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Examining Indicators of Technological and Effort Creep in the WCPO Purse Seine Fishery

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Executive Summary

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). Effort creep has implications for maintaining stocks around target reference points, and can affect vessel profits. Pilling et al. (2016) reviewed candidate indicators of effort creep in the western and central Pacific Ocean (WCPO) purse seine fishery at the request of the Parties to the Nauru Agreement (PNA). The work was supported by SC12, which noted its relevance for skipjack harvest control rule development (SC12, 2016; para 645). PNA requested that the Pacific Community (SPC) report annually on trends in effort creep by updating key tables from that paper, and expressed interest in similar work being undertaken so that any adjustment for effort creep would be compatible across the WCPO (SC12, 2016; para. 641). In this paper, we update and summarize information available to SPC as of March 2020, which includes complete data for 2007-2018 (for some indicators partial data for 2019), to present trends in potential 'proxy' indicators of effort creep in the tropical tuna purse seine fishery (Table 1).

To supplement the updates to the previously presented proxy indicators, this paper includes additional vessel, technological, and fishing strategy related metrics, thought to influence fishing efficiency. We have also included information on how catch per set relates to numbers of sets per day. These additional metrics were summarized from operational (set-level) observer data.

Most of the direct effort indicators (e.g. sets per day) have shown increasing trends over the longer-term, but with variable trends over the recent time period. The number of sets per day has gradually increased over time, reflecting an increase in 'actual' fishing effort within the fishing day limits. When considering set types both within and outside PNA EEZs, there has been an increasing trend in sets per day since 2007 for free-school (unassociated) sets and a slight decreasing trend for sets associated with fish aggregating devices (FADs; i.e. associated sets). The general increase in sets per day, particularly within PNA EEZs, can be attributed to increased rates of free-school sets since the implementation of the Vessels Days Scheme (VDS) and FAD closure period. The most notable increase in free-school sets occurred in 2010.

Observer data indicates that the percentage of fishing days with more than one set was recently at around 20% and has shown a minor increase since 2008. When more than one set per day was observed the additional sets in that day were dominated by free-school sets. The data suggested that when more than one set is done in a day the additional sets are primarily aimed at harvesting more fish rather than making up for lower catch rates.

Catch per unit effort (CPUE) metrics declined from 2008 to 2011 after which they were variable but stationary, with the exception of a slight increasing trend in metric tonnes per day in the PNA EEZs due to the increase in mean number of sets per day. Catch rates however have shown high interannual variability, and are difficult to interpret in relation to effort creep. Of note is the stable long-term trend in catch rates for FAD associated sets compared to declining trends for free-school sets. However, the increased rate of unassociated sets from the late 2000s likely impacted the decline in unassociated CPUE due to (potentially) less skilled operators conducting more free-school sets. Stability of FAD catch rates may partly relate to higher capture efficiency for FAD related sets. Improvements in FAD technologies (such as sonar) 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; and/or potential increases in catch rates due to the use of new technology may be offset by a declining biomass.

Vessel size, hold capacity and engine power characteristics, which may influence effort creep, displayed a minor increasing trend from 2007. The composition of vessels in terms of year of construction showed differing patterns over time depending on the flag state. Entrance of new vessels (i.e. constructed post-2000) have become notable for some flags over recent years, some states have maintained a mixture of new and older vessels since 2008, whereas others have remained dominated by old vessels constructed pre-2000. The influence of year of vessel construction on catch rates has changed over time. From 2007-2012, catch rates were typically higher for more recently constructed vessels. However, from 2013 (with the exception of vessels constructed prior to 1980), there was no longer a trend in catch rates with vessel year of construction. This suggests that since 2012, older vessels have become more efficient, perhaps due to refits and uptake of newer technology. Consistent with this theory full uptake of technological advances such as bird radars occurred by the early 2010s, net designs changed, real-time oceanographic data became widely available, and skiff horsepower increased. More recently the use of FAD buoys with sonar has increased dramatically, along with an increase in average skipper experience. Uptake of technological and gear advances has no doubt influenced the capture efficiency of the fleets, particularly for the older vessels. A challenge for future work in this area is to identify a limited suite of vessel characteristics and technology/gear features that directly (or indirectly) influence effort creep, and; develop quantitative relationships between these features and effective effort changes over time.

While there is evidence to indicate effort creep has, and is, occurring in the purse seine fishery, quantifying the impact of effort creep on the relationship between fishing effort units (i.e. VDS days) and fishing mortality rate remains problematic. This is largely due to the fact that effort creep is influenced by numerous variables that can have individual, additive and multiplicative effects on catchability. Disentangling effort creep influences on catch rates over time from those due to biomass changes and other spatio-temporal drivers of availability will require more sophisticated statistical approaches. We are hopeful this will help identify how effort creep (due to multiple variables) is influencing catchability, and provide the basis for developing quantitative effort creep metrics that are of more relevance to assessment and management. From a management perspective, while it may be possible to estimate effort creep implications retrospectively, effort creep is problematic to forecast and monitor because it is not linearly related with time and new factors can come into play. Management procedures should, however, be designed to be robust to the influences of unknown future effort creep within a plausible range. This is being examined by management strategy evaluation (MSE) as part of the development of management procedure options for the skipjack purse seine fishery (e.g. Hamer et al., 2020; Scott et al., 2020).

We invite WCPFC-SC16 to:

- Note the trends in the purse seine fishery metrics, and the need to ensure related information is available to understand the potential influences on effort creep;
- Note the value of developing consistent and complete information on vessel characteristics, and improved information on the effects of changing FAD technologies and levels of application in the WCPO purse seine fishery; and
- Recognize the continued importance of developing quantitative metrics of effort creep for management use and development of management procedures.

Table 1: Summary of recent (average 2017-18 vs 2015-16) and longer-term (2007-2018) trends in different indicators within and outside PNA EEZs.

Indicator	**2017/2018 vs 2015/2016**		**Per annum linear regression trend, 2007-2018**[3]	
	PNA	Non-PNA	PNA	Non-PNA
Sets/year	+20%	+5%	+4%	+4%
Sets/day	+3%	-10%	+3%	+2%
Total tuna CPUE (mt/day)	-10%	-32%	+1%	-2%
Total tuna CPUE (mt/set)	-13%	-24%	-1%	-2%
Total tuna CPUE (mt/set) - ASS sets	-7%	+2%	0%	0%
Total tuna CPUE (mt/set) - UNA sets	-18%	-45%	-2%	-4%
Total tuna catch	+4%	-22%	+2%	-1%
Total skipjack catch	+2%	-31%	+2%	-1%
Vessel length (m)	+1%		0%	
Vessel gross registered tonnage (GRT)	+1%		+1%	
Vessel horsepower (HP)	+0%		+1%	
Well capacity (mt)	+1%		+3%	

[3] Percent change relative to 2007 level, estimated through linear regression of the data across the period 2007-2018. Values rounded to the nearest whole percentage.

1 Introduction

Standard metrics of fishing effort such as fishing days and units of gear deployed, if used as the primary management control on fishing mortality can be confounded by changes in technology (e.g. bird radars, gear technology, access to high resolution oceanic data, advanced echo sounders etc.) and other operational efficiencies, such that the potential catch associated with a unit of effort may increase over time independent of the stock biomass. This increase in capture efficiency is often referred to as an increase in "effective effort" or "catchability". This situation where fishing vessel catch efficiency increases over time within an effort-based management framework is referred to as "effort creep". Effort creep is an important factor to consider in effort-based management systems, as it can gradually undermine the effectiveness of the effort controls in limiting fishing mortality, and lead to sub-optimal fleet investments (Pilling et al., 2016).

Effort creep can be difficult to quantify because it is often comprised of many different components which include but are not limited to: vessel length, engine power, fishing technologies, and skipper/crew experience. Furthermore, to be useful in assessment and management, any metrics of effort creep need to be scalable to impacts on effective effort or catchability. For the 12th Scientific Committee (SC12), a suite of indicators were developed to evaluate and monitor effort creep. The approach and indicators proposed were supported by SC12, and deemed directly relevant for the development of harvest strategies for skipjack (Pilling et al., 2016). However, these indicators primarily focused on understanding and capturing trends in factors that are thought to be driving effort creep, rather than quantify the relationship between effort creep metrics and effective effort, which remains a challenging ongoing research area. In addition, the PNA[4] requested that the Pacific Community (SPC) report annually on trends in effort creep indicators by updating key outputs from that paper, and expressed interest in standardizing the process of adjusting the management scheme for effort creep across the WCPO (SC12 report, para 641). In 2019, the effort creep indicators were updated for SC15 (Vidal et al., 2019), and this paper details the trends in purse seine effort and effort creep indicators in the WCPO over time and summarizes the latest information available to SPC as of March 2020 (includes complete data through 2018 and partial data for 2019 for some indicators). In this year's report, we have also included data from observers, and from vessel registries to increase the information on vessel characteristics and use of technology. Three groups of proxies for effort creep were established in 2016 (Pilling et al., 2016):

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.

Here, we provide an update for these indicators, and summarize the catchability trends from the most recent skipjack and yellowfin stock assessments.

[4] Parties to Nauru Agreement (PNA) states include the Federated States of Micronesia, Kiribati, the Republic of the Marshall Islands, Nauru, Palau, Papua New Guinea, Solomon Islands, Tokelau, and Tuvalu

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

Aggregate (1°x1°) raised logsheet data, summarized by approximate exclusive economic zone (EEZ)/high seas area for the WCPFC Convention Area within the latitudinal range 20°N-20°S, were used to evaluate changes in effort creep indicators from the period 2007-2018 (with partial data for 2019 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). Effort and catch within archipelagic waters were excluded from the estimates. Long-term trends were examined over the time period since the implementation of the Vessel Day Scheme (VDS; 2007-2018[5]) by fitting a linear smoother and are expressed as percentage change per year relative to 2007. Recent changes in indicators are summarized by taking ratios between average effort, catch per unit effort (CPUE), and catch in 2017-18 compared to 2015-16 calendar years.

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 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 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 man-made 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 departure 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/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 number of unassociated sets per year had a notable increased in PNA EEZs in 2010 as the VDS was fully implemented, and although variable, has remained well above pre-2010 levels in recent years. In contrast, the number of unassociated sets per year outside PNA EEZs has shown a more gradual increase over time since 2007 (Figure 1). It appears that the effort constraints imposed in PNA EEZs under the VDS

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

from the late 2000s provided an incentive to make additional unassociated sets within a fishing day to maximize harvest potential within a vessel's allocated fishing days. Between 2015-2016 and 2018-2019, the overall number of sets per year increased by 20% and 5%, inside and outside PNA EEZs, respectively. Over the period 2007-2018 there has also been a positive linear trend in total sets per year relative to 2007 of 4% per year for both PNA and non-PNA EEZs (Table 1).

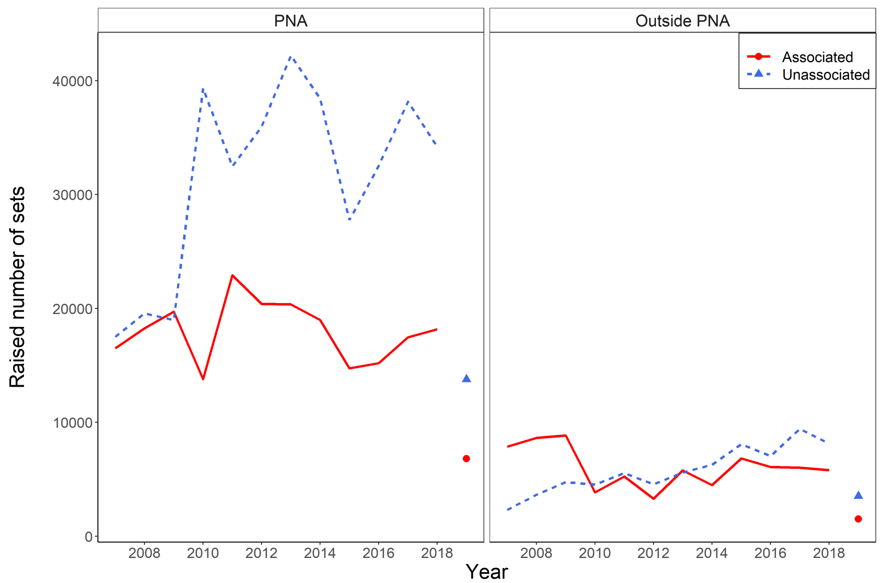

Figure 1: Time series of total raised purse seine sets per year, for associated and unassociated set types, inside (left) and outside (right) PNA EEZs from 2007-2019. Note: 2019 is included as points on each figure but data are incomplete.

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. The number of sets made per fishing day has generally increased since 2007 for unassociated sets, in both PNA and non-PNA EEZs (Figure 2). For associated sets, the average sets per day inside and outside PNA EEZs have been relatively stable since 2010 (Figure 2). The average sets per day across both set types (Figure 2) increased by 3% from 2015-2016 to 2017-2018 for PNA EEZs and decreased by 10% for non-PNA (Table 1). The recent decrease for non-PNA EEZs was due to the spike in setting rates in 2015 (Figure 2). Over the longer time series (2007-2018) there has been a positive linear trend in average sets per day (set types combined) relative to 2007 of 3% and 2% for PNA and non-PNA EEZs, respectively (Table 1).

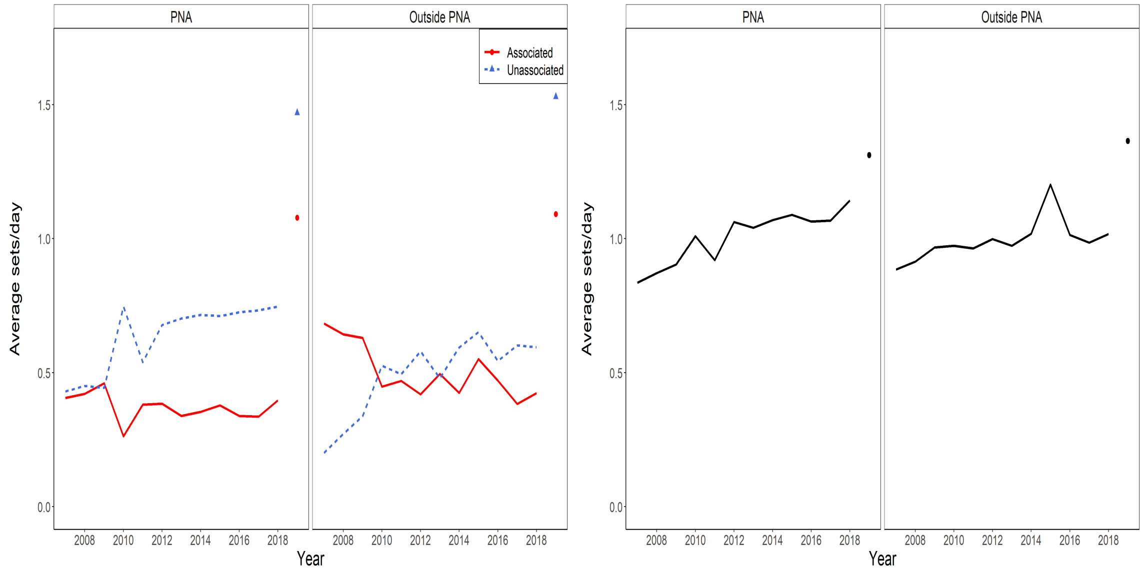

Figure 2: Time series of setting rate (sets per fishing day) for associated and unassociated set types (left) and all sets (right), for waters inside and outside PNA EEZs, from 2007-2019. Note: 2019 is included as points on each figure but data are incomplete.

2.2 Disaggregated sets per day: observer data

An important aspect to understanding effort creep is how individual vessel behaviors and characteristics change over time. Here we have summarized operational (set-level; unraised data) effort data collected by fishery observers which would included most activity since 2008 (when 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). Figure 4 shows that when only one set is made per day, it is typically a FAD set, however when two or more sets are made, unassociated sets dominate the additional sets. This breakdown highlights what may be strategic differences between vessels, with some focusing largely on productive FAD sets and other specializing on free-school sets. It should be noted that these summaries include the FAD closure period, during which free-school sets would dominate, thus potentially skewing this partition by set type towards greater proportions of free-school sets.

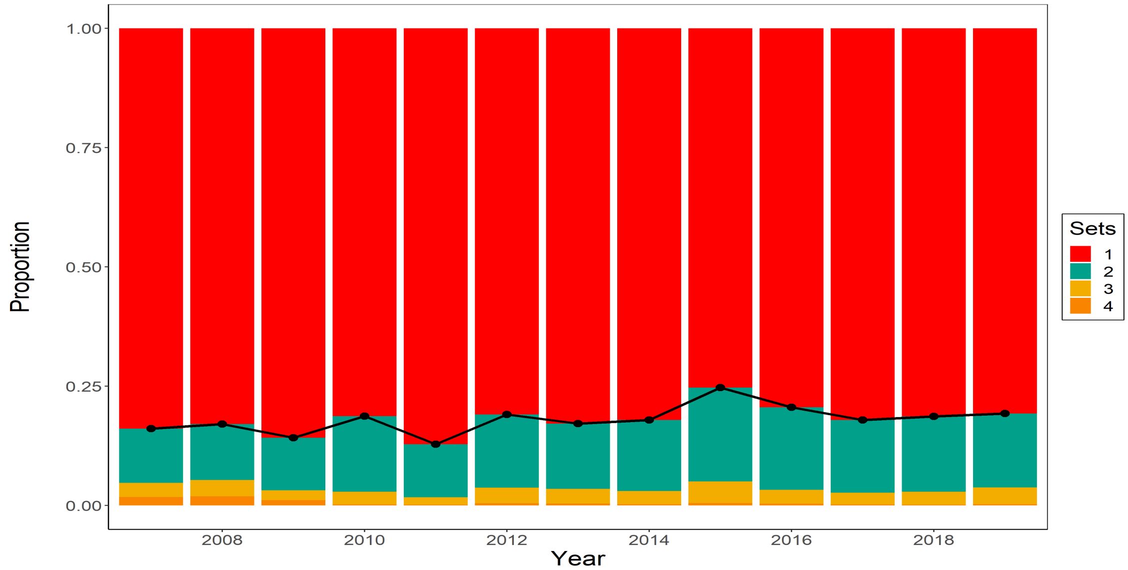

Figure 3: The proportion or fishing days characterized by number of sets per day (1-4) from 2007-2019, showing a slight increase in sets per day.

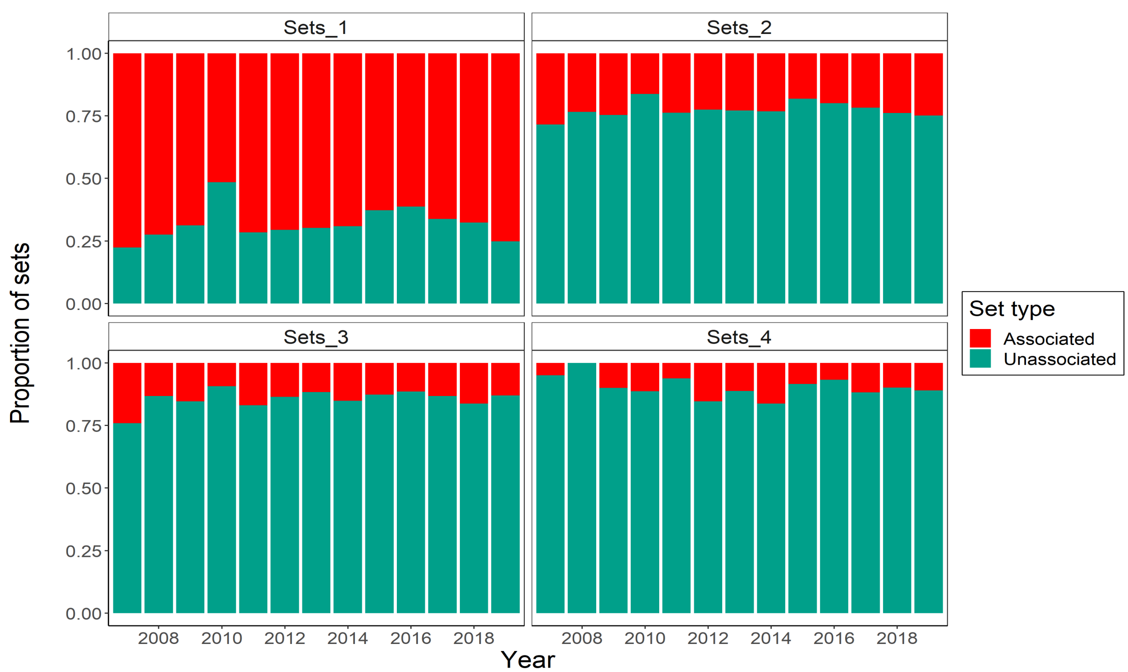

Figure 4: This figure decomposes the proportion of sets by set type, relative to the number of sets made within a fishing day. The panel labels indicate fishing days with numbers of sets made per day ranging from 1 to 4. I.e. for days where 4 sets are made, approximately 80% of sets are unassociated; but for days when 1 set is made, 80% of sets are associated.

The motivation for making multiple sets per day is not always clear, but there are two general hypotheses: 1. multiple sets serve to compensate for poor sets earlier in the day; or 2. some vessels seek to maximize catch within a vessel day by making multiple sets. The catch rates per day (Figure 5) 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, however there is a tendency towards larger catches when one or two set are made per day, compared to days with three and four set (Figure 5). 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 lower per set catches earlier in the day. Figure A1 supports this conjecture by showing that the median and distribution of catches for the first set in a day are similar irrespective of how many sets are done per day.

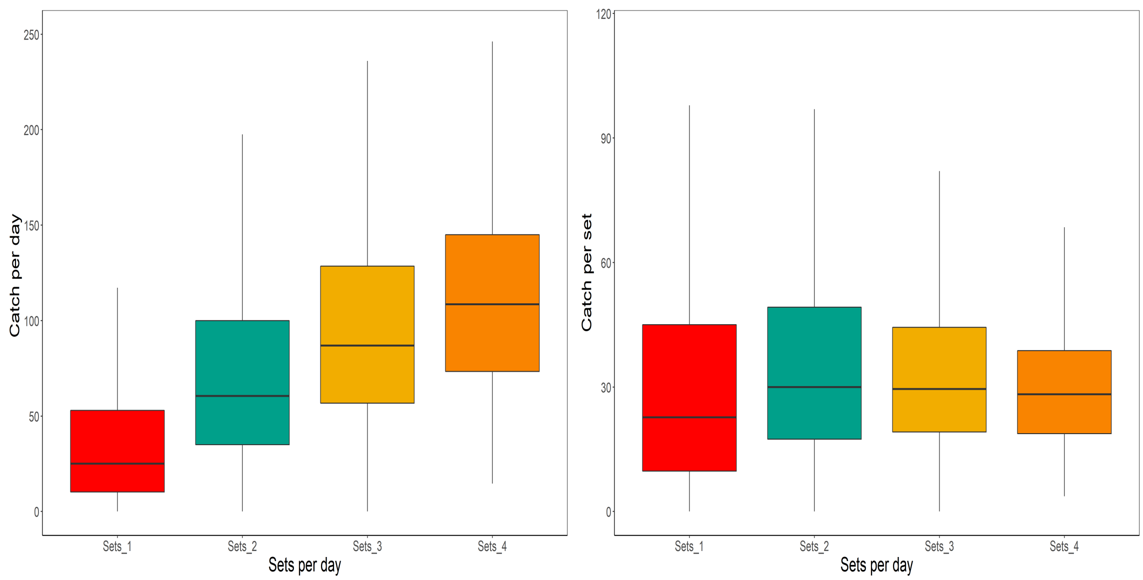

Figure 5: Distribution of total tuna catch per day, aggregated across years, for days with 1 - 4 purse seine sets.

2.3 Purse seine CPUE inside and outside PNA EEZs

Trends in the nominal CPUE were measured as total tuna metric tonnes caught per day fished (mt/day), and per set (mt/set). 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 6. The majority of the catch (approximately 70-90%) was comprised of skipjack (Figure 8), which drives these trends. The stable catch composition data also suggests that increased numbers of free school sets is not due to increased targeting of yellowfin.

Catch rates within PNA EEZs have been consistently higher than non-PNA areas (Figure 6). CPUE inside and outside PNA EEZs has, however, shown similar dynamics since 2007, although the catch rates outside PNA EEZs have varied by larger amounts. The drop in CPUE outside the PNA EEZs in 2010 appears consistent with closure of key high seas areas (Pilling et al., 2016), likely indicating that the remaining fishing areas were of lower suitability to purse seine fishing, or that the vessels fishing only on the high seas were less productive. Comparison of average CPUE between 2017-18 and 2015-2016 showed decreases of 13% for mt/set and 10% for mt/day inside PNA EEZs, and 32% and 24%, respectively, outside PNA EEZs. These recent trends are largely driven by the high catch rates observed in 2015. From 2007 to 2018, mt/day has shown an increase of 1% per year inside PNA EEZs, but a decrease of 2% per year for non-PNA areas. CPUE in mt/set has decreased by 1% and 2% per year relative to 2007 for PNA and non-PNA areas, respectively (Figure 6).

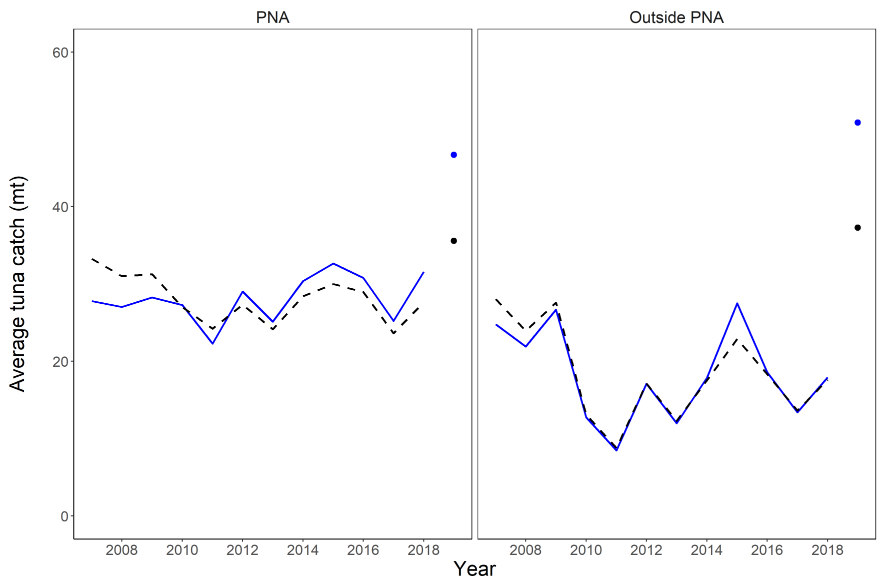

Figure 6: Time series of nominal purse seine total tuna CPUE in terms of mt/day (blue; solid lines) and mt/set (black; dashed lines) inside and outside PNA EEZs, from 2007-2018. Note: 2019 is included as points on each figure but data are incomplete.

Considering set types, for associated sets in both PNA and non-PNA areas there has been no long-term trends in mt/set since 2007 (Figure 7). For unassociated sets, mt/set shows similar dynamics for PNA and non-PNA areas, but with higher variability than associated sets, and higher varibility in non-PNA areas. From 2007-2018 there is also a decreasing trend in mt/set for unassociated sets of 2% and 4% per year (relative to 2007) for PNA and non-PNA areas, respectively. Comparisons between 2015-2016 and 2017-2018 show that CPUE declined by 7% for associated sets inside the PNA, but increased by 2% outside PNA. However, over the same period, unassociated CPUE declined substantially by 18% and 45% inside and outside PNA EEZs, respectively (Table 1). These recent declines are again, largely driven by the high catch rates observed in 2015 (Figure 7).

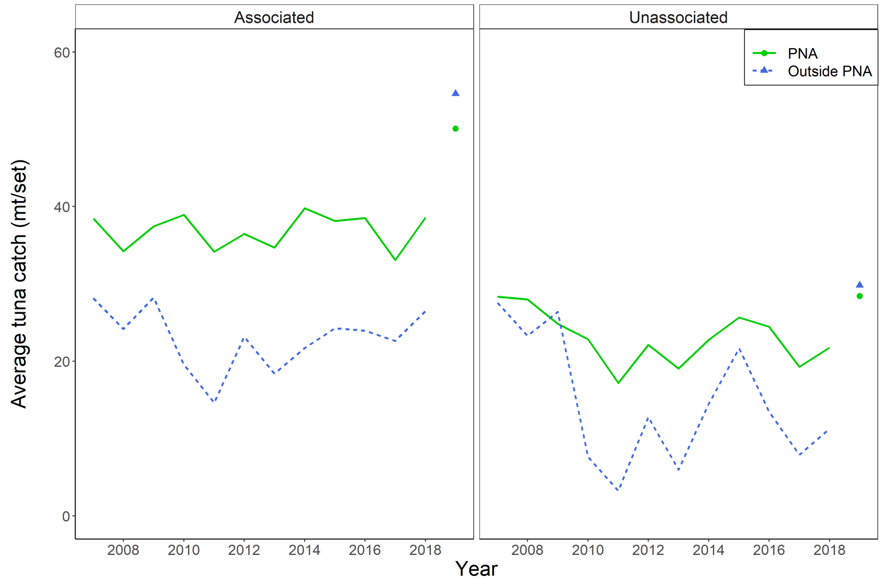

Figure 7: Time series of nominal purse seine total tuna CPUE (mt/set) for associated sets (left) and unassociated sets (right) inside and outside PNA EEZs. Note: 2019 is included as points on each figure but data are incomplete.

The technology associated with FAD fishing has become more sophisticated through time, specifically with the adoption of sonar-equipped FADs. 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'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, potentially saving on fuel expenditures.

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 2017 were estimated in an analysis presented at SC14 (Escalle et al., 2018). Using fishery data combined with updated PNA FAD tracking information (2016-2019), it was estimated that at the scale of the WCPO there were approximately 31,000 FAD deployments in 2016, 34,500 in 2017, 39,500 in 2018, and 33,400 in 2019 (Escalle et al., 2020), with the median number of active FADs per vessel estimated to be 45–75. 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 priority for future developments in indicators of effort creep.

2.4 Aggregate purse seine catches inside and outside PNA EEZs

Within PNA EEZs, average annual total tuna catch increased by 4% from 2015-2016 to 2017-18. Over the longer-term there is a positive linear trend of 2% per year relative to 2007 (Table 1) (Figure 8). Outside PNA EEZs, average annual tuna catch decreased by 22%, from 2015-16 to 2017-18 (Table 1), influenced by the high 2015 catch associated with a strong El Niño event, and the corresponding shift in fishing effort to the east. Not surprisingly, both longer (2007-2018) and short-term (2015-16 to 2017-18) trends for skipjack catch are similar to overall tuna catch (Table 1). The apparent increase in catches for unassociated sets in PNA EEZs since 2007 is related to previously discussed increases in the number of unassociated sets being made. 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 8). 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.

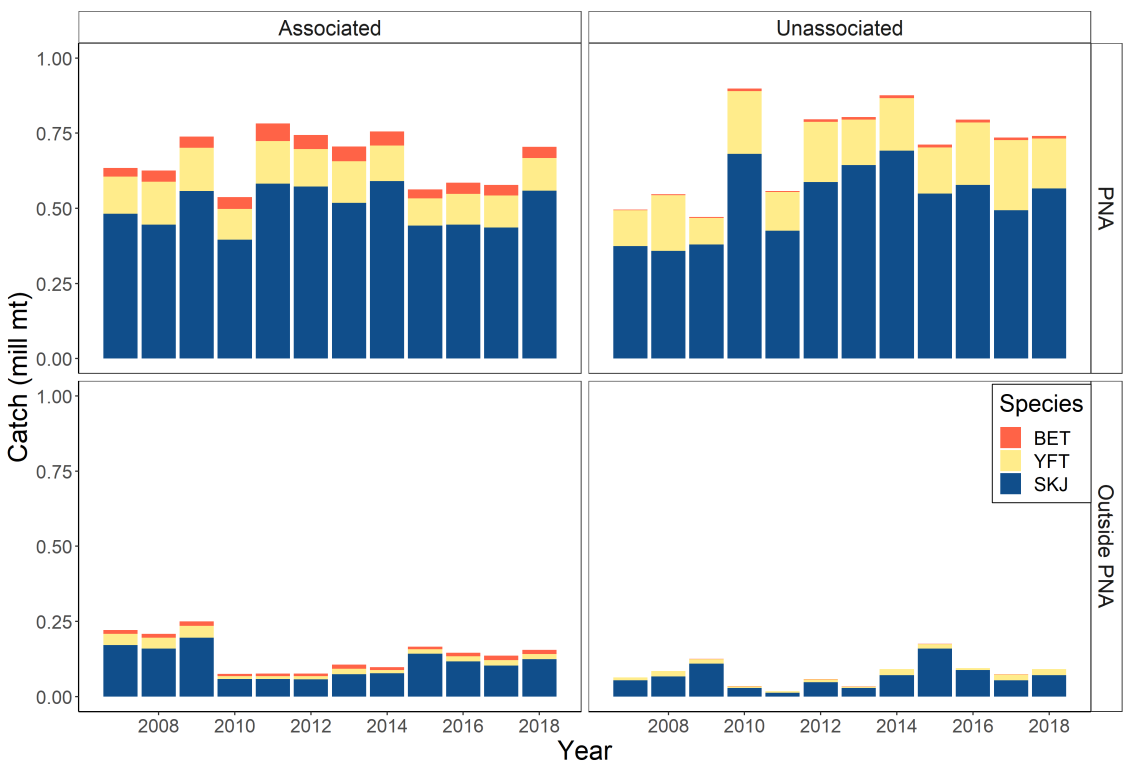

Figure 8: Time series of purse seine catches inside (left) and outside (right) PNA EEZs, for associated (top) and unassociated (bottom) sets from 2007-2018.

2.5 *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.

The accuracy of information in these vessel registers still needs to be verified and standardized, to ensure consistency in measurements used, submitted characteristic values, and completeness of information for some fields. Based upon the information currently available, Figure 9 shows the evolution of average vessel length (m), gross registered tonnage (GRT), and engine horsepower for vessels on the FFA Register. In addition, data on the well capacity (mt) of purse seine vessels, collected by observers, is presented to show changes over time. A very minor long-term increase is seen in these characteristics, and more recently these indicators have increased by 0-1% (Table 1). We note that estimates reflect vessels that may operate in specific tropical WCPO areas.

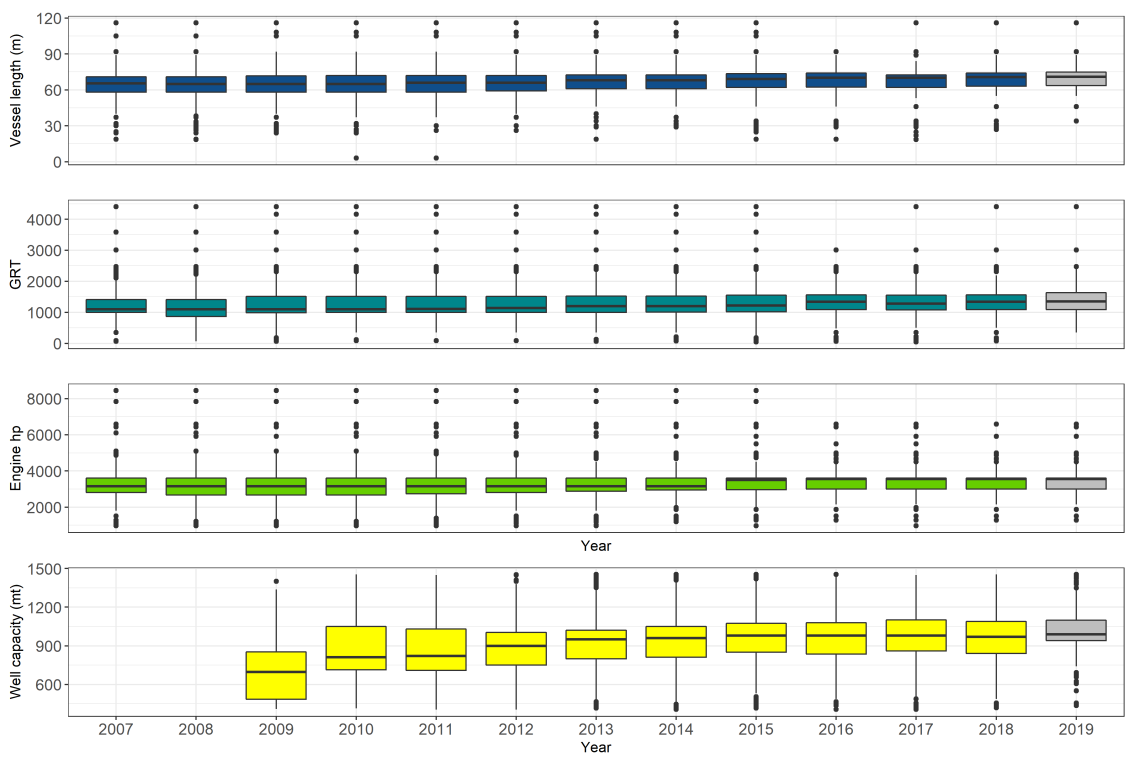

Figure 9: Boxplots illustrating the distribution of vessel size characteristics of purse seine vessels registered annually on the FFA Vessel Register in terms of length overall (m; top); gross registered tonnage (GRT); engine horsepower; and well capacity (mt; bottom). The well capacity data were obtained from observer collected data.

The age of purse seine vessels is often thought to be an important indicator of efficiency and capacity. Evidence suggests that newer vessels tends to be larger (even within the 50-80 m size class), faster, and have a larger well capacity. Newer vessels may be less apt to breakdown and require untimely repairs, and be fitted with up-to-date technology such as FAD tracking equipment, advanced sonar and bird detecting radars, and more efficient systems for processing catches. To investigate the fleet composition by country vessels are flagged to, and evaluate the influence of the year of vessel construction on catch rates, we used the FFA vessel registry data. Figure 10 shows country (i.e. flag) specific patterns in fleet age composition through time. Some fleets appear to be composed largely of older vessels, while others appear to be investing more heavily in upgrading the purse seine fleet. China, Chinese-Taipei, Korea, Federated States of Micronesia, Papua New Guinea, and more recently, the Philippines, show a decreasing trend in vessel age and are adding younger, newer vessels (i.e. construction post-2000) to their fleets. New Zealand, Spain, Ecuador, El Salvador, and Tuvalu appear to be operating largely with an older fleet of vessels. The USA, Japan Korea and Papua New Guinea have maintained a spread of older and newer vessels over time since 2010 Figure 10. Reflagging of vessels would have influenced these changes over time along with construction of new vessels.

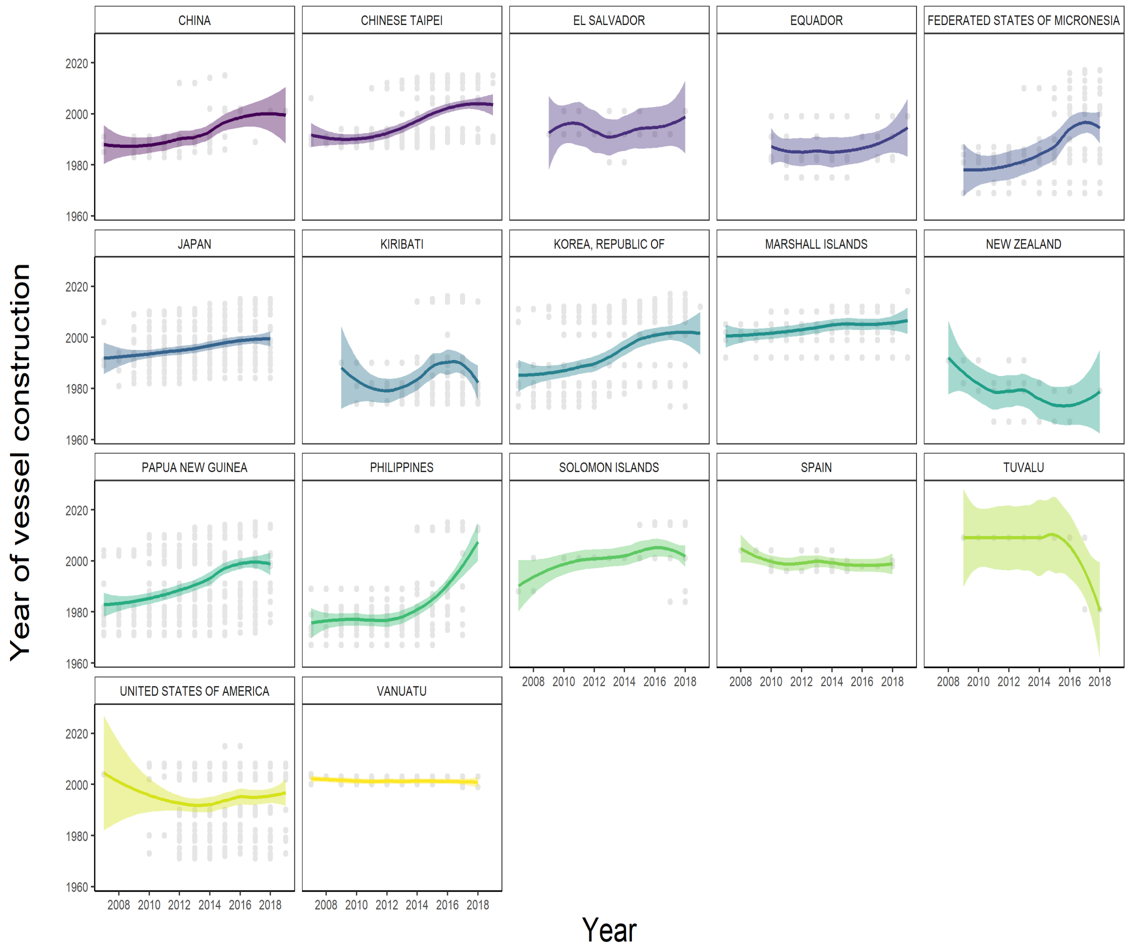

Figure 10: Panel plot illustrating the distribution of vessels, by year of construction, through time, separated by country the vessel is flagged to. The colored lines and bands represent a loess smoother with 95% confidence intervals, respectively. The dots represent individual vessels.

Vessel upgrades can be costly, and therefore the capital investment must be offset by revenue to ensure profitability. The catch rates by year of vessel construction, or vessel age, suggest that in the earlier part of the time series newer vessels were generally more efficient than older vessels (Figure 11). However, through the years, this contrast in catch rates based on vessel age has become less obvious. In the most recent years (since 2013), catch rates (mt/set) appear to be fairly consistent across vessel age, excepting for the oldest vessels (pre-1980 construction), suggesting that other factors may be influencing the productivity of catch rates.

Figure 11: Smoothed trend, from a generalized additive model, in observed CPUE (mt/set) by year of vessel construction, over the time series, 2007-2018.

Technological upgrades/advances need not be overly expensive relative to mechanical or structural vessel features. Observers have also collected detailed information on vessel and gear characteristics as well as technologies fishers are using to better locate and harvest tuna. Here, we present a descriptive summary of a suite of metrics predicted to influence catch rates (Figure 12). The efficiency of purse seine effort is largely comprised of two general aspects: 1. the ability to locate fish, and 2. the ability to capture fish. Here we demonstrate that there are a wide range of potential indicators of effort creep, all of which could be increasing the ability of fishers to locate and capture tuna, and most of which appear to be increasing through time.

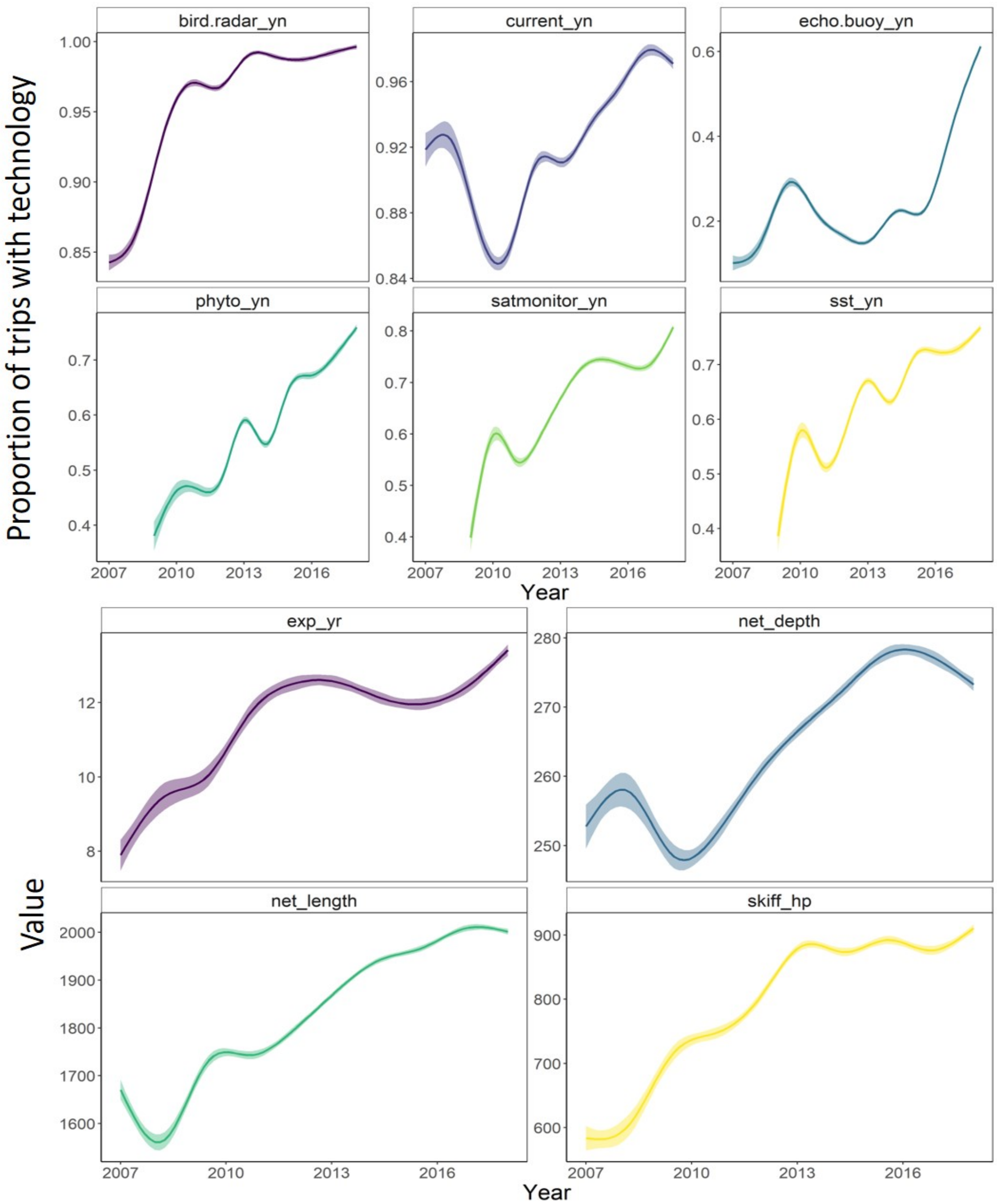

Figure 12: Smoothed (generalized additive model) trends in observer collected data on vessel, gear, and technological characteristics. For binary response variables (yes/no), the y-axis value is the mean proportion of trips for which the specific equipment/technology was used. Variables included: bird radar (y/n); current meter (y/n); echo-sounder FAD buoys (y/n); skipper experience (years); net depth (m); net length (m); phytoplankton monitor (y/n); satellite weather monitor (y/n); skiff horsepower; and sea surface temperature monitor (y/n).

Monitoring vessel characteristics may allow the technical drivers of effort creep to be identified. These may be specific to set types; e.g. more powerful blocks, larger net mesh, net configuration/length, and knotless mesh may increase the effectiveness of free-school fishing, while adoption of echo-sounders on FADs may increase the effectiveness of FAD fishing. Preliminary analyses suggest a very minor influence of vessel size on CPUE (Figure A3). The observation that catch rates of older vessels seemed to improve relative to newer vessels (post-2000 construction) over time is consistent with the observed increase in the uptake of technological tools, advanced net designs, better skiffs, etc., as opposed to major physical or mechanical changes to the purse seine vessels.

A challenge for our ongoing research is to identify a limited suite of characteristics that directly (or indirectly) influence effort creep. The relationship between the change in a characteristic and the level of effort creep is however not necessarily linear, nor may that effect continue through time. In turn, efficiency may have increased at a higher rate than the growth in an individual characteristic, as the combined impact on efficiency of changes in different characteristics may be greater than the individual effects alone. Finally, while it may be relatively simple in theory to monitor technology usage/uptake rates, gear features and vessel characteristics; the ways in which skippers and crew take advantage of new fishing technologies may vary with time and across fleets, leading to complex spatio-temporal relationships between these potential effort creep indicators and catchability gains. Identifying characteristics that influence CPUE, and then modelling their combined effects where data allow, taking the stock size into account, may help identify the overall level of effort creep and whether a single characteristic, or a suite of characteristics (multivariate index), can act as a suitable indicator(s) for monitoring and management purposes.

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 is 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.

3.1 Skipjack tuna

Catchability estimates for skipjack tuna from the four main tropical purse seine fisheries are predicted to have increased throughout the time series (1972-2018; Figure 13), based on the 2019 stock assessment (Vincent et al., 2019). Estimates of catchability from the tropical purse seine fisheries in the western region (Region 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 (2015-2018), catchability estimates have continued to increase, with the exception of the unassociated eastern (Region 8) fishery, which has remained stable (Table 2). Over the longer-term (2007-2018), skipjack purse seine catchability increased by 1.2 and 1.4% in the western region for the associated and unassociated fisheries, respectively. In the eastern region, catchability increased for the associated fishery by 1.6% and declined for the unassociated fishery by 0.3% (Table 2).

Table 2: Relative change in catchability for the skipjack tuna unassociated (UNA) and associated (ASS) tropical purse seine fisheries from Regions 7 and 8 of the 2019 skipjack stock assessment.

Fishery	2017-2018 vs 2015-2016	Per annum linear regression trend, 2007-2018[6]
Western ASS (Region 7)	+3%	+1.2%
Western UNA (Region 7)	+8%	+1.4%
Eastern ASS (Region 8)	+6%	+1.6%
Eastern UNA (Region 8)	0%	-0.3%

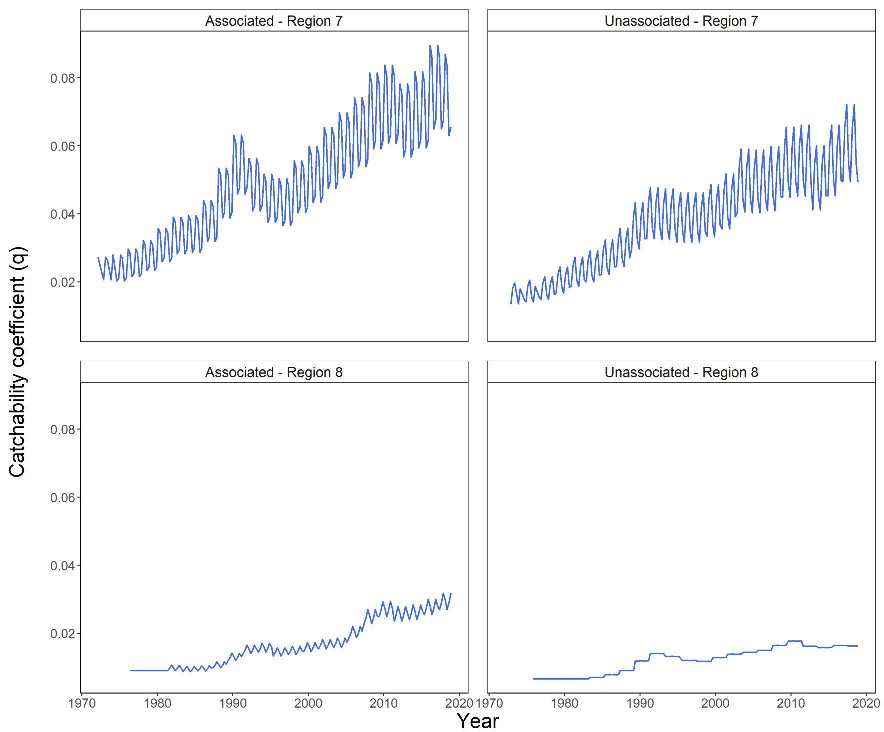

Figure 13: MULTIFAN-CL quarterly time series estimates of tropical purse seine fishery catchability within the 2019 skipjack stock assessment model (Regions 7 and 8; 1972-2018).

3.2 Yellowfin tuna

Yellowfin tuna catchability estimates from the most recent SC-agreed (2017) yellowfin stock assessment (Tremblay-Boyer et al., 2017), also showed a general positive trend from the beginning

[6]Percent change relative to 2007 level, estimated through linear regression of the data across the period 2007-2018.

of the time series (1968), until approximately the early 2000s, in Regions 3 and 4 (Figure 14). Over the past 15 years, catchability in Region 3 has shown a negative trend for the associated and unassociated fisheries (excepting the most recent time periods in the assessment). In Region 4, associated catchability has declined slightly from the peak in the mid-2000s, while the unassociated fishery has fluctuated considerably without a discernible trend for approximately the past 20 years.

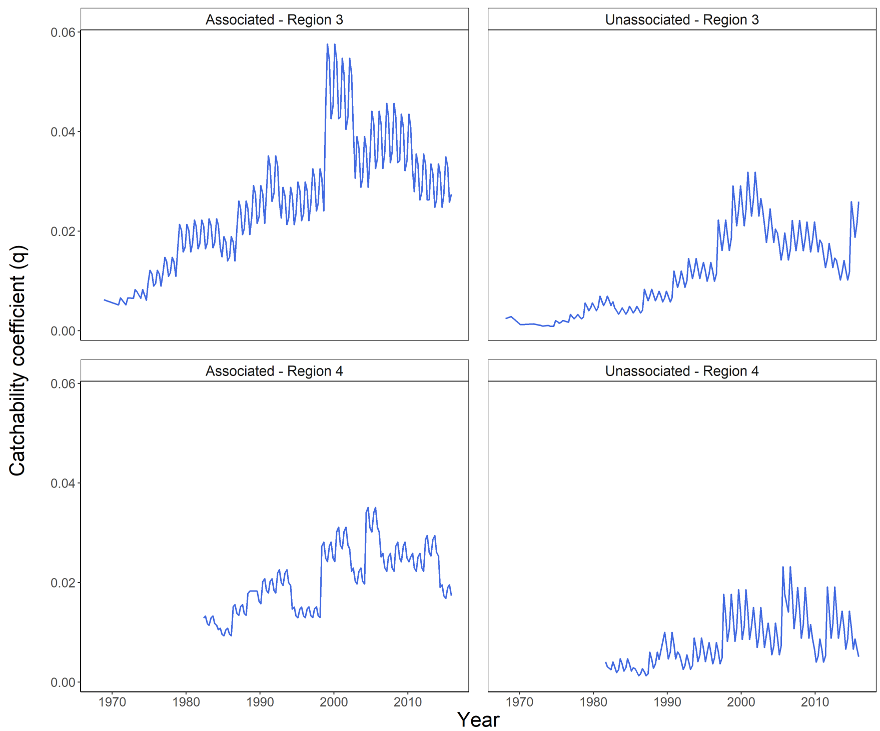

Figure 14: MULTIFAN-CL quarterly time series estimates of tropical purse seine fishery catchability within the 2017 yellowfin stock assessment model (Regions 3 and 4; 1968-2015).

Relatively large fluctuations in yellowfin catchability were estimated in the most recent years of the 2017 yellowfin stock assessment. Between 2012-2013 and 2014-2015 (2015 was the terminal year in the assessment) no change was detected in the catchability from the Region 3 associated fishery while a 42% increase in catchability was estimated for the Region 3 free school fishery (Table 3). In the eastern tropical region (Region 4) a 29% decline in catchability was estimated for the unassociated fishery, and a 32% decline for the free-school fishery. Over the longer-term (2007-2015), catchability estimates declined by 1.4 to 3.8% across the four fisheries evaluated (Table 3). The high variability in estimated catchability suggests it may not be accurately representing the relationship between effort and fishing mortality. Because of this potential disconnect for yellowfin, as compared to skipjack, yellowfin catchability estimates may be less informative for evaluating purse seine effort creep.

Table 3: Relative change in yellowfin tuna catchability for the unassociated (UNA) and associated (ASS) tropical purse seine fisheries from Regions 3 and 4 of the 2017 yellowfin stock assessment.

Fishery	2014-2015 vs 2012-2013	Per annum linear regression trend, 2007-2015[7]
Western ASS (Region 3)	0%	-3.8%
Western UNA (Region 3)	+42%	-1.4%
Eastern ASS (Region 4)	-29%	-2.4%
Eastern UNA (Region 4)	-32%	-3.3%

3.3 Catchability from stock assessments as an indicator of effort creep

In theory, catchability estimates should be amongst the best indicators of effort creep, as they estimate the aggregate effect of changes in vessel efficiency on fishing mortality and take into account changes in stock abundance, which catch and catch rate indicators cannot do easily. However, these model-based estimates integrate over fleets, depending on how fisheries are defined in the assessment model; fleets specific to PNA waters cannot be separated out. Using catchability estimates as indicators of effort creep for management use has several limitations, including: these estimates are only updated once a new assessment is performed and estimates in the final years of the assessment are considered the most uncertain; they assume that the assessment is completely correct with respect to recent trends in abundance; and for some stocks, like yellowfin, there is considerable inter-annual variability. Therefore, there remains considerable uncertainty in the use of catchability estimates for monitoring and assessing effort creep and application to management.

4 Ongoing research into effort creep indicators

SPC has been focusing on developing models to standardize purse seine CPUE, across the spatial distribution of the purse seine fleet. The work developed thus far to standardize skipjack CPUE, will be presented to SC16 (Vidal et al., 2020). These models have been developed to explicitly account for vessel and gear characteristics predicted to influence catchability over time, e.g. vessel length, net length, and well capacity, but to also account for variability in the environment predicted to influence either catchability or density of tunas. There are many ways in which vessels can increase efficiency through time, either abruptly or more gradually, some of which are detailed in this paper, but the influence of many others remains unknown. For example, some fishing companies have dedicated analysts synthesizing information from FAD networks and oceanographic sensing software, to better direct vessels towards productive fishing locations. This aspect of the fishery is predicted to be highly influential with respect to catch rates, but yet remains difficult to quantify. SPC is actively working to develop multivariate metrics, aimed at

[7] Percent change relative to 2007 level, estimated through linear regression of the data across the period 2007-2018.

capturing different facets of efficiency gains, with which to quantify how changes in vessel, gear, and fishing strategy characteristics map to changes in catchability, and thus fishing mortality. These analyses will require more sophisticated statistical modelling beyond the scope of this annual report, but key result will be included in future versions.

Thus far, the effort metric used for these analyses has been the set. The way in which effort is defined is an integral component to these analyses, and one that we are interested in re-evaluating. Over the next few months, we will be looking more closely into the Vessel Monitoring System (VMS) data to assess whether changes in fishing behaviors over time can be detected, and whether those changes have implications for how we perceive fishing effort. Lastly, we are working to develop a fisher survey, to obtain information on fishing strategies, information technologies, and changes in effective effort, from the industry, as they perceive it (Wichman et al., 2020). We hope to gain valuable information from such a survey to better inform these analyses, to reevaluate our hypotheses regarding important drivers of efficiency changes, and to foster greater communication with and engagement from the industry regarding this research.

5 Effort creep indicators and management advice

In the WCPO purse seine fishery, limits on vessel fishing days through the VDS are the main tool for management of fishing mortality. In this scheme vessel days are also pro-rated in relation to vessel length such that larger vessel pay more for a vessel day than smaller vessels, however, over time and following implementation of the VDS, vessel sizes have become similar across the fleet. Use of technologies such as sonar equipped FADs is not considered in daily charge rates, but may now be a more important influence on effort creep than vessel length.

Irrespective of being able to monitor effort creep, ultimately, metrics for monitoring effort creep should be relevant and scalable to management controls on fishing mortality. For example, a change in the effort creep index of x units results in a change in the catchability or effective effort of y units. Quantifying this relationship will be very useful for retrospectively understanding the implications of effort creep. However, because effort creep is non-linear with time and new vessel features/technologies periodically come into play, it is unreasonable to expect that a 'fixed' effort creep indicator can be hardwired for the future. Furthermore, as mentioned above, using the catchability estimates from stock assessment modelling is not practical for informing regular effort allocation decisions. We suggest that the best approach is to use management strategy evaluation (MSE) to inform the design of management procedures that are robust to plausible impacts of effort creep that may be indicated from retrospective studies.

SPC is currently using an MSE modelling framework to explore how robust different management procedures are in meeting objectives such as target reference points (TRPs), in the face of different levels of effort creep. Figure 15 is an example of the output from a recent MSE simulation study for skipjack tuna in the WCPO that compared the performance of two management procedures for the purse seine fishery under scenarios of no effort creep and effort creep that resulted in a 3%

increase in effective effort per year (Scott et al., 2019). The comparison shows that the management procedure HCR 1 is a safer option than HCR 2, however it is still not effective enough under the effort creep scenario to maintain the depletion level at the chosen TRP (i.e. the top dotted line in each graph). These simulation studies are key to advising management on the choice of robust harvest control rules. Monitoring effort creep indicators is still important for highlighting when and if effort creep impacts are moving outside of the plausible ranges used to develop the original management procedure. In this case MSE would be again used to inform the choice of new management procedures that are more robust to the new levels of effort creep.

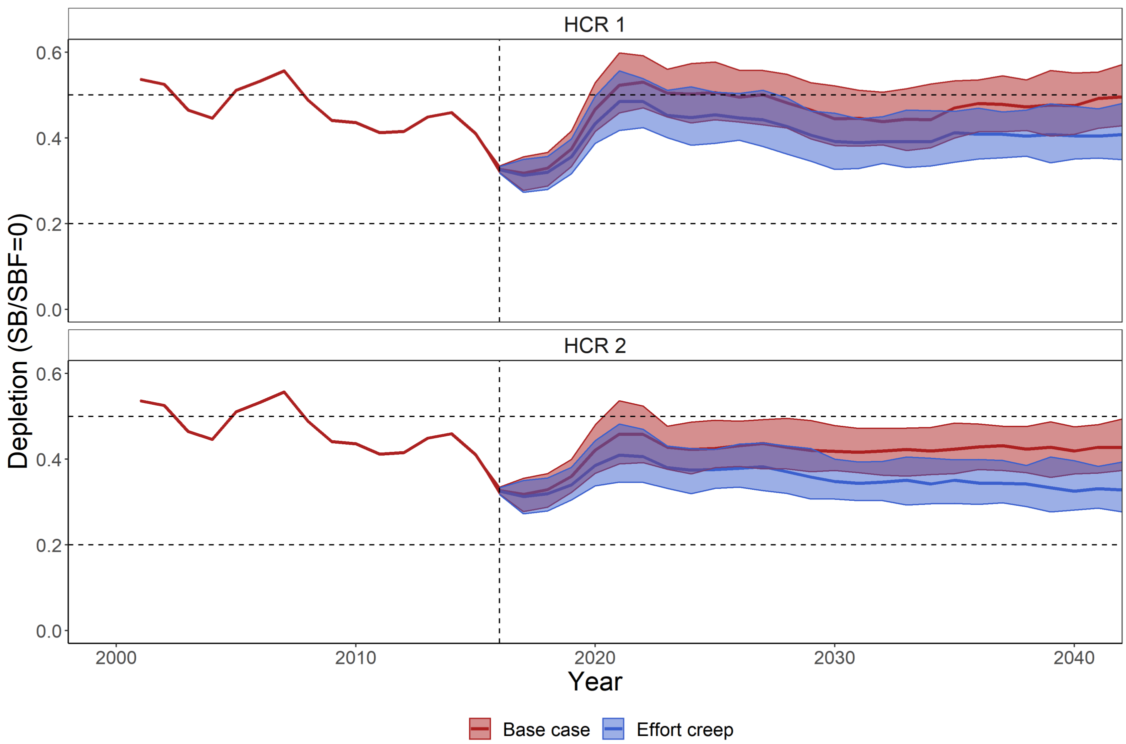

Figure 15: Results of an MSE simulation study to evaluate performance of two management procedures (HCR 1, HCR 2) under assumed levels of per annum increases in effort creep (0%: Base case, maroon; and 3%: Effort creep, blue) on stock depletion, relative to target (top dotted lines) and limit (bottom dotted lines) reference points for the WCPO skipjack fishery. The ribbons represent the 20-80th percentiles, while the solid lines shows the median projection estimates. The vertical dashed line is the start of the projection period (Source: Scott et al. 2019)

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6 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. Within the context of the WCPO effort-managed system, the most salient concern is that effort creep is masking a declining stock. In situations where stock status indicators such as CPUE are hyperstable, declines in the biomass can be detected too late when significant and disruptive management action is required to allow rebuilding. In this context, disentangling the changes in underlying biomass from stability in CPUE and changes in effective effort is paramount.

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. 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 that while catch rate indicators for FAD associated sets have been relatively stable over the longer term there is evidence for declining trends in catch rates for unassociated free-school sets. This may be an indication of hyperstability in purse catch rates on FADs influenced by effort creep (i.e. new FAD technology). Other indicators of effort creep such as vessel-based indicators and number of sets per day have also increased. The link between trends in these indicators, underlying stock biomass, and the ultimate level of effort creep within the tropical WCPO purse seine fishery however remains unclear. Ultimately, the effectiveness of potential adjustments to the management framework can be tested within Management Strategy Evaluation (e.g. Scott et al., 2016) to ensure that any proposed management approach is robust to this uncertainty. The development of suitable indicators to quantify changes in effort creep over time, and which are useful and appropriate for tropical tuna management, is an area of ongoing research at SPC.

We invite WCPFC-SC16 to:

- Note the trends in the purse seine fishery metrics, and the need to ensure related information is available to understand the potential influences on effort creep;
- Note the value of developing consistent and complete information on vessel characteristics, and improved information on the effects of changing FAD technologies and levels of application in the WCPO purse seine fishery; and
- Recognize the continued importance of developing quantitative metrics of effort creep for management use and development of management procedures.

7 Acknowledgements

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Appendix

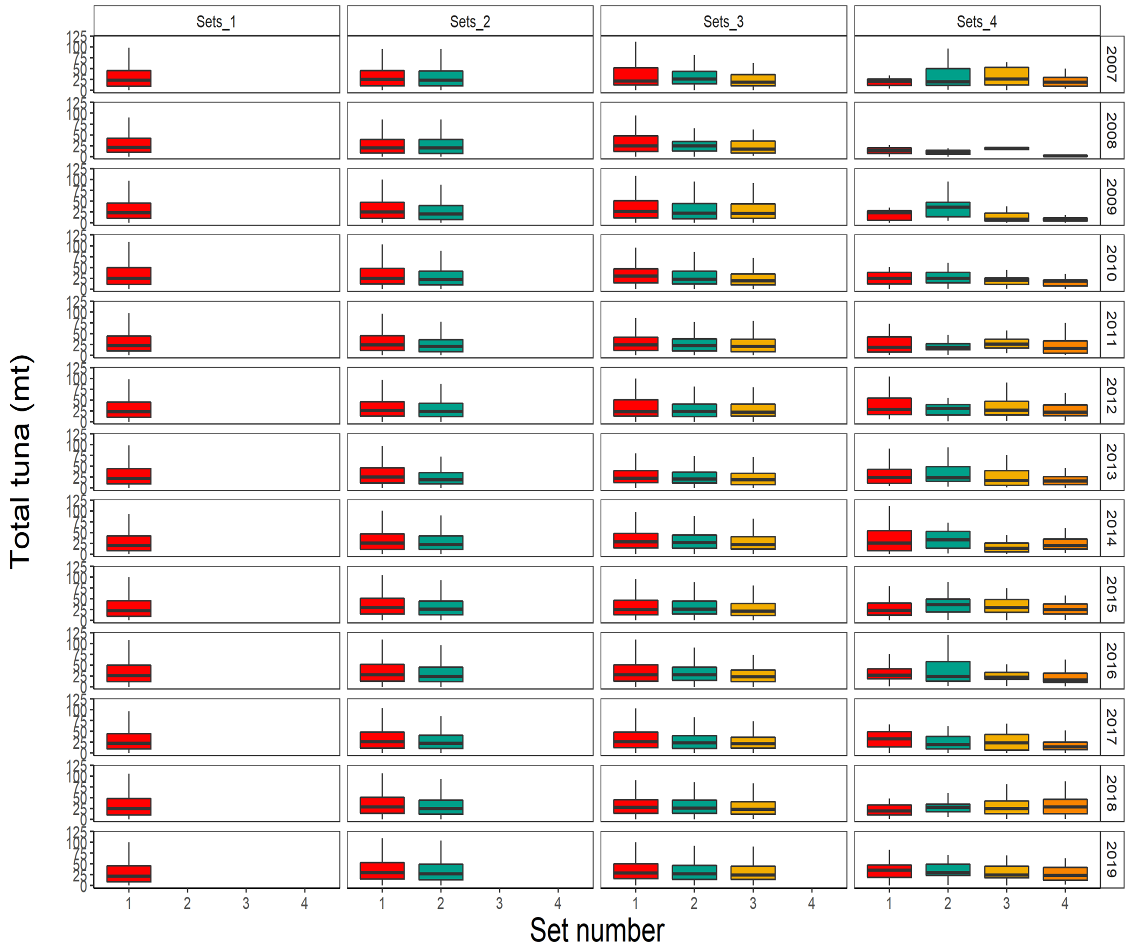

Figure A1: Distribution of total tuna catch per set, for days with 1 - 4 sets per day, from 2007-2019. The graphs shows that the median and distribution of catches for set number 1 are similar irrespective of how many sets are done per day

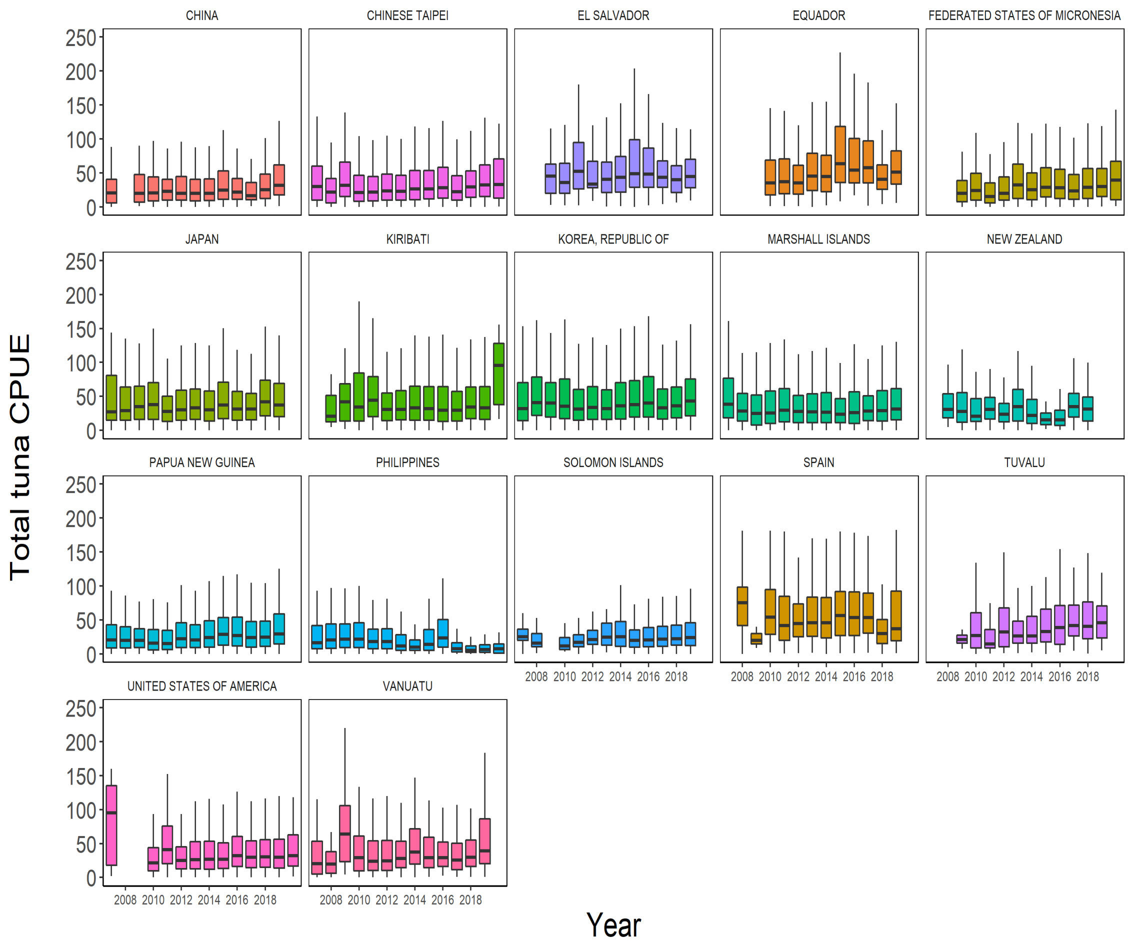

Figure A2: Distribution of total tuna catch per set, by country vessels are flagged to, from 2007-2019. It should be noted that outliers have been suppressed for illustrative purposes.

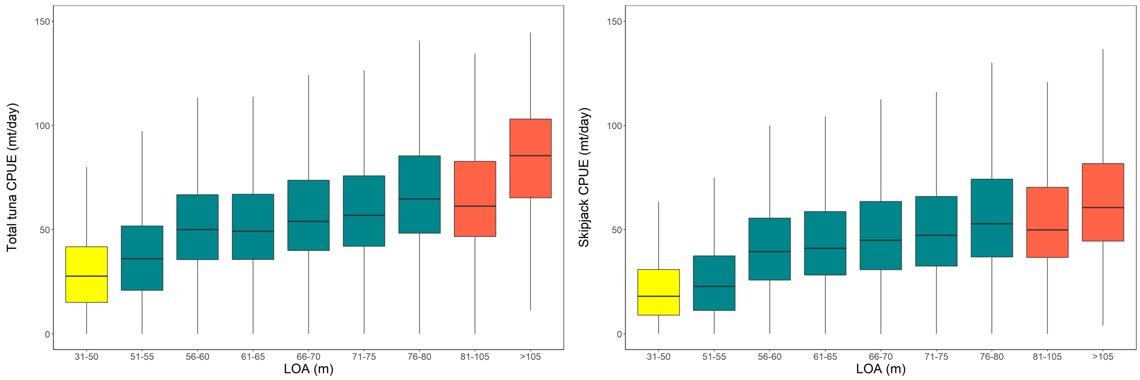

Figure A3: Boxplots illustrating the distribution of trip level total tuna (left) and skipjack (right) catch per day from vessel logsheet data, grouped by vessel size class, from 2007-2018. The colors indicate the vessel size classes associated with the VDS. Note: species compositions here have not been corrected for observer sampling.

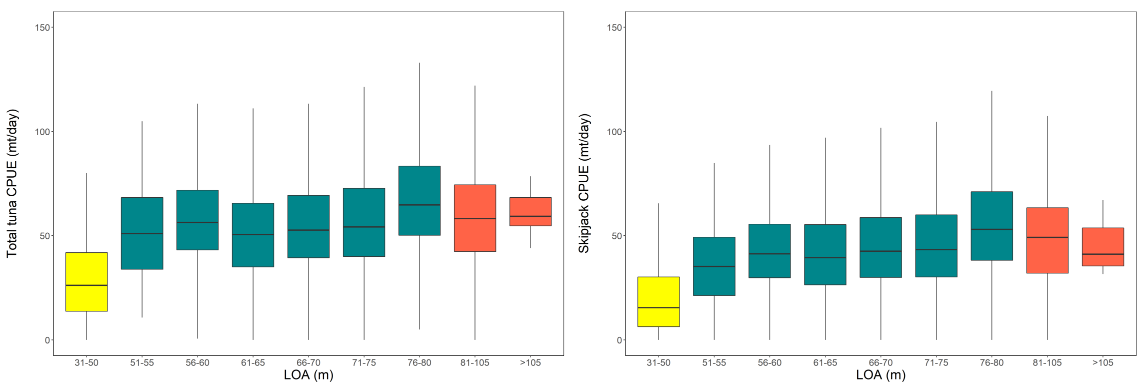

Figure A4: Boxplots illustrating the distribution of trip level combined tuna (left) and skipjack (right) catch per day from vessel logsheet data, grouped by vessel size class, from 2016-2018. The colors indicate the vessel size classes associated with the VDS. Note: species compositions here have not been corrected for observer sampling.