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Effort Creep within the WCPO Purse Seine Fishery

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Executive Summary

Technological advancements and regulatory actions within the tropical tuna purse seine fishery are thought to have resulted in increased capture efficiency for fleets operating in the western and central Pacific Ocean (WCPO). The purse seine fishery has evolved in many ways over the last 10-15 years, this evolution is associated with changes to fishery operations, which can have both positive and negative consequences for the industry as well as the stocks. It is important to understand and monitor how fishing operations have changed over time in order to guide data collection, analysis, and interpretation of fishery-dependent data to inform management decisions.

Paragraph 2(iv) of the Vessel Day Scheme (VDS) text notes that the annual meeting of the Parties will "receive a briefing from the Administrator on catch and effort levels and any observed or potential increase in average effective fishing effort for each fishing day since the introduction of the Management Scheme (effort creep)". This paper describes a suite of effort creep indicators for the purse seine fishery operating in the WCPO, and highlights important trends that may be relevant to fishery managers, with respect to the sustainable management of tropical tuna stocks.

Effort creep is the phenomenon where effective fishing effort, within an effort-based management framework, changes over time due to increased knowledge/skill, improved fishing vessels, and enhanced technologies, thereby enabling fishers to catch more fish per unit of effort (e.g., a fishing day). If effort creep is unaccounted for it can undermine management objectives and give a biased perception of stock productivity. In 2016, Pilling et al. (2016) reviewed candidate indicators of effort creep in the WCPO purse seine fishery at the request of the Parties to the Nauru Agreement (PNA). In this paper, we update and summarize information available to SPC as of March 2021, on catch and effort levels and any observed or potential increase in average effective fishing effort for each fishing day since the introduction of the VDS management framework. The objectives of this paper are to provide managers with trends in potential 'proxy' indicators of effort creep in the tropical tuna purse seine fishery (Table 1). These data are complete from 2007 through 2019, with partial data presented for 2020 for specific indicators.

Most of the catch and effort indicators have shown increasing trends in recent years as well as over the longer-term. The number of sets per day has gradually increased over time, reflecting an increase in 'actual' fishing effort within the fishing day limits. The general increase in sets per day, both within and outside PNA EEZs, can largely be attributed to increased rates of free-school sets since the implementation of the VDS and FAD closure period.

Observer data indicates that the percentage of fishing days with more than one set has generally hovered around 20%. When more than one set per day was observed, the additional sets in that day were dominated by free-school sets. The data suggest that when more than one set is done in a day, the additional sets are primarily aimed at harvesting more fish rather than compensating for lower catch rates of earlier sets.

Aggregate catch per unit effort (CPUE) metrics (mt/day and mt/set) have generally increased within PNA waters with catch per day exceeding catch per set in recent years (2016-2019) due to

the increase in mean number of sets per day (12%). Outside PNA waters the recent trends are more variable, but both catch per set and catch per day have generally increased (2 and 5%, respectively). Set type or fishing mode specific CPUE trends have been relatively stable over the time series, with associated sets generally producing higher catch rates. Improvements in FAD technologies (such as echo-sounder FAD buoys) may also improve CPUE for FAD sets, but practical and fish behavioral limitations mean that, in general, only one FAD set is feasible per day. The relatively stable CPUE for FAD associated sets suggests that: the new technology may not yet be good enough – or understood/applied well enough – to lead to notable increases in catch rates; FAD density may be negatively affecting catch rates (i.e. more FADs may lead to smaller school associations with each FAD); and/or potential increases in catch rates due to the use of new technology may be offset by a declining biomass.

To evaluate the relative impact of the fishery with respect to recent trends in the stock biomass, we have presented a catchability proxy. Due to changes in the assessment model framework, catchability is no longer an estimated parameter describing the time-varying relationship between catch rates and biomass. In lieu of the catchability estimates from the stock assessment we have developed a new catchability proxy, calculated as the average catch per fishing day in each year relative to total biomass, this provides an indicator of the relative efficiency of a fishing day. Over the time series, relative purse seine efficiency within PNA waters has increased by 6%, annually, resulting in a near doubling of this catchability proxy over the time series.

Overall, trends in the effort creep proxies within the PNA EEZs have generally been positive, with average long-term trends in per day and per set catch and effort indicators increasing by 0-3%, per year, while the catchability proxy suggests a more substantial annual increase of 6%. Effort creep is difficult to quantify with certainty because it is a multi-faceted and complex phenomenon, often lacking the full complement of data to precisely assess it. Even so, these proxy indicators have consistently suggested the presence of some level of effort creep, especially when considered within the context of trends in the skipjack stock. Based on the indicators presented in this report, assuming a level of effort creep of between 3 and 6% per year appears appropriate. These trends should be considered by the SC. They can also be incorporated appropriately into harvest strategy analyses to ensure management advice is robust to effort creep.

We invite the Scientific Committee to note:

- the trends in the purse seine fishery metrics, and the need to ensure related information is available to understand the potential implications of effort creep;
- the trends in tuna mt/day have increased, largely resulting from increased free-school sets/day;
- the overall lack of strong trends in catch per set for both fishing modes, potentially due to gear/processing limitations or tuna school size dynamics;
- the overall impact of the gradual increase in catch and effort relative to general declines in the underlying tuna biomass;
- the value of continued development of FAD characteristics and FAD tracking databases; and

- the importance of developing quantitative metrics of effort creep for management use and development of management procedures.

Table 1: Summary of recent (average 2018-19 vs 2016-17) and longer-term (2007-2019) trends in different indicators within and outside PNA EEZs.

Indicator	**2016/2017 vs 2018/2019**		**Per annum linear regression trend, 2007-2019**[3]	
	PNA	Non-PNA	PNA	Non-PNA
Sets/year	+5%	+57%	+3%	+2%
Sets/day	+12%	+20%	+3%	+5%
Total tuna CPUE (mt/day)	+20%	+23%	+3%	+2%
Total tuna CPUE (mt/set)	+6%	+2%	0%	-1%
Total tuna CPUE (mt/set) - ASS sets	+5%	+6%	0%	0%
Total tuna CPUE (mt/set) - UNA sets	+6%	+7%	0%	0%
Total tuna catch	+12%	+59%	+3%	+0%
Total skipjack catch	+24%	+57%	+3%	+0%
Vessel length (m)	-2%		0%	
Vessel gross registered tonnage (GRT)	-2%		+1%	
Vessel horsepower (HP)	+0%		0%	
Well capacity (mt)	+2%		+2%	

[2]Percent change relative to 2007 level, estimated through linear regression of the data across the period 2007-2019. Values rounded to the nearest whole percentage.

1 Introduction

Fisheries management regimes that are based on effort or input controls require continued monitoring of the unit of effort used to constrain the fishery. Relative efficiency of a unit of effort or "effective effort" can change over time due to the adoption of new technologies, fisher skill, or enhanced communication and access to information. If these changes are not adjusted for, they have the potential to confound changes in fishing mortality and undermine management objectives. This gradual or abrupt change in fishing efficiency, with an effort-based management framework, is generally referred to as effort creep (Pilling et al., 2016).

Effort creep can be difficult to quantify because it is composed of both measurable and unmeasurable components (Eigaard et al., 2014). The measurable components relate to nominal fishing effort (e.g. vessel length, engine horsepower, days fishing), while the unmeasurable components may relate to factors related to technological efficiency, increased information, knowledge and skills of individual fishers. In 2020, the effort creep indicators were updated for SC16 (Vidal et al., 2020). This 2021 paper details the trends in nominal purse seine effort and effort creep indicators in the WCPO over time, using the latest information available to SPC as of March 2021 (includes complete data through 2019 and partial data for 2020 for some indicators). When this report was first compiled in 2016 (Pilling et al., 2016), three groups of proxies for effort creep were established:

1. trends in tuna catch levels, catch rates, and alternative fishing effort values;
2. estimates of trends in vessel and technological characteristics; and
3. trends in estimated 'catchability' from Western and Central Pacific Fisheries Commission (WCPFC) stock assessment models,

and have since been updated on an annual basis.

Here, we provide an update for the first two indicators, but note that updates on estimated catchability trends are no longer directly applicable, due to changes in the tropical tuna assessment modeling approaches. Briefly, in 2020, the yellowfin and bigeye tuna assessment models (Ducharme-Barth et al., 2020; Vincent et al., 2020) used what is referred to as an index fishery approach with catch conditioning (Methot and Wetzel, 2013). The general idea is to have a standardized 'index' fishery which informs the model on trends in abundance, and then extraction fisheries which are associated only with catch, no effort. As a result, catchability q is assumed to be time-invariant for the index fishery (because it is standardized to control for potential changes in fishing efficiency, unrelated to abundance), and the extraction fisheries have no effort, and therefore, no estimated catchability. Given that effort is not integrated into the assessment model as it was in years past, and that q is no longer an estimated parameter, we have developed a catchability proxy which is described in the appendix. For posterity and for context as to long-term trends, the most recent estimates of purse seine catchability from the assessment model (2019) have been retained in this report.

In addition, there have been a few modifications to the data extraction which should be noted. In previous reports, EEZs associated with China, Indonesia, Philippines, and Vietnam were removed from the data set prior to analysis. This year, it was recommended to also remove data from the northern area of Australia's EEZ. As noted in this and past reports, the data set is also filtered to include only fishing activity between 20N and 20S, so some of these exclusions would not have any impact on the results. Two changes that did produce notable differences this year, were i) an exclusion of vessels flagged to Indonesia, Philippines (domestic fleet only), or Vietnam, and ii) a correction to the EEZ coordinate database, which was mistakenly including the Eastern Pacific Ocean in region I5, the international waters in the eastern tropical region of the WCPO. The decision to exclude certain flagged vessels was made because they are fleets with smaller vessels and lower catch rates, and are not considered representative of the overall purse seine activity in the regions of interest. The EEZ database correction means that a small amount of additional catch and effort from the EPO waters was likely included in the 'Outside PNA' summaries in last year's report, but has since been corrected.

These changes have impacted some results, but there was also a change to the data since last year that would have impacted the results for the comparison of aggregated CPUE regardless. Logsheet data have been received for the Philippines fleet operating in High Seas Pocket #1 (HSP1). In the past, catch rates from the domestic fishery, based on limited port sampling data, were used to estimate catch rates in HSP1. These domestic catch rates are characterized by high effort and low catch, and therefore, when applied to the HSP1 region, it was effectively drawing down the catch rates for the 'Outside PNA' region. We have excluded Philippines flagged vessels from this analysis, but even if they were included, the catch rates outside the PNA waters would now be higher due to this data update.

2 Examination of trends in effort, catch rates, and catch

Aggregate raised logsheet data, summarized by EEZ/high seas area for the Western and Central Pacific Fisheries Commission (WCPFC) Convention Area, were used to evaluate changes in effort creep indicators from the period 2007-2019 (with partial data for 2020 included for some rate indicators). Trends in overall catch, catch rates, effort levels, and vessel characteristics provide simple indicators of effort creep. The indicator values presented in this document were estimated separately for fishing effort within and outside of the PNA EEZs (where for the purposes of this paper, PNA refers to PNA Parties + Tokelau). Recent changes in indicators are summarized by taking ratios between average effort, catch per unit effort (CPUE), and catch in 2018-19 compared to 2016-17 calendar years. Long-term trends were examined over the time period since the implementation of the Vessel Day Scheme (VDS; 2007-2019[3]) by fitting linear regressions and are expressed as percentage changes per year relative to 2007.

It should be noted that in this report, effort in days refers to the aggregate effort by year, set type, and EEZ, and is not indicative of fishing days as defined by the VDS. SPC does not currently

[3]The VDS was implemented in 2008, but 2007 was included as a baseline.

monitor vessel days in respect of the management framework, nor does it receive information regarding claim adjustments based on fishing/non-fishing activities. Therefore, there are likely to be discrepancies between the proxy indicators presented here and analyses relative to the VDS.

2.1 Purse seine effort inside and outside PNA EEZs

Fishing days in the WCPO tropical tuna purse seine fishery are generally limited through the PNA VDS, EEZ-nominated effort and skipjack catch levels, and high seas effort limits. In this document, associated sets are defined as those that target schooling aggregations of fish associated with floating objects, whereas unassociated sets target free-schooling fish aggregations. Floating objects, in this context, include manufactured anchored and drifting FADs (e.g., buoys or rafts), as well as natural floating objects, such as logs, whales, and whale sharks, around which fish may aggregate. FAD sets are typically made during the early morning hours when tuna are aggregated near the surface, prior to their movement into deeper waters for daytime foraging. For this reason, purse seine vessels typically only make one FAD set per day, whereas unassociated or 'free-school' sets are made throughout the day, but rarely after dark.

While total number of sets per year is not considered a reliable metric of effort creep, as it depends on the total number of allowed and used fishing days per year, it is included here to provide context with respect to total fishing effort over time, within the region. The total number of raised unassociated and associated sets have generally been fairly stable over the last 10 years, both inside and outside PNA waters (Figure 1). The number of associated sets within PNA waters has fluctuated but has been relatively stationary over the time series, compared to the unassociated sets that show a step change (increase) from 2009 to 2010. Outside PNA waters, the number of associated sets has gradually been increasing since about 2010, but at a much lower level as compared to fishing activity within PNA EEZs (Figure 1).

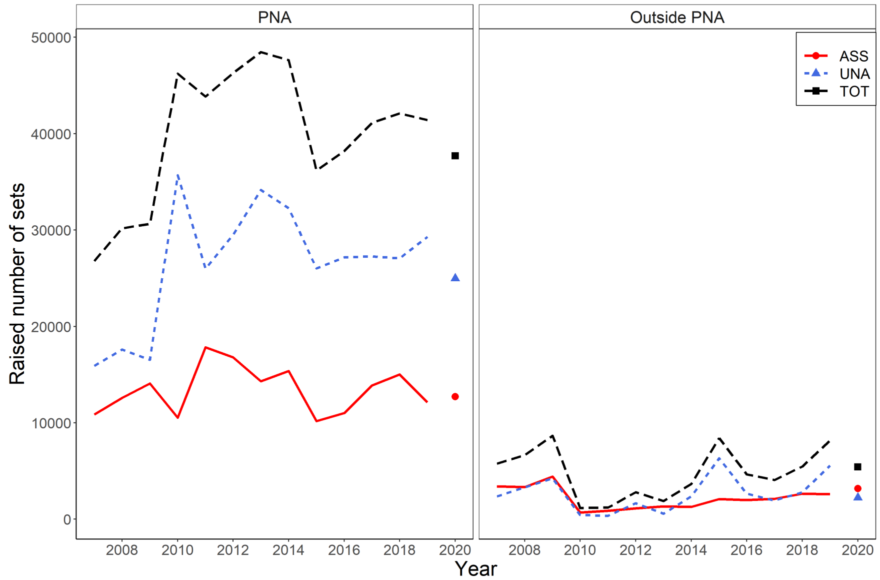

Figure 1: Time series of total raised purse seine sets per year, for associated and unassociated set types, inside (left) and outside (right) PNA EEZs from 2007-2019. Total raised sets is represented with the dashed black line for each region. Note: estimated number of sets made in 2020, by set type, is included as points on each figure, but data are incomplete.

The recent trends presented in this paper are sensitive to short-term variability, and for that reason, relatively large changes can be observed as compared to the longer term trends. However, it is also important to note that the long-term trends described in Table 1 represent annual changes, which when compounded over the full time series, may be substantial. When comparing catch and effort from 2016-2017 to 2018-2019, the changes were largely positive across all metrics both within and outside PNA waters. Sets per year and sets per day increased by 5 and 12% in PNA EEZs and by 57 and 20%, respectively, outside PNA waters. The relatively large changes outside PNA waters should be interpreted relative to the overall magnitude of catch and effort which is much lower than within PNA waters. The long-term trends varied between a 2 and 5% increase, per year (Figure 2).

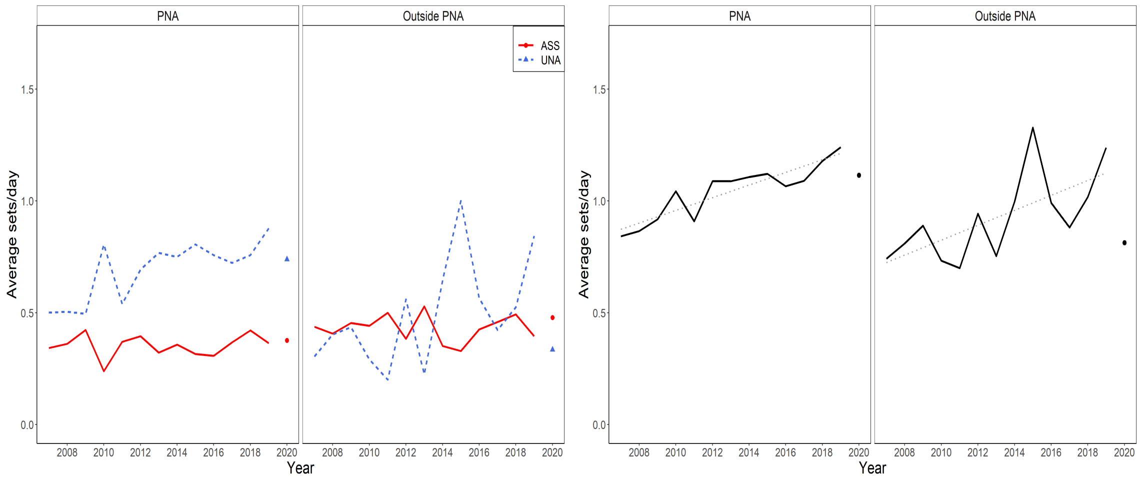

Figure 2: Time series of setting rate (sets per fishing day) for associated and unassociated set types (left) and all sets (right), for waters inside and outside PNA EEZs, from 2007-2019. The linear trend through the data points is plotted in the right-hand panel. Note: 2020 is included as points on each figure but data are incomplete.

In situations where fishing days are limiting, effective effort could increase through changes in activity within a fishing day, such as an increase in the number of sets made per day. This behavior has again been observed in the most recent years, as the aggregate number of sets per day and per year continue to increase, even within the VDS constraints.

2.2 Disaggregated sets per day: observer data

An important aspect to understanding effort creep is how individual vessel behaviours and characteristics change over time. Here we have summarized operational (set-level; unraised data) effort data collected by fishery observers which would include most activity since 2007 (when the aim for 100% observer coverage was implemented), to track the proportion of fishing days with two or more sets. There has been a modest increase in the number of sets per vessel fishing day over time, with approximately 20% of all fishing days involving more than one fishing set in recent years (Figure 3). The trend in sets per day noted in the aggregate logsheet data are not necessarily as obvious in the observer data; however there are some differences to note. The average number of sets per day in the logsheet data has increased over time, but remains just above one set per day. Also, it has been noted in the past that small or failed sets sometimes go unreported in the logsheet data, whereas observers would record all sets irrespective of catch size. The gradual increase in logsheet sets over time may also be an indication of an increase in positive sets, such that additional sets are being reported. Either way, there may be implications for effort creep.

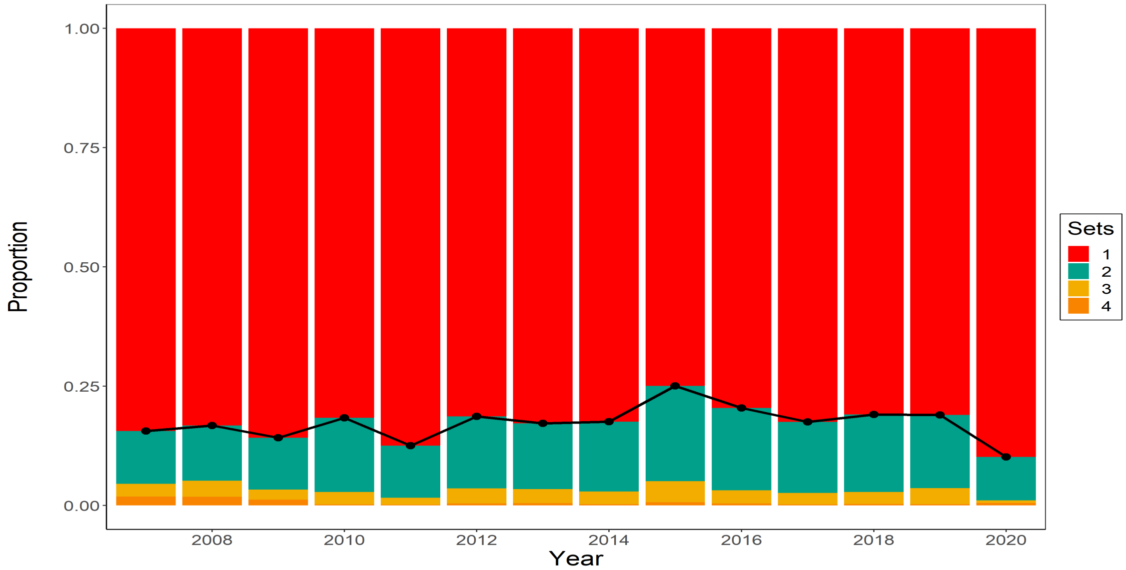

Figure 3: The proportion or fishing days characterized by number of sets per day (1-4) from 2007-2020, showing a slight increase in sets per day. Note: 2020 data are provisional at this time.

The motivation for making multiple sets per day can vary, but there are several general hypotheses: i) multiple sets serve to compensate for poor sets earlier in the day; ii) some vessels seek to maximize catch within a vessel day by making multiple sets; or iii) perhaps local abundance is high and more sets are made opportunistically. The catch rates per day (Figure 4) indicate that multiple set days tend to produce larger daily catches as compared to fishing days with fewer sets. The distributions of catches per set are similar irrespective of how many sets per day (Figure 4). The median catch per set is slightly lower for sets on one set days, however, overall these comparisons suggest that the motivation for doing more sets in a day is apparently to increase harvest rather than to make up for notably lower per set catches earlier in the day.

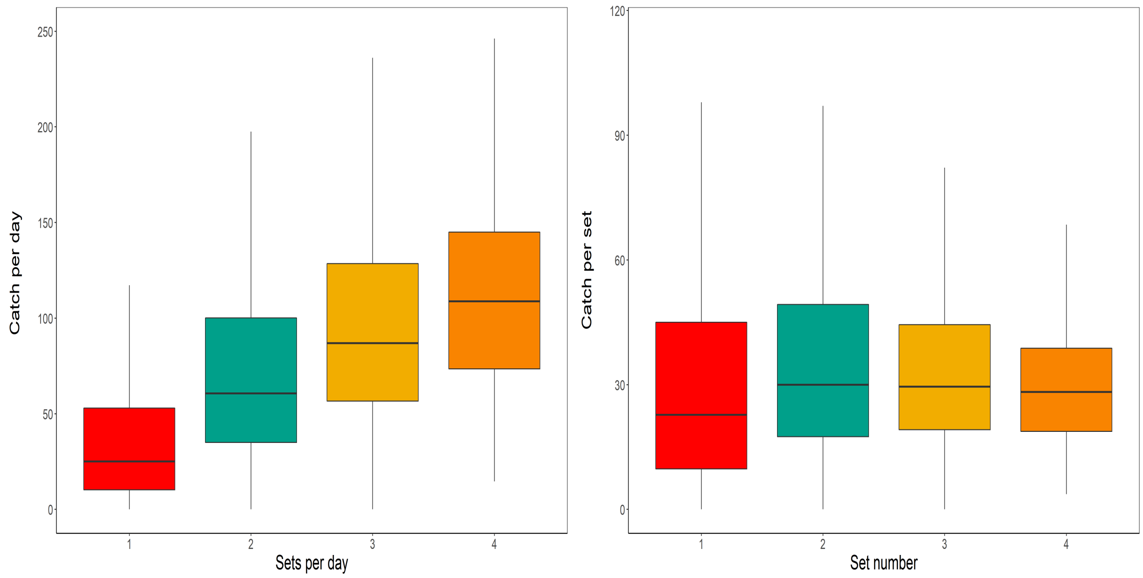

Figure 4: Distribution of total tuna catch per day, aggregated across years, for days with 1 - 4 purse seine sets.

2.3 Purse seine CPUE inside and outside PNA EEZs

Trends in nominal catch per unit effort (CPUE) were measured as total tuna metric tonnes caught per set (mt/set) and day fished (mt/day). The latter was calculated to account for increases in the number of sets made per day which were shown above, and both metrics are presented in Figure 5. The majority of the catch (approximately 70-82%) was comprised of skipjack (Figure 7), which drives these trends. The stable catch composition data in Figure 7 also suggests that increased numbers of free school sets is not clearly due to increased targeting of yellowfin.

Catch rates within PNA EEZs have generally been comparable with those in non-PNA areas (Figure 5), but again, the magnitude of overall catch and effort should be noted. CPUE inside and outside PNA EEZs has, however, shown similar dynamics since 2007, although the catch rates outside PNA EEZs have been more variable. Comparison of average CPUE between 2018-19 and 2016-2017 showed an increase of 6% for mt/set and 20% for mt/day inside PNA EEZs, and an increase of 2% and 23%, respectively, outside PNA EEZs. These short-term increases could be in part due to the reduction of the FAD closure period in the most recent years (from 4 months in 2016 & 2017 to 3 months in 2018 & 2019). The long-term trends in catch per set and catch per day for both regions ranged between no change and a 3% increase, per annum (Table 1).

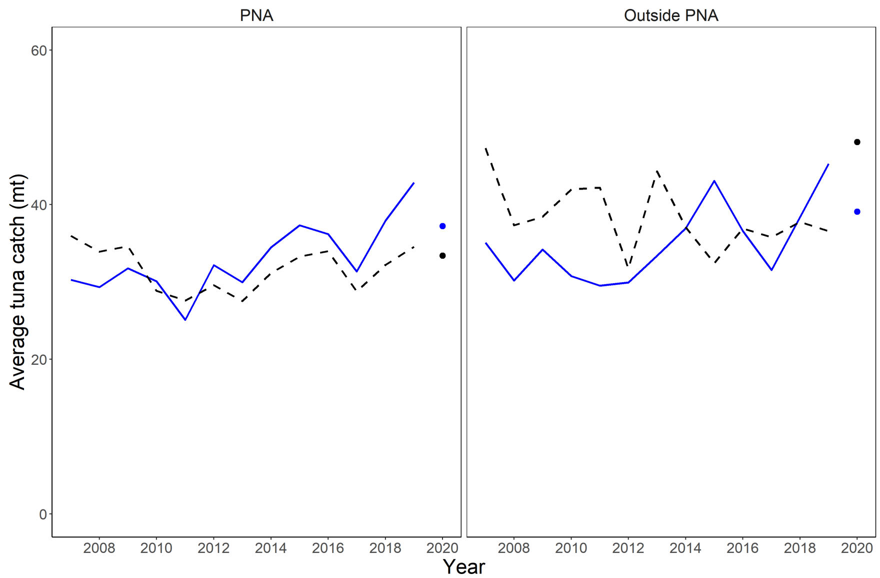

Figure 5: Time series of nominal raised purse seine total tuna CPUE in terms of mt/day (blue; solid lines) and mt/set (black; dashed lines) inside and outside PNA EEZs, from 2007-2019. Note: 2020 is included as points on each figure but data are incomplete.

The two main purse seine fishing modes, associated and unassociated sets, are quite different in nature, and therefore there is interest in evaluating catch rates separately when considering potential effort creep. The recent trends suggest that catch rates (mt/set) for associated and unassociated sets inside PNA waters have increased by 5 and 6%, respectively (Figure 6). Outside PNA waters, the recent changes have been similar, with a 6% increase in associated CPUE and a 7% increase in unassociated CPUE (Table 1; Figure 6). Overall CPUE has been relatively stable for sets both within and outside PNA waters. Catch rates for associated sets have been higher than for free school sets, and areas outside PNA waters have generally produced higher associated catch rates, but the time series from both regions are fairly synchronous. Further, it also important to note that catches outside PNA waters are much lower overall compared to PNA waters.

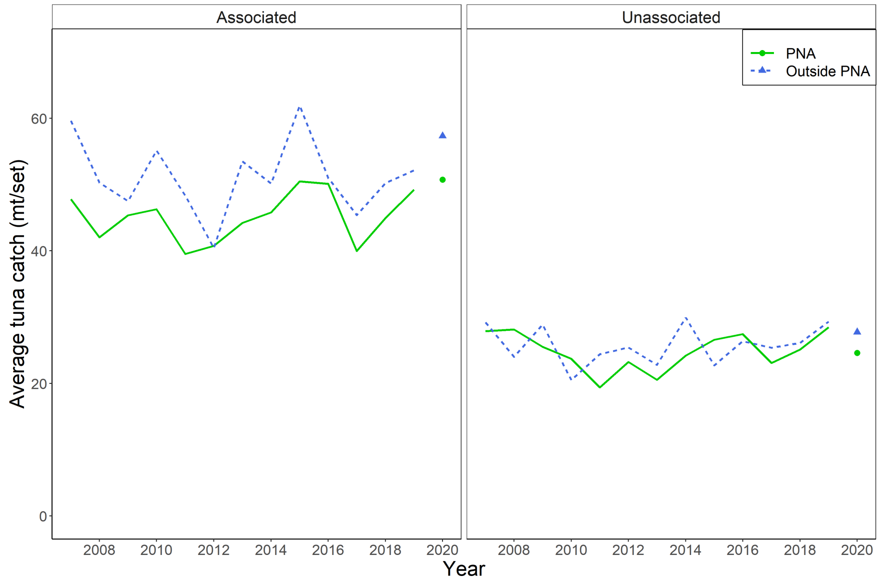

Figure 6: Time series of nominal purse seine total tuna CPUE (mt/set) for associated sets (left) and unassociated sets (right) inside and outside PNA EEZs. Note: 2020 is included as points on each figure but data are incomplete.

2.4 FAD dynamics and implications

The technology associated with FAD fishing has become more sophisticated through time, specifically with the adoption of satellite tracked and sonar-equipped FAD buoys. It is now possible for vessels to have a general sense of the size of the fish aggregations present at a FAD at a given time, based upon acoustic information provided by the FAD buoy's sonar system. With this knowledge, fishers can, in theory, more efficiently direct their efforts towards the most productive FADs, while minimizing the risk of fishing an unproductive FAD. Further, being able to accurately locate FADs with high biomass associated can reduce the amount of steaming time, allowing more time for other fishing operations. Through time, there has been an increase in the reliance on FAD-fishing, and along with that reliance there has been an increase in the deployment of manufactured fish aggregating devices (Escalle et al., 2021).

More detailed information on FAD deployments, in particular the proportion of sonar-associated FADs, FAD technology, the influence of the FAD closure period, and related CPUE changes is needed. In particular, the number of deployed and actively monitored FADs could be a key characteristic of vessel fishing strategy responsible for effort creep. The number of active FADs and FAD deployments per vessel between 2011 and 2019 were estimated and published in Escalle et al. (2021). Using fishery data combined with FAD tracking information, it was estimated that at the scale of the WCPO there were approximately 31,000 FAD deployments in 2016 and approximately 34,100 in 2017, 39,500 in 2018 and 35,200 in 2019. A general increasing trend was detected through time, with a median raised number of active buoys of 45 per vessel per day in 2016 compared to 75 in 2019 (Escalle et al., 2021). It is unknown at this point how FAD density influences catch rates and also how FAD technologies (e.g., sonar-equipped FADs) are changing fishing strategies and catch rates. Integration of FAD information is a continued priority for future developments in indicators of effort creep.

2.5 Aggregate purse seine catches inside and outside PNA EEZs

Within PNA EEZs, average annual total tuna catch increased by 12% while annual skipjack catch increased by 24% from 2016-2017 to 2018-19. Over the longer-term there is a positive linear trend of 3% per year relative to 2007 (Table 1; Figure 7). Outside PNA EEZs, average annual tuna catch increased by 59% while skipjack increased by 57%, from 2016-17 to 2018-19 (Table 1). Not surprisingly, both longer (2007-2019) and short-term (2016-17 versus 2018-19) trends for skipjack catch are similar to overall tuna catch (Table 1). The species catch composition in both associated and unassociated sets has remained dominated by skipjack (annual average of 78% skipjack for both set types). The FAD sets, however, tend to catch a higher proportion of bigeye tuna than the unassociated sets, while unassociated sets have a slightly higher proportion of yellowfin tuna (Figure 7). Total catch serves as an important proxy indicator for fishery impact, but can be directly influenced by factors unrelated to effort creep such as the number of vessels participating in the fishery and stock biomass; and therefore, CPUE metrics and daily setting rates are considered a more informative direct indicator of effort creep.

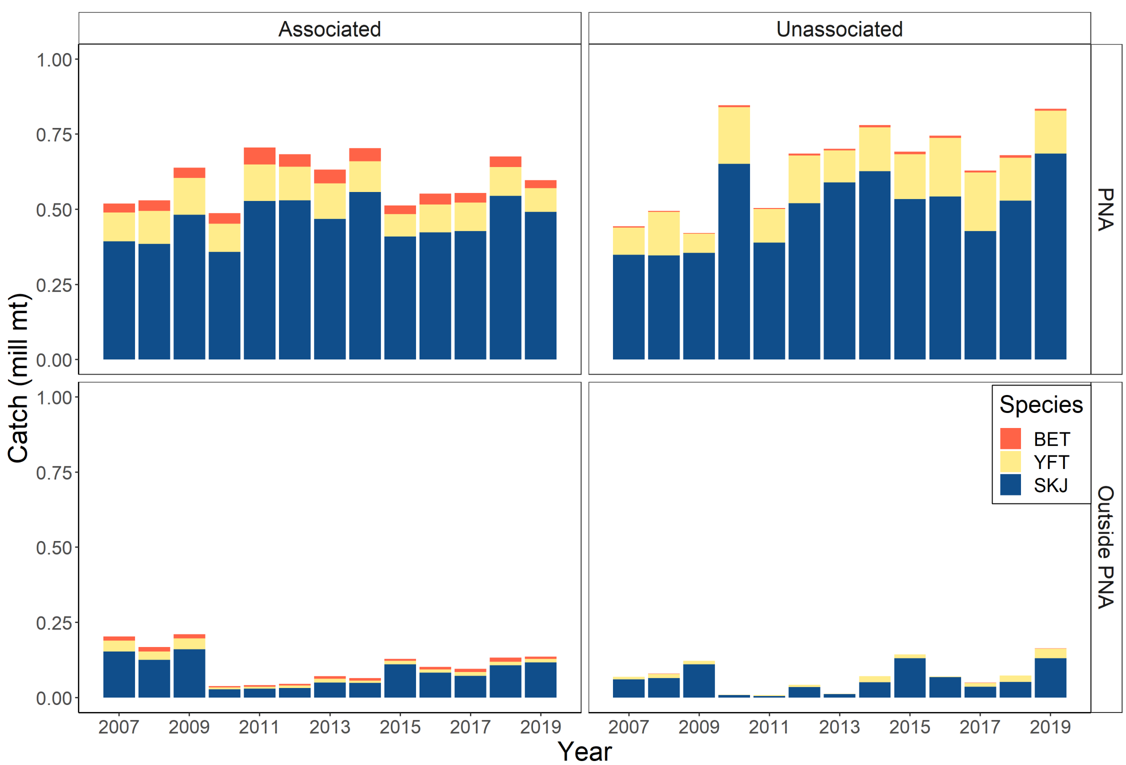

Figure 7: Time series of purse seine catches inside (left) and outside (right) PNA EEZs, for associated (top) and unassociated (bottom) sets from 2007-2019.

2.6 *Changes in vessel, gear, and technological characteristics within the purse seine fishery*

Changes in the size of vessels or other specific vessel or gear characteristics, are a possible indicator of effort creep. There are three potential sources of vessel characteristic data which may cover different components of the tropical purse seine fishery: the WCPFC Record of Fishing Vessels; the FFA Vessel Register; and the PNA VDS Register. Additional information with respect to vessel and gear/technological characteristics as well as access to and use of different information technologies are available from observer collected data. It should be noted that the observer data are incomplete for 2020, which is why there is very little variability in well capacity, but those data will become more complete over the coming year.

These metrics show recent trends between 0-2% and longer term trends ranging from no change to a 3% increase, per annum (Table 1; Figure 8). Although physical characteristics are certainly important, we predict that it has increasingly become variables that might fall into the technical efficiency category that are likely influencing the modern fishery; aspects such as electronics, communication, FAD-mounted echo-sounders, land-based analysts, etc. Continued research to try to disentangle these effects to better understand effective effort are ongoing.

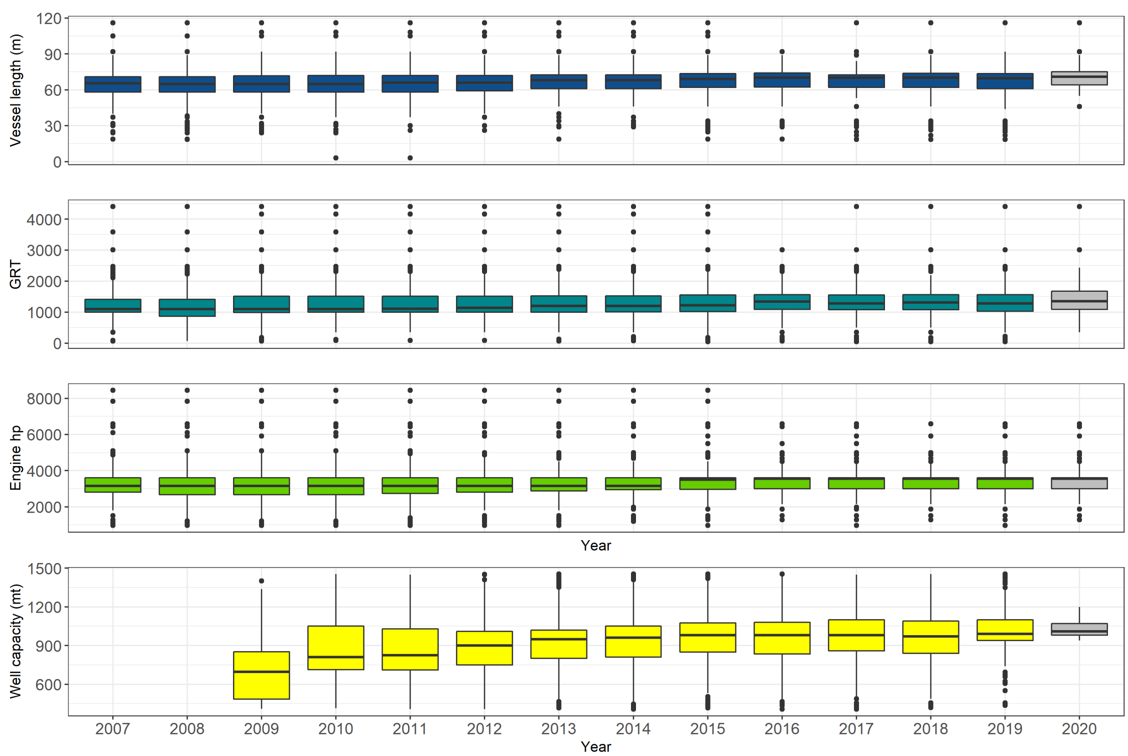

Figure 8: Boxplots illustrating the distribution of vessel size characteristics of purse seine vessels registered annually on the FFA Vessel Register in terms of length overall (m; top); gross registered tonnage (GRT); engine horsepower; and well capacity (mt; bottom). The well capacity data were obtained from observer collected data.

3 Estimated catchability trends

Within the MULTIFAN-CL stock assessment model, the fishery-specific parameter 'catchability' (or q) measures the impact of a single unit of effort of a given fishery on the stock over time; i.e. it translates the level of fishing effort into the level of fishing mortality. Catchability was estimated as a time-varying parameter for fisheries such as purse seine, for which fishing mortality is believed to change through time due to processes such as persistent shifts in the spatial distribution of the stock, changes in the fleet composition (e.g., increase in high CPUE vessels), and effort creep. As noted in the introduction, with changes to the assessment modeling framework in recent years, catchability is no longer being estimated; and it is likely, this shift towards an 'index fishery' approach will be applied for the next skipjack assessment as well. For posterity, we have included the catchability estimates form the 2019 assessment, as well as a proposed proxy indicator (detailed in the appendix) for moving forward.

3.1 Skipjack tuna

Catchability estimates for skipjack tuna from the main tropical purse seine fisheries have increased throughout the time series (1972-2018; Figure 9), based on the 2019 stock assessment (Vincent et al., 2019). The assessment regions that these statistics correspond to are detailed in Figure A3. Please note, in this report we have included Region 6 in addition to Regions 7 & 8 which have been presented in the past. As a result, we are referring to Region 6 as the western region, Region 7 as the central region, and Region 8 as the eastern region. Estimates of catchability from the tropical purse seine fisheries in the western and central regions (Region 6 & 7) have been consistently higher than the eastern region (Region 8), and within each region, catchability has generally been higher for the associated fisheries as compared to the unassociated (free-school) fisheries. Over the recent time period (2016-2018), catchability estimates have been relative stable (Table 2). Over the longer-term (2007-2018), skipjack purse seine catchability increased by approximately 3% in the western region for the associated and unassociated fisheries, respectively, and 1% in the central region. In the eastern region, catchability increased for the associated fishery by approximately 2% and remained relatively stable for the unassociated fishery (Table 2).

Table 2: Relative change in catchability for the skipjack tuna unassociated (UNA) and associated (ASS) tropical purse seine fisheries from Regions 6 - 8 of the 2019 skipjack stock assessment (Figure A3).

Fishery	2018 vs 2016-2017	Per annum linear regression trend, 2007-2018
Western ASS (Region 6)	+1%	+3%
Western UNA (Region 6)	-3%	+3%
Central ASS (Region 7)	+4%	+1%
Central UNA (Region 7)	+2%	+1%
Eastern ASS (Region 8)	+3%	+2%
Eastern UNA (Region 8)	-1%	0%

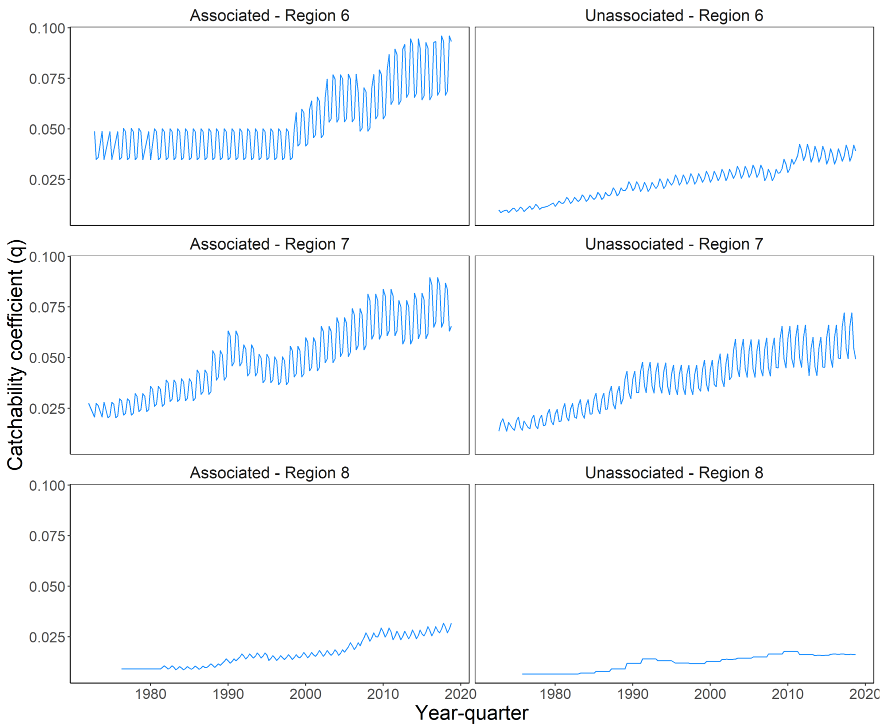

Figure 9: MULTIFAN-CL quarterly time series estimates of tropical purse seine fishery catchability within the 2019 skipjack stock assessment model (Regions 6 - 8; 1972-2018).

4 Summary

Understanding effort creep as it relates to effort-based management requires coupling changes in effort creep indicators with changes in effective fishing effort, which remains challenging. The relationship between effort creep proxies and effective effort may be non-linear and variable over time. Effort creep can lead to the relationship between catch rates and biomass changing over time, in particular the phenomenon of hyperstability where CPUE remains stable when available biomass is in fact declining. This has clear implications for the use of CPUE as an indicator of abundance trends within stock assessment.

Within the context of the WCPO effort-managed system, the most salient concerns regarding effort creep are: i) that changes in fishing efficiency could be masking a declining stock, and ii) the changes in effective effort are undermining the effort-based management framework. In situations where stock status indicators such as CPUE are hyperstable, declines in the biomass can be detected too late and significant and disruptive management action is then required to allow rebuilding. In this context, disentangling the changes in underlying biomass from stability in CPUE and changes in effective effort is paramount. Additionally, if effective effort is increasing but is unaccounted for, effort limits imposed by the management framework are unlikely to be effective at achieving the desired management outcomes. Information on effort creep is necessary to appropriately adjust effort limits, based on management objectives.

Effort creep also has implications for the performance of the VDS in relation to economic returns to PNA members. Increased efficiency could have at least two implications: i) if vessels can catch more fish in one day they may not need to purchase as many days, and ii) if fishers can catch more fish in one day without incurring significant additional cost, the value of a day could be higher. These responses may warrant further consideration in relation to optimizing the economic performance of the VDS.

To monitor and adjust overall fishing effort levels for effort creep, recent changes in CPUE provide perhaps the most obvious starting point for an indicator. However, purse seine CPUE is thought to be relatively insensitive to changes in underlying fish biomass compared to that from the longline fishery, due to the schooling behavior of fish. In the WCPO, the continued reliance on FADs as well as advances in FAD technologies (e.g., sonar equipped FADs) is perceived to be one of the major changes influencing fishing strategies and catch efficiency for purse seine fleets. In addition, the use of electronics to detect fine-scale, near real-time oceanographic conditions may enable fishers to better identify productive fishing locations, thereby potentially increasing set efficiency for free-school sets. Reliably quantifying the extent to which these changes impact effective effort over time remains a research priority.

In this analysis, we have examined catch and effort indicators independently from vessel characteristic indicators (e.g., vessel length, GRT, well capacity); further analyzing changes in catch rates with respect to changes in vessel characteristics or technologies employed may improve our ability to assess effort creep. For example, enhanced freezing capacity is likely making it possible for vessels to move onto their next set more quickly than they were able to historically. Continued research into the development of suitable effort creep indicators will focus on these integrated analyses, including improved understanding of changes in operational decision making and fishing strategies influenced by advances in technology.

We note the importance of enhanced data collection from the fishery, including the wide array of drifting FADs throughout the Pacific. Building a more complete and accessible database with information on the location, movement, and characteristics of FADs should enhance these analyses. In addition, access to Vessel Monitoring System (VMS) data is now available for the past 10 years. These data may become increasingly important as we investigate changes in fisher behavior over time. SPC looks forward to continuing to work with the PNA on effort creep in the purse fishery so that the implications of this process for management can be better understood and accounted for.

Acknowledgments

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A1 Appendix

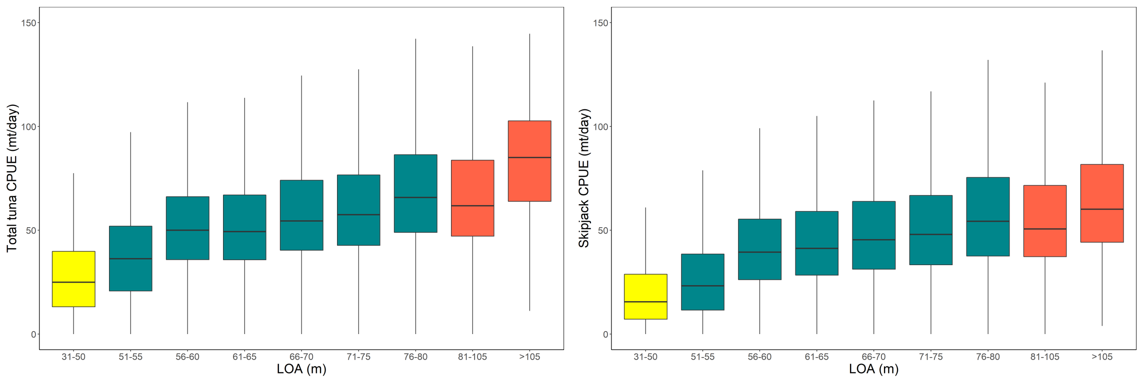

Figure A1: Boxplots illustrating the distribution of trip level total tuna (left) and skipjack (right) catch per day from vessel logsheet data, grouped by vessel size class, from 2007-2019. The colors indicate the vessel size classes associated with the VDS. Note: species compositions here have not been corrected for observer sampling.

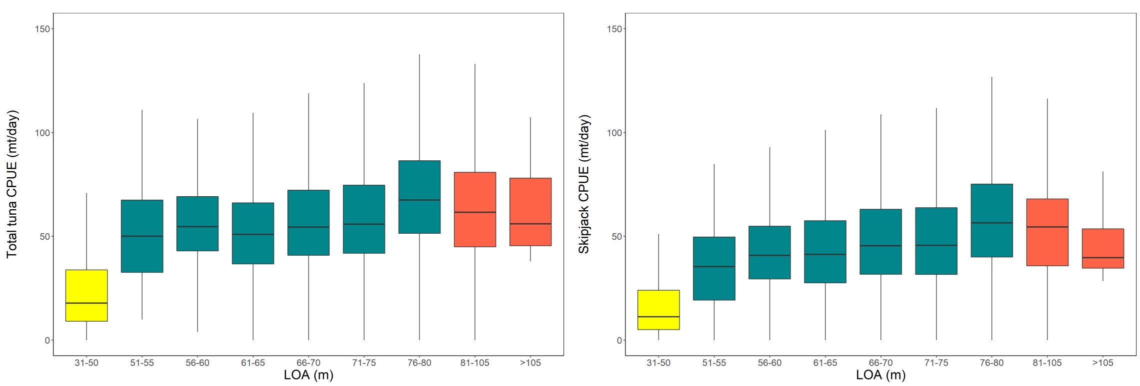

Figure A2: Boxplots illustrating the distribution of trip level combined tuna (left) and skipjack (right) catch per day from vessel logsheet data, grouped by vessel size class, from 2016-2019. The colors indicate the vessel size classes associated with the VDS. Note: species compositions here have not been corrected for observer sampling.

A2 Additional analysis for 2021

A 2.1 Catchability proxy

In previous reports, catch and effort metrics have been presented without direct reference to estimates of the underlying biomass. Available biomass will undoubtedly influence the abundance and distribution of tropical tunas, and therefore have an impact on catch rates. In addition, one of the main concerns with respect to using purse seine catch and effort data for assessment and monitoring is the notion of hyperstability. If effort creep exists and is unaccounted for, declines in biomass may be masked by increasing fisher efficiency. Similarly, it is difficult to think about effort creep without the context of changes in biomass. Therefore, this year, in lieu of catchability estimates from the assessment models we are presenting a catchability proxy. We have used the nominal annual catch per day, year, and region (inside and outside PNA waters), divided by estimated skipjack biomass in each year (for the tropical assessment regions 3-8; Figure A3), to yield a catchability proxy that could be compared across time.

Purse seine catch rates are not entirely composed of skipjack, but largely a combination of both skipjack and yellowfin tuna. However, skipjack is the primary landed species and therefore used for this proxy indicator.

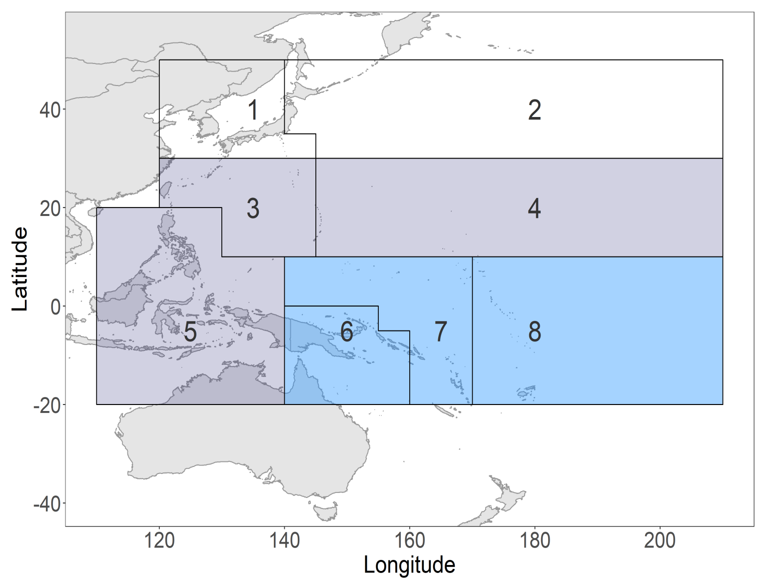

Figure A3: Skipjack assessment regions used for the catchability proxy (Regions 3-8, shaded in blue and purple). The regions shaded in blue (Regions 6-8) are those for which catchability estimates from the 2019 stock assessment are presented.

Specifically, we used annual catch (mt) C_y divided by total fishing days E_y as an approximation of average catch per day. This catch per day was then divided by biomass in each year B_y, from the most recent stock assessment, to derive the catchability proxy q_y, or the relative proportion of the stock caught in one day of fishing. It should be noted that the same annual regional total biomass estimates were applied to both the PNA and non-PNA waters; biomass has not been weighted by the area of the respective regions.

$$q_y = \frac{C_y/E_y}{B_y}$$

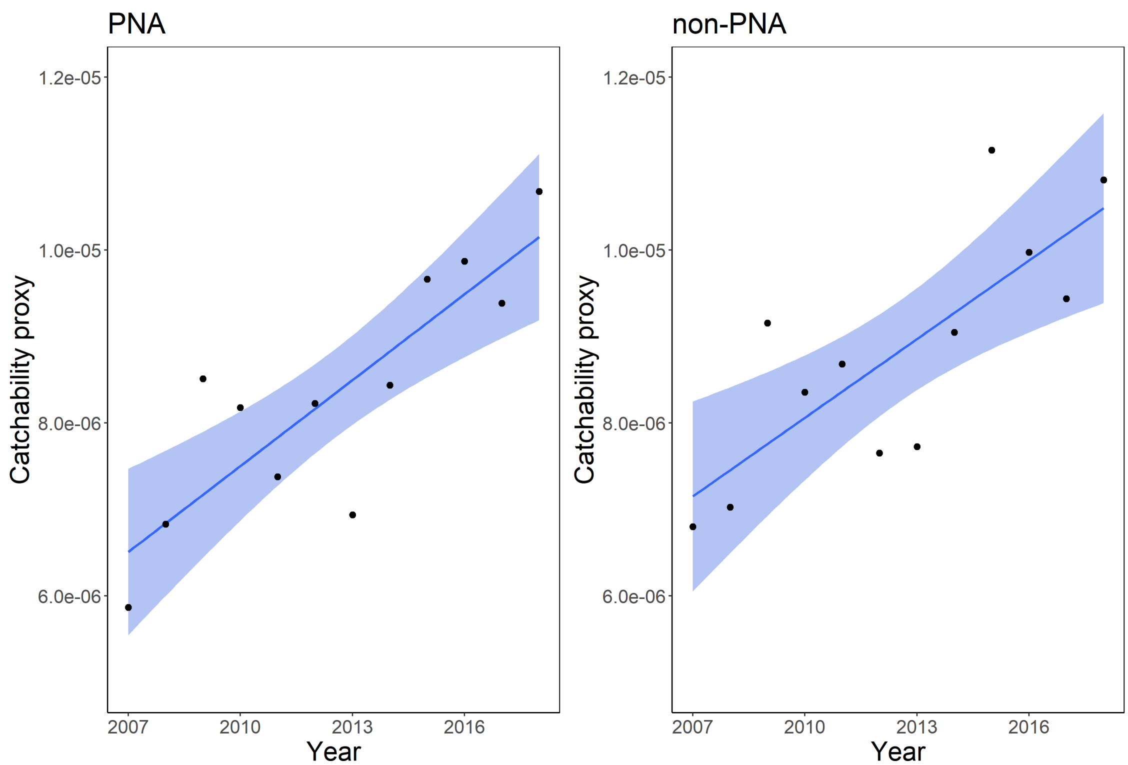

Figure A4: Catchability proxy by management area (inside and outside PNA EEZs) from 2007-2018.

Although the skipjack biomass has been relative stable over the long term, it has declined over the time series discussed in this report. Here, the annual rate of increase in the catchability proxy was approximately 5-6% for both within and outside PNA waters (Table A1). Outside PNA waters, the catchability proxy was highly variable, owing in part to relatively low effort; therefore, this uncertainty must be considered when interpreting these trends.

As the VDS is an effort-based management framework with the fishing day as the effort unit, these results are potentially important. If we focus on the PNA regions, a 6% per annum change in the catchability proxy equates to an approximate 82% increase in daily efficiency over the time series.

Table A1: Summary of relative daily exploitation rate (average 2018-19 vs 2016-17) and longer-term (2007-2019) trends within and outside PNA EEZs.

Indicator	2016/2017 vs 2018/2019		Per annum linear regression trend, 2007-2019	
	PNA	Non-PNA	PNA	Non-PNA
Catchability proxy[4]	+11%	+11%	+6%	+5%

[4]Skipjack biomass estimates are only available through 2018 for the calculation of the catchability proxy indicators.