one hour before sunrise; and 1.5 hours before sunrise.

Time relative to sunrise	ASS	UNA
Sunrise		
Predawn	90	10
1 hour before sunrise		
Predawn	95	5
1.5 hours before sunrise		
Predawn	96	4

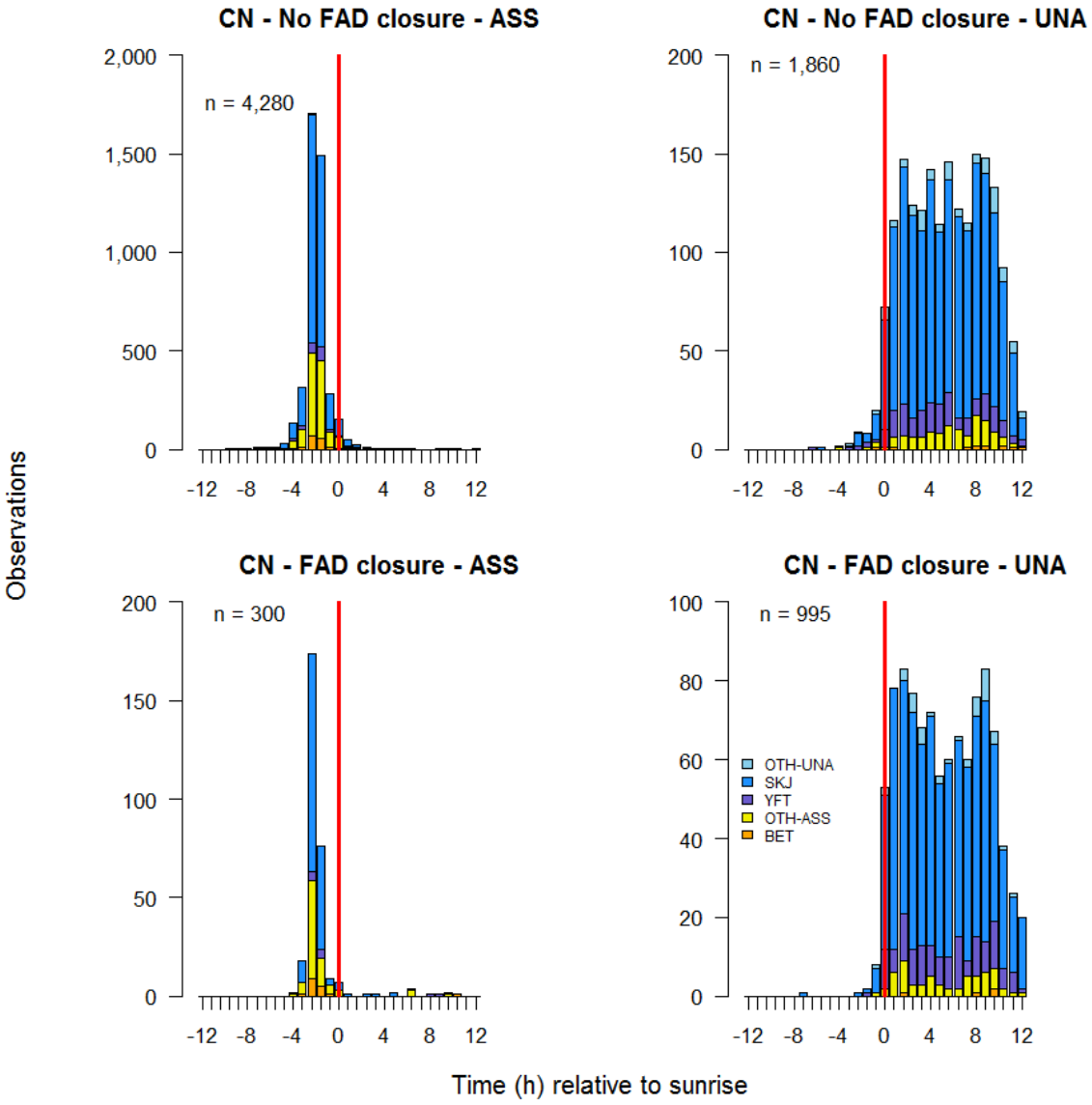

Figure A1: Purse seine set times relative to sunrise where time = 0 (red line), in 48 minute time bins, during the non-FAD closure period (top) and the FAD closure period (bottom) for Chinese flagged vessels fishing in the WCPO between 20^{o}N and 20^{o}S from 2010-2015. Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.

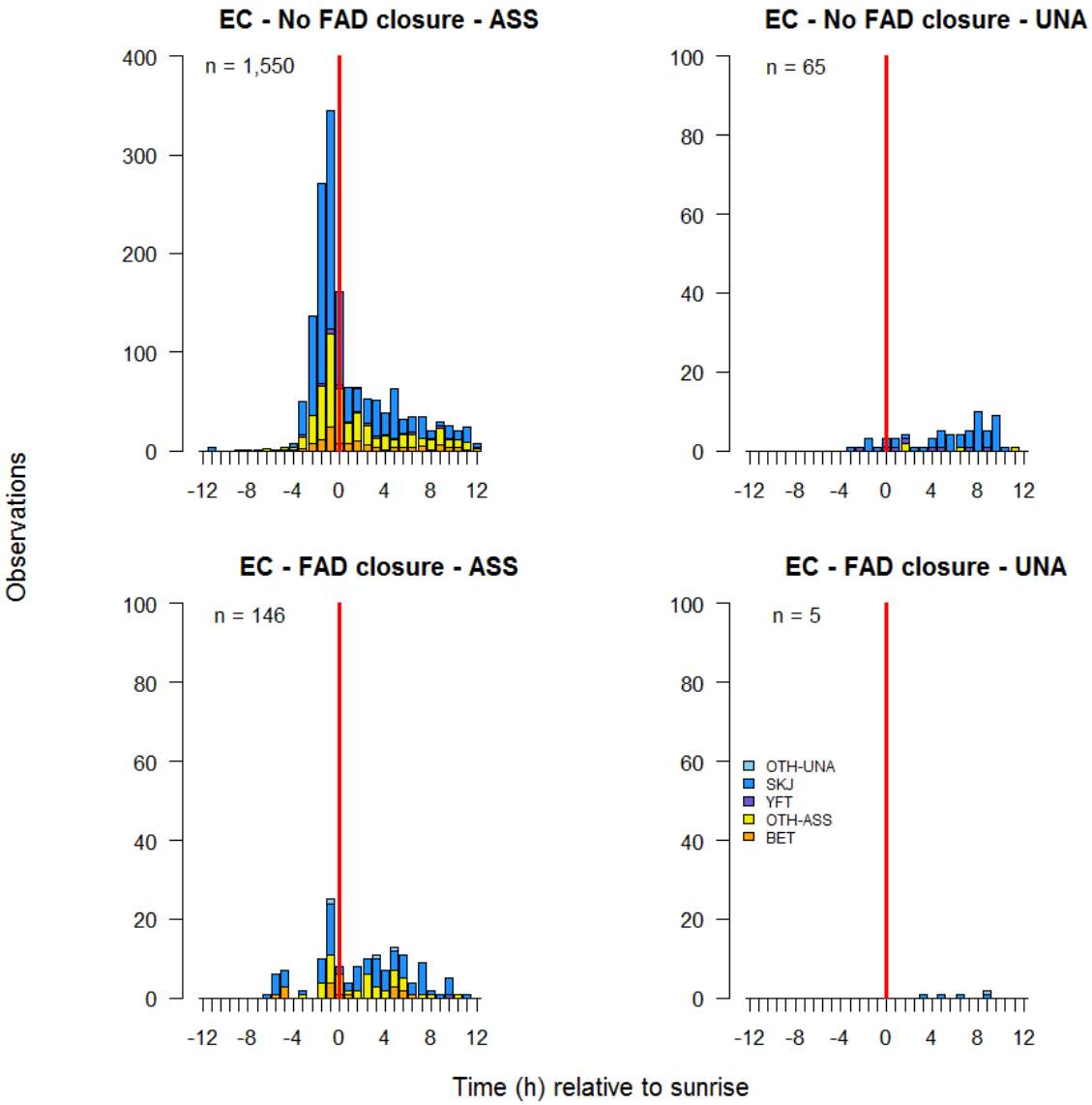

Figure A2: Purse seine set times relative to sunrise where time = 0 (red line), in 48 minute time bins, during the non-FAD closure period (top) and the FAD closure period (bottom) for Ecuadoran flagged vessels fishing in the WCPO between 20°N and 20°S from 2010-2015. Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.

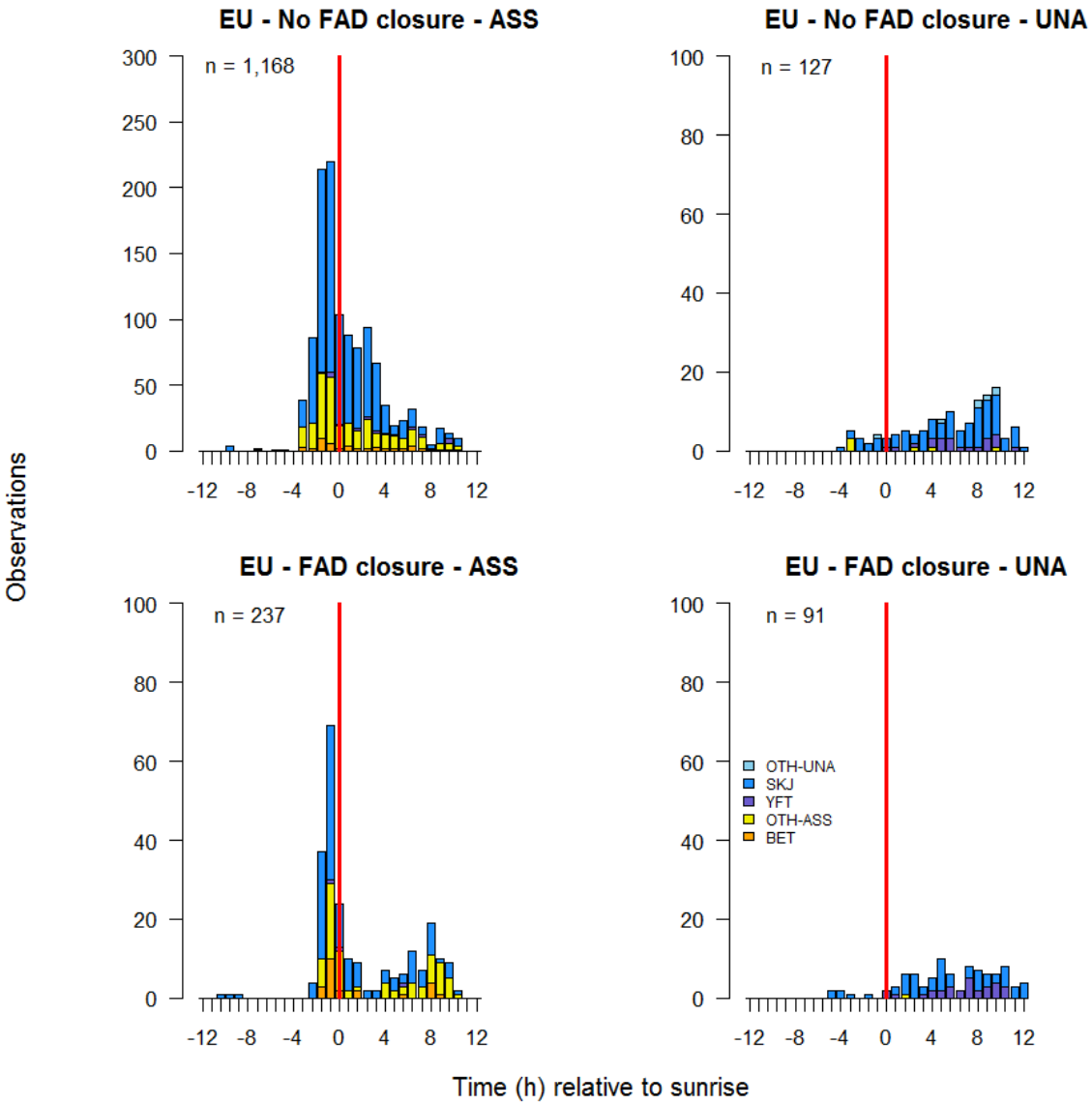

Figure A3: Purse seine set times relative to sunrise where time = 0 (red line), in 48 minute time bins, during the non-FAD closure period (top) and the FAD closure period (bottom) for European Union flagged vessels fishing in the WCPO between 20°N and 20°S from 2010-2015. Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.

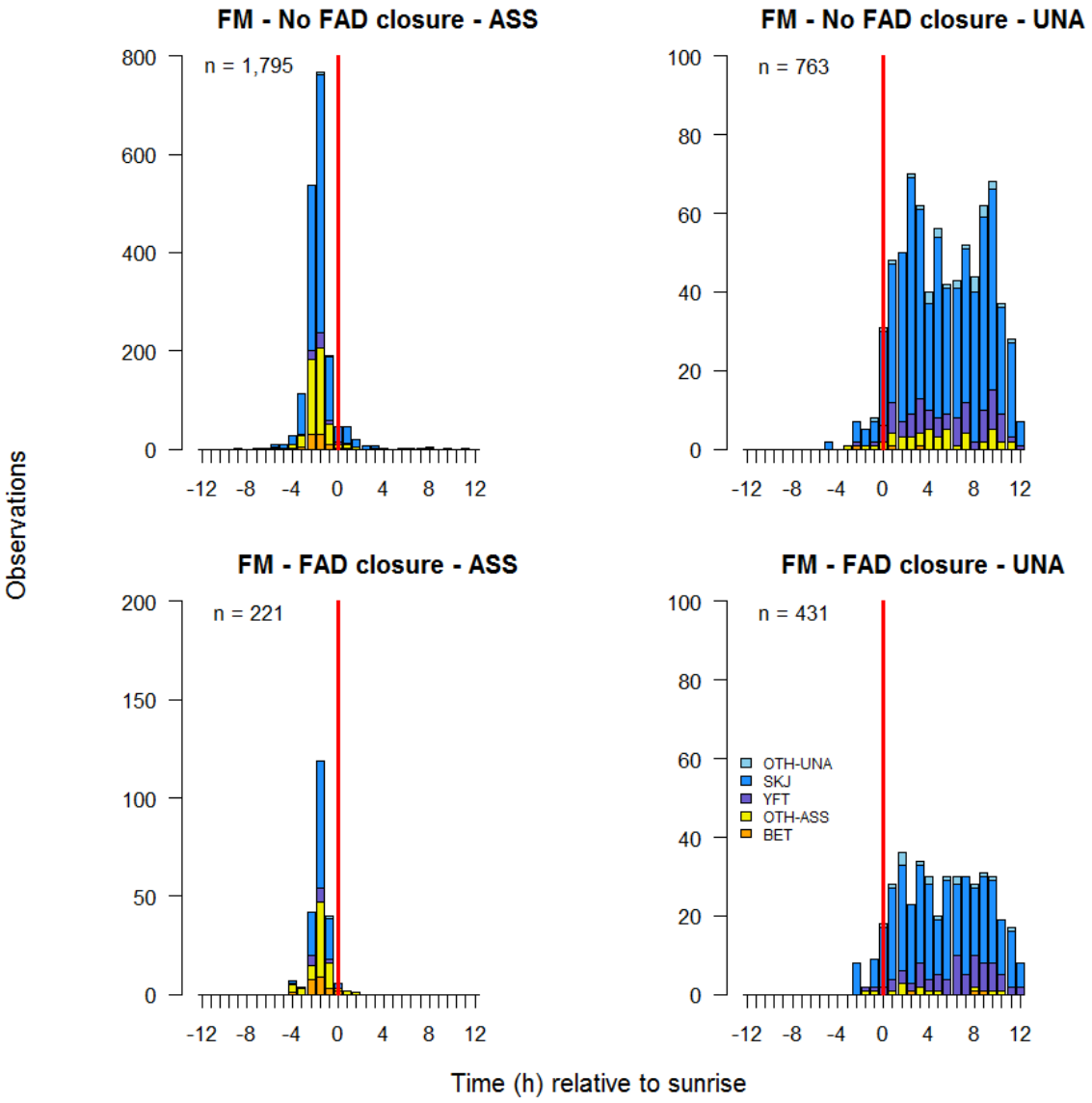

Figure A4: Purse seine set times relative to sunrise where time = 0 (red line), in 48 minute time bins, during the non-FAD closure period (top) and the FAD closure period (bottom) for Federated States of Micronesia flagged vessels fishing in the WCPO between 20°N and 20°S from 2010-2015. Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.

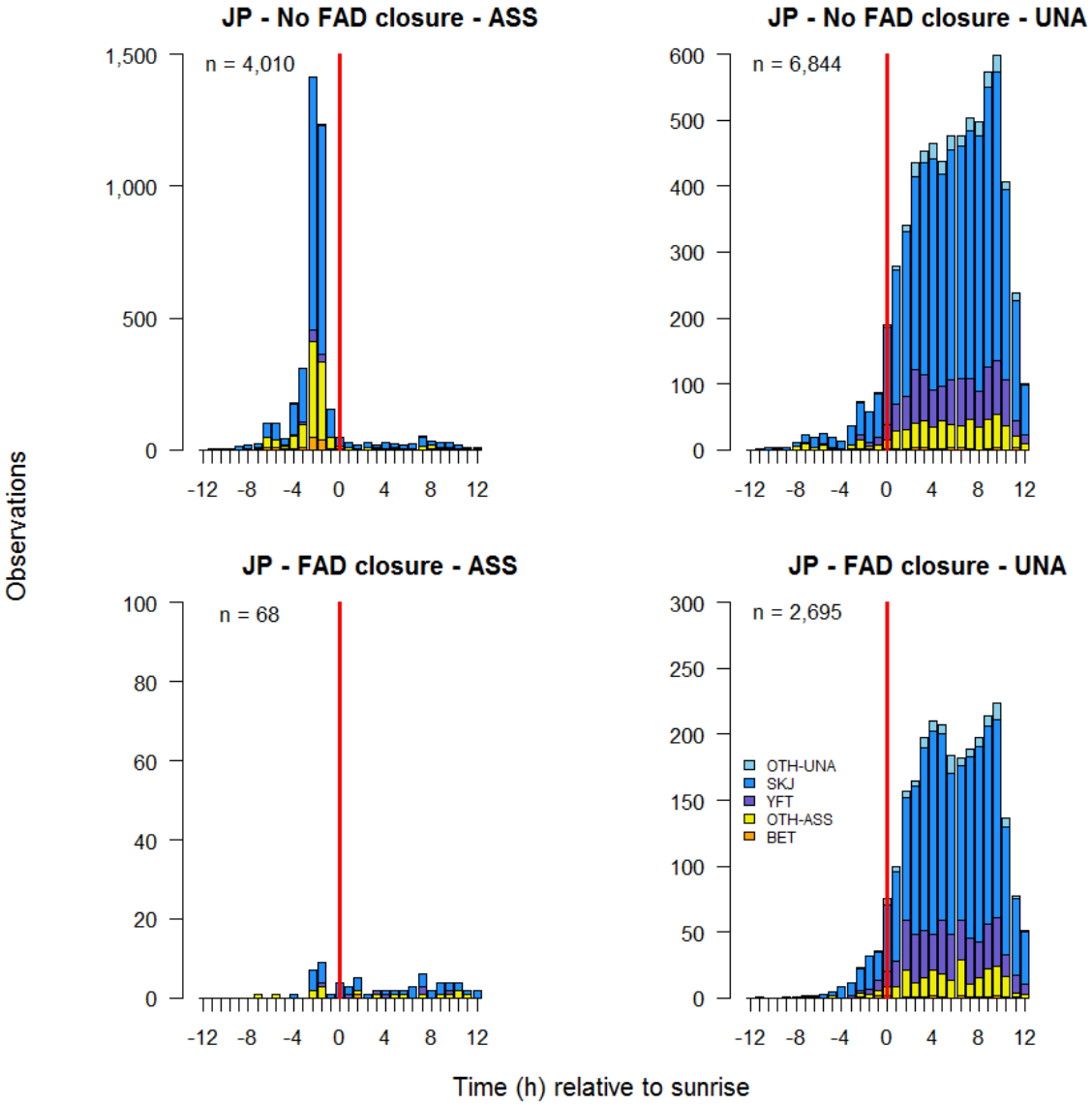

Figure A5: Purse seine set times relative to sunrise where time = 0 (red line), in 48 minute time bins, during the non-FAD closure period (top) and the FAD closure period (bottom) for Japanese flagged vessels fishing in the WCPO between 20^{o}N and 20^{o}S from 2010-2015. Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.

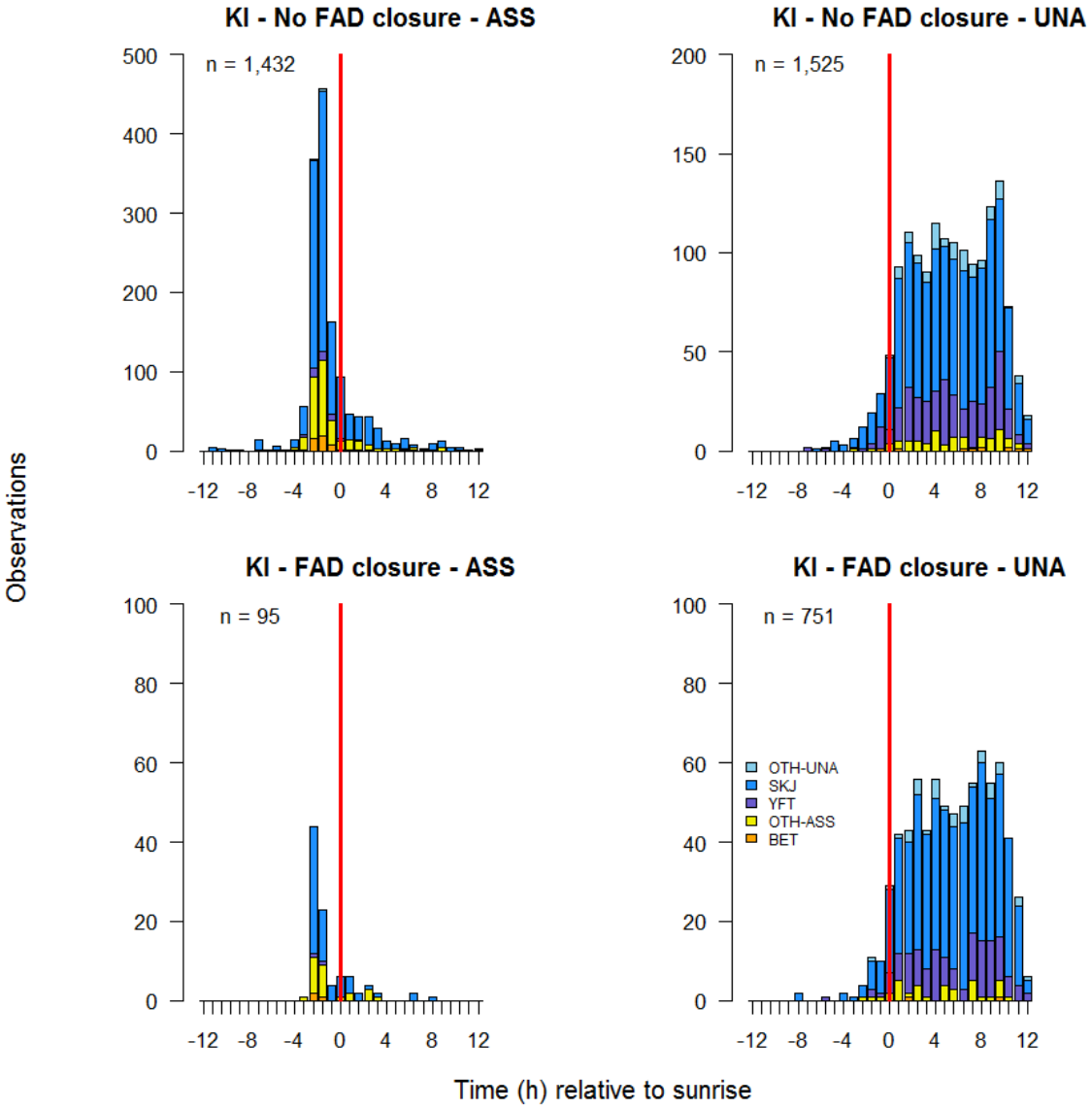

Figure A6: Purse seine set times relative to sunrise where time = 0 (red line), in 48 minute time bins, during the non-FAD closure period (top) and the FAD closure period (bottom) for Kiribati flagged vessels fishing in the WCPO between 20^{o}N and 20^{o}S from 2010-2015. Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.

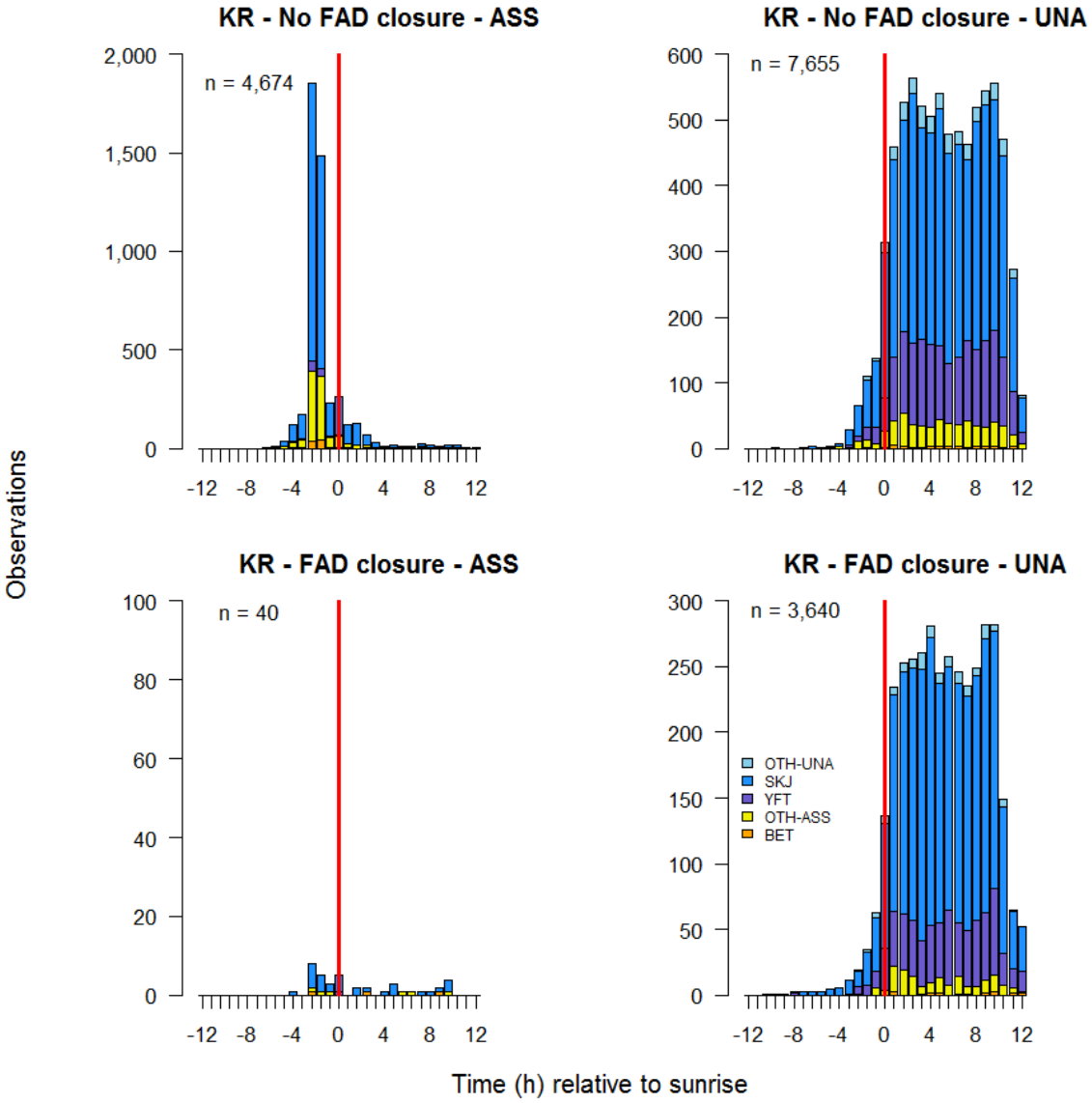

Figure A7: Purse seine set times relative to sunrise where time = 0 (red line), in 48 minute time bins, during the non-FAD closure period (top) and the FAD closure period (bottom) for Korean flagged vessels fishing in the WCPO between 20^{o}N and 20^{o}S from 2010-2015. Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.

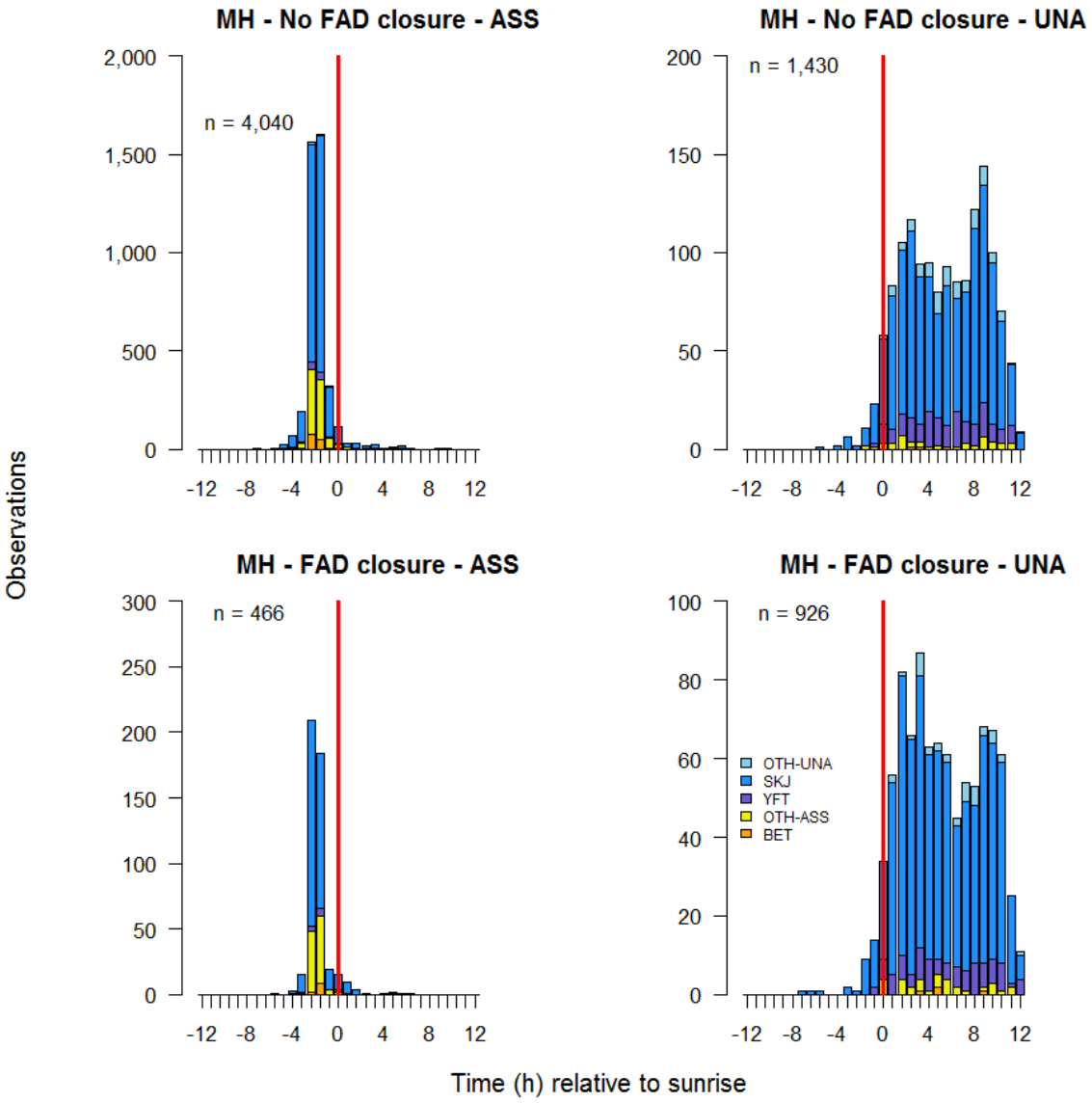

Figure A8: Purse seine set times relative to sunrise where time = 0 (red line), in 48 minute time bins, during the non-FAD closure period (top) and the FAD closure period (bottom) for Marshall Islands flagged vessels fishing in the WCPO between 20^{o}N and 20^{o}S from 2010-2015. Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.

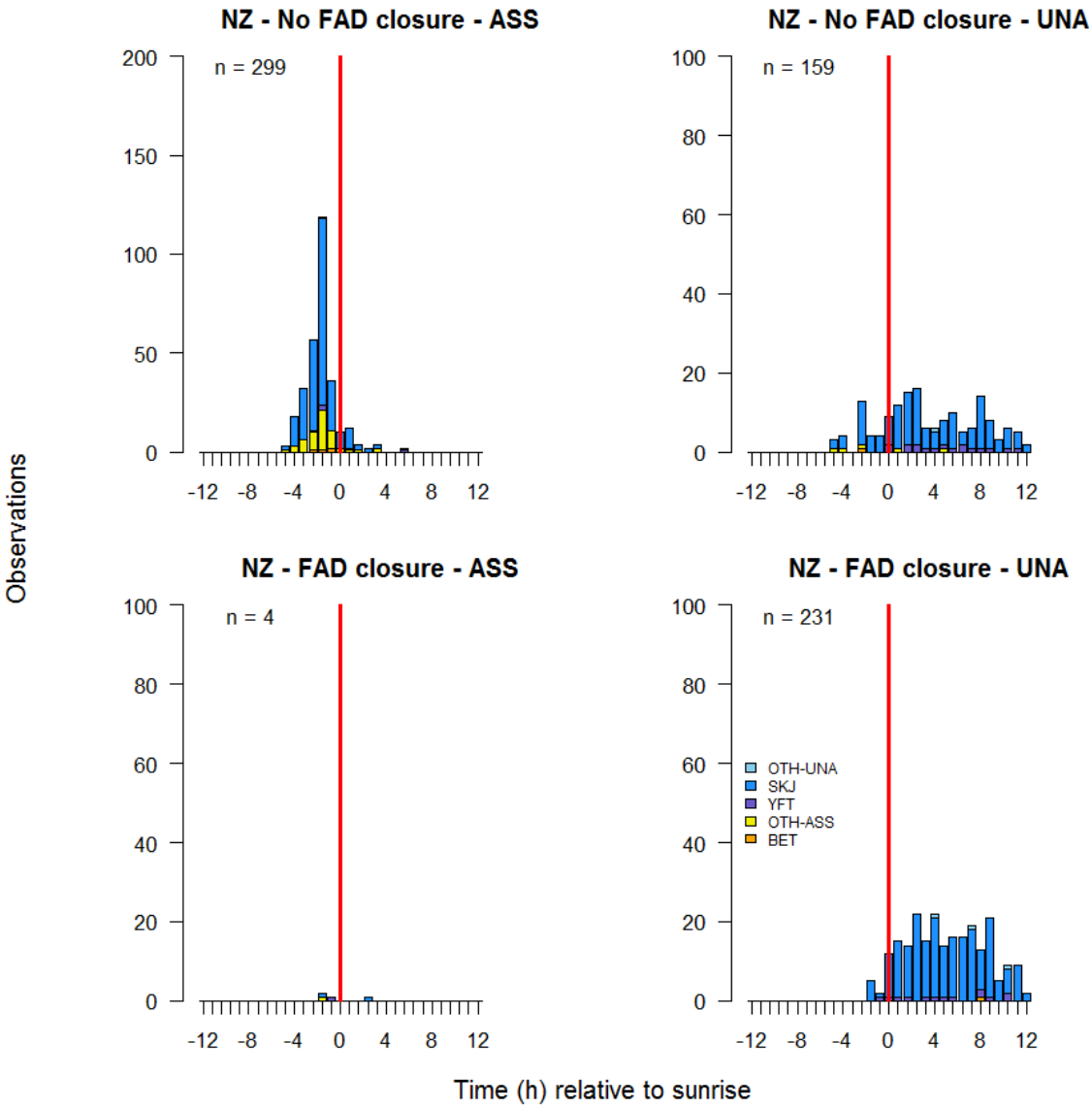

Figure A9: Purse seine set times relative to sunrise where time = 0 (red line), in 48 minute time bins, during the non-FAD closure period (top) and the FAD closure period (bottom) for New Zealand flagged vessels fishing in the WCPO between 20°N and 20°S from 2010-2015. Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.

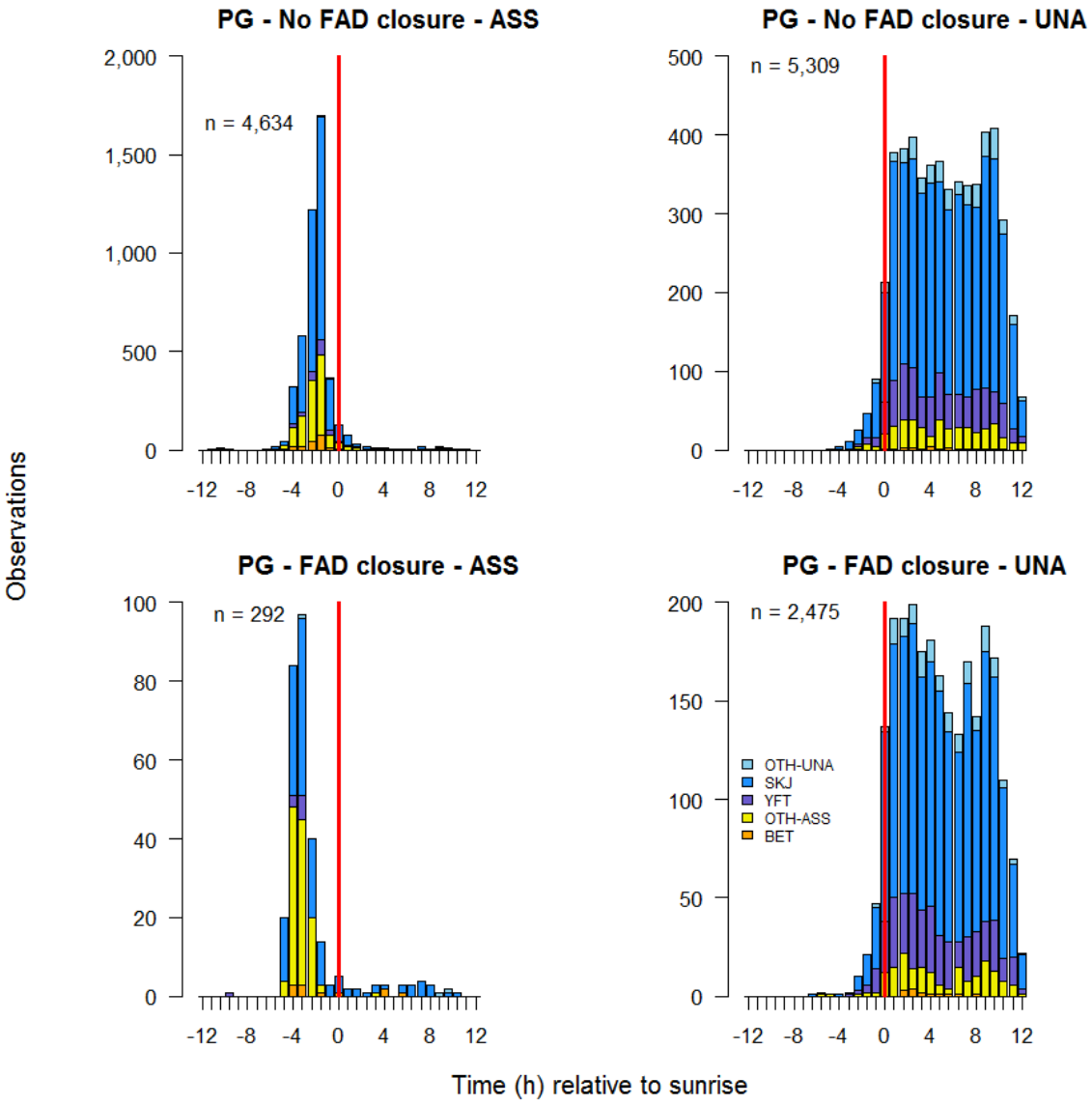

Figure A10: Purse seine set times relative to sunrise where time = 0 (red line), in 48 minute time bins, during the non-FAD closure period (top) and the FAD closure period (bottom) for Papua New Guinea flagged vessels fishing in the WCPO between 20°N and 20°S from 2010-2015.Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.

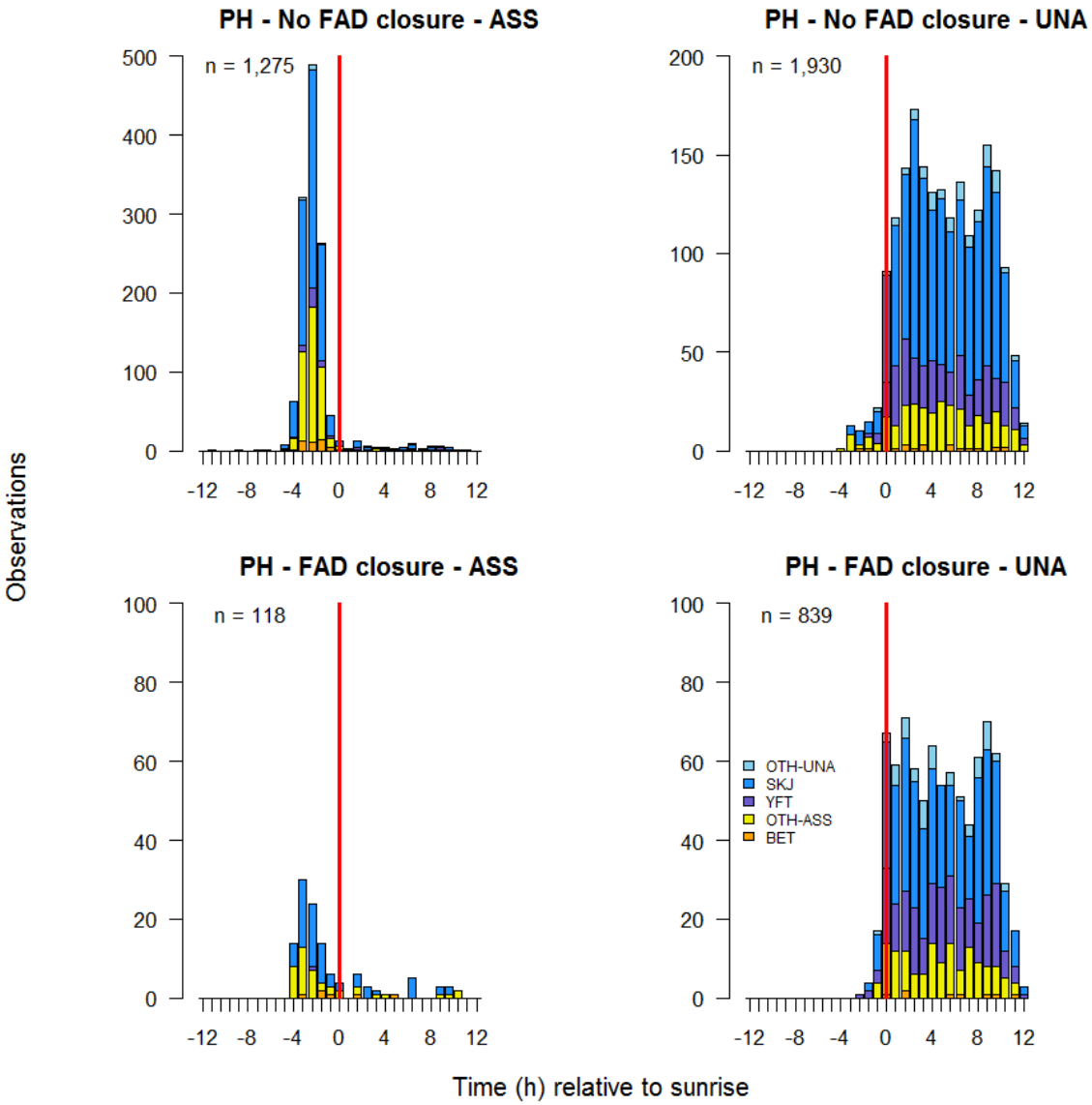

Figure A11: Purse seine set times relative to sunrise where time = 0 (red line), in 48 minute time bins, during the non-FAD closure period (top) and the FAD closure period (bottom) for Philippines flagged vessels fishing in the WCPO between 20°N and 20°S from 2010-2015. Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.

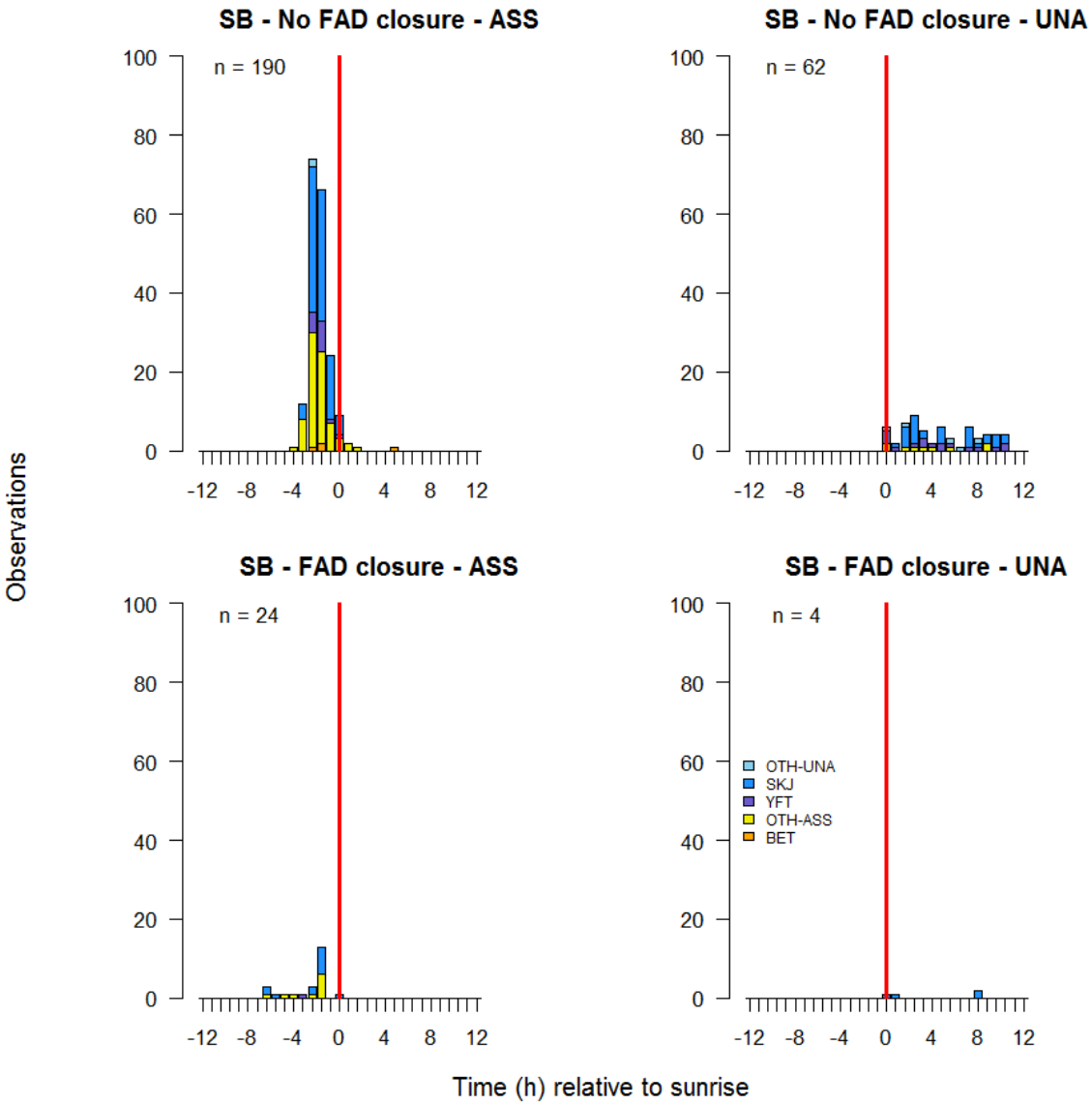

Figure A12: Purse seine set times relative to sunrise where time = 0 (red line), in 48 minute time bins, during the non-FAD closure period (top) and the FAD closure period (bottom) for Solomon Islands flagged vessels fishing in the WCPO between 20°N and 20°S from 2010-2015. Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.

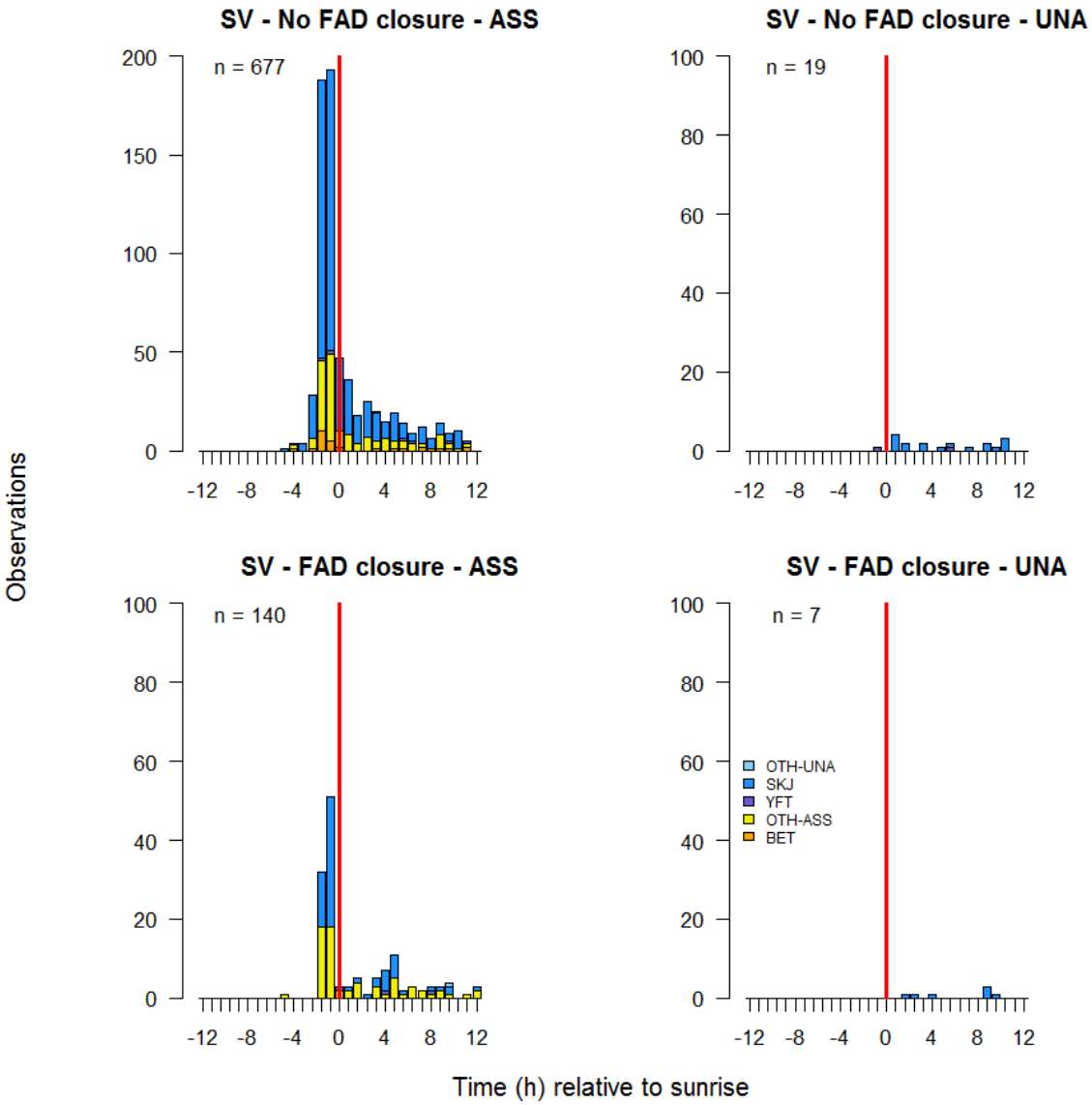

Figure A13: Purse seine set times relative to sunrise where time = 0 (red line), in 48 minute time bins, during the non-FAD closure period (top) and the FAD closure period (bottom) for El Salvadore flagged vessels fishing in the WCPO between 20^{o}N and 20^{o}S from 2010-2015. Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.

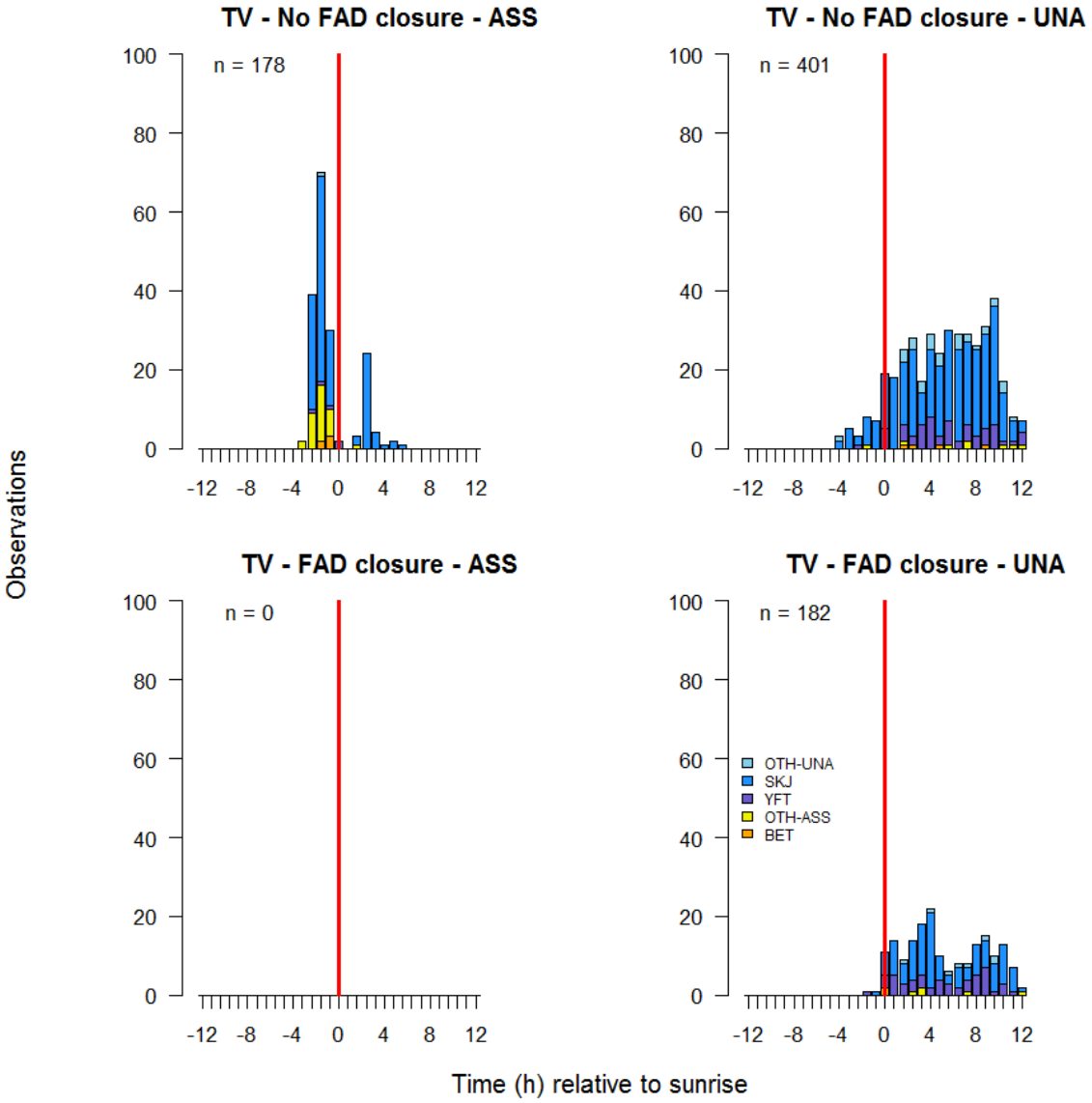

Figure A14: Purse seine set times relative to sunrise where time = 0 (red line), in 48 minute time bins, during the non-FAD closure period (top) and the FAD closure period (bottom) for Tuvalu flagged vessels fishing in the WCPO between 20^{o}N and 20^{o}S from 2010-2015. Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.

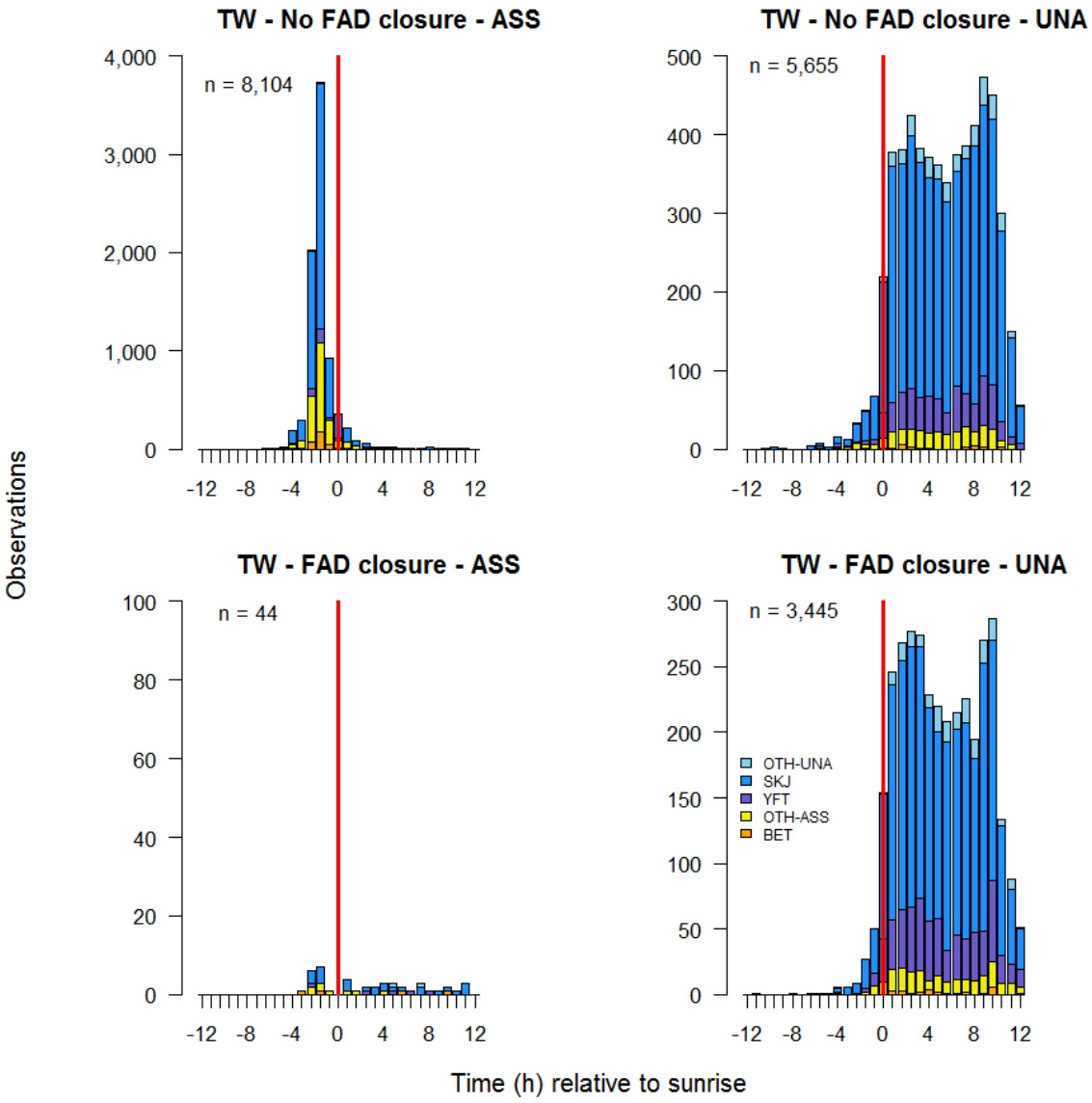

Figure A15: Purse seine set times relative to sunrise where time = 0 (red line), in 48 minute time bins, during the non-FAD closure period (top) and the FAD closure period (bottom) for Chinese Taipei flagged vessels fishing in the WCPO between 20°N and 20°S from 2010-2015. Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.

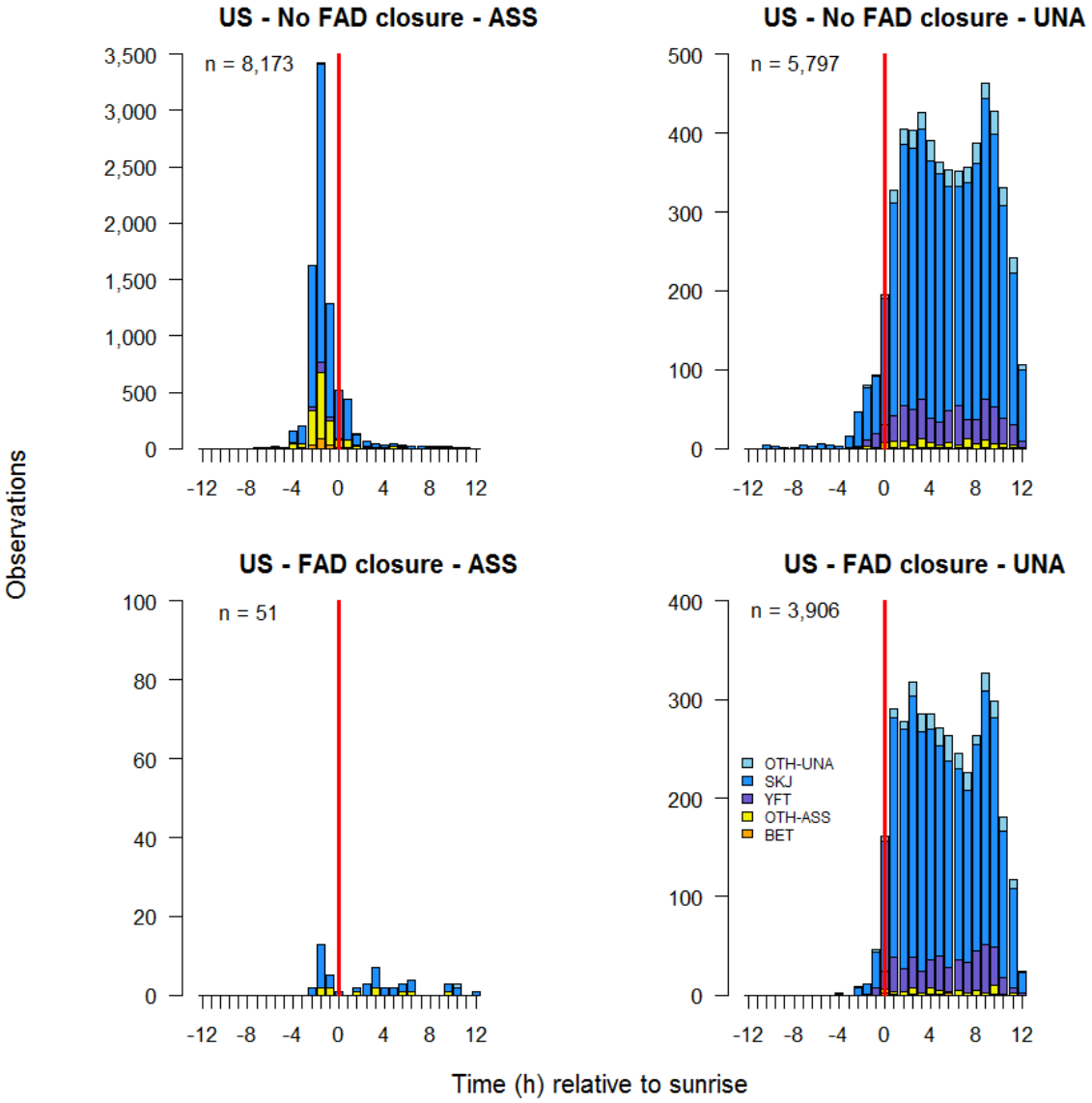

Figure A16: Purse seine set times relative to sunrise where time = 0 (red line), in 48 minute time bins,, during the non-FAD closure period (top) and the FAD closure period (bottom) for USA flagged vessels fishing in the WCPO between 20^{o}N and 20^{o}S from 2010-2015. Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.

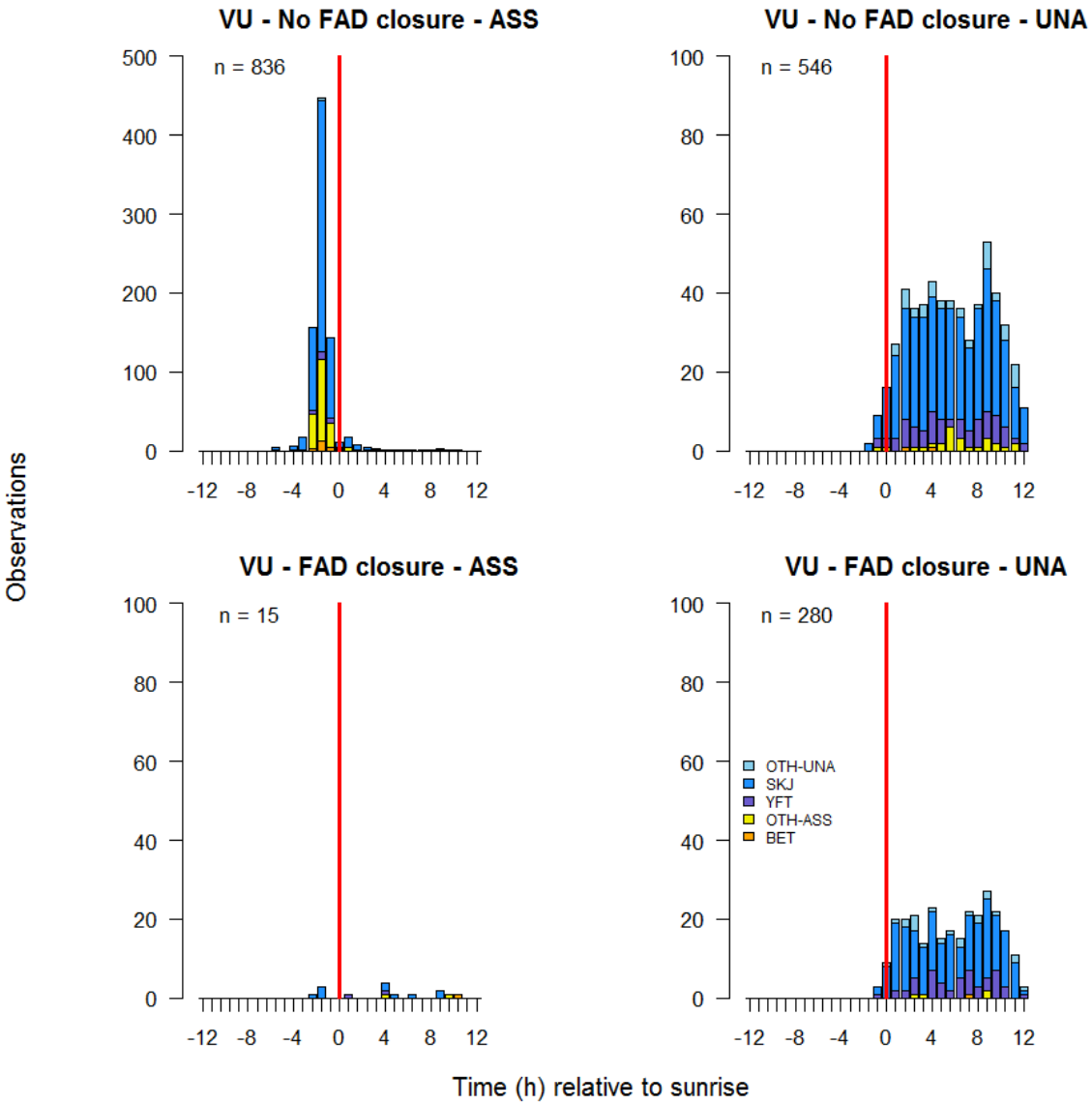

Figure A17: Purse seine set times relative to sunrise where time = 0 (red line), in 48 minute time bins, during the non-FAD closure period (top) and the FAD closure period (bottom) for Vanuatu flagged vessels fishing in the WCPO between 20°N and 20°S from 2010-2015. Colours represent the identified cluster associated with each set type: BET = bigeye; OTH-ASS = bycatch associated with FADS; YFT = yellowfin; SKJ = skipjack; OTH-UNA = bycatch occurring in free schools.