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Evaluation of Effort Creep Indicators in the WCPO Purse Seine Fishery

WCPFC-SC15-2019/MI-IP-05

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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 report 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 report para. 641). In 2018, the effort creep proxies were updated for SC14 in paper WCPFC-SC14-2018/MI-IP-05 (Muller et al., 2018).

In this paper, we update and summarize information available to SPC as of July 2019 to present trends in potential 'proxy' indicators of effort creep in the tropical tuna purse seine fishery (Table 1). Most of the effort-based indicators (e.g., sets/day, vessel characteristics) have increased over the recent period while catch per unit effort metrics have declined when examined within and outside PNA EEZs. However, these do not yet provide a direct measure of the level of effort creep in the fishery.

The number of sets per day has gradually increased over time, reflecting an increase in effective effort within fishing day limits. The trend is different between set types, with free-school set frequency increasing over the time series, while the rate of associated sets per day has remained fairly constant, following an initial decline. Catch per set and catch per day have both declined slightly over the time series, and more substantially over the short-term. Total tuna catch rates have remained fairly stable over the time series, but have declined over the short-term (2015-2018), largely due to the relatively low catch rates in 2017. While recent changes in catch and CPUE may reflect the ultimate consequences of effort creep, we note that purse seine CPUE may be relatively insensitive to changes in underlying fish biomass, due to fish schooling behavior and aggregation by fish aggregation devices (FADs). Improvements in FAD technologies have the potential to lead to increases in CPUE for FAD sets, but practical limitations mean that, in general, only one FAD set can be made per day. The relatively stable associated set CPUE over time suggests that new technology may not yet be good enough – or understood well enough – to lead to notable increases in catch rates; FAD density may be affecting catch rates; and/or potential increases in catch rates due to the use of new technology may be masking a declining biomass. The relationship between trends in purse seine CPUE, the underlying biomass, and effort creep remains unclear. Disentangling operational, stock, fishery and oceanographic influences is challenging, and an area of proposed future research.

Vessel characteristics, which may impact effort creep, all displayed increasing trends over time. A challenge is to identify a limited suite of vessel characteristics that directly (or indirectly) influence effort creep, noting that trends in different characteristics are likely correlated (i.e.

larger vessels have greater hold capacities, etc.).

We invite SC15 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
- note the importance of developing quantitative metrics of effort creep for management use and development of harvest control rules.

Table 1: Summary of relative trends in different indicators (average 2017/18 vs 2015/16) within and outside PNA EEZs.

Indicator	2017/2018 vs 2015/2016		Per annum linear regression trend, 2007-2018[4]	
	PNA	Non-PNA	PNA	Non-PNA
Sets/year	+20%	+6%	+4%	+6%
Sets/day	+3%	-8%	+3%	+2%
Total tuna CPUE (mt/day)	-10%	-31%	+1%	-3%
Total tuna CPUE (mt/set)	-13%	-25%	-1%	-4%
Total tuna CPUE (mt/set) - ASS sets	-9%	-1%	0%	-1%
Total tuna CPUE (mt/set) - UNA sets	-17%	-47%	-2%	-5%
Total tuna catch	+4%	-21%	+2%	-1%
Total skipjack catch	+2%	-30%	+2%	-1%
Vessel length (m)	+1%		0%	
Vessel gross registered tonnage (GRT)	+1%		+1%	
Vessel horsepower (HP)	+1%		+1%	

[4]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.

Introduction

Effort creep describes the situation where fishing vessel catch efficiency increases over time within an effort-based management framework. Effort creep can have negative consequences for fish stocks as well as the fishing fleets if: 1) adjustments to management measures do not appropriately account for changes in effective effort, or if 2) management actions create incentives for sub-optimal fleet investments (Pilling et al., 2016).

Fishing effort can be difficult to quantify directly because it is a composite metric comprised of many different components which include but are not limited to: vessel length, engine power, fishing technologies (e.g., bird radars, remote oceanographic sensors, echo sounders, helicopters), and skipper/crew experience. For the 12th Scientific Committee (SC12), a suite of indicators were developed to evaluate and monitor effort creep. The approach and indicators put forth were supported by SC12, and deemed directly relevant for the development of a harvest control rule for skipjack (Pilling et al., 2016). In addition, the PNA[5] requested that the Pacific Community (SPC) report annually on trends in effort creep 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 2018, the effort creep indicators were updated for SC14 (Muller et al., 2018).

This paper details the trends in purse seine effort in the WCPO over time and summarizes the latest information available to SPC as of 3 July 2018. 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 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 proxy groups, and summarize the catchability trends from the most recent skipjack and yellowfin stock assessments.

Examination of trends in catch, catch rate effort

Aggregate (1°x1°) raised logsheet data, summarized by approximate 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. Trends in overall catch, catch rates, effort levels, and vessel characteristics provide simple indicators of effort creep. The indicator values

[5]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, and Tuvalu

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 included in the estimates due to the nature of the aggregate data used. Trends were examined over the time period since the implementation of the Vessel Day Scheme (VDS; 2007-2018[6]). Recent trends are summarized by taking ratios between average effort, catch per unit effort (CPUE), and catch in 2017-18 compared to 2015-16, to evaluate recent changes in the indicators.

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. The total number of sets per year, by set type, has increased steadily for free-school sets, both inside and outside PNA EEZs, while the number of associated sets has stayed relatively constant (Figure 1). 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. Total number of sets/year is not considered a metric of effort creep, but is included here to provide context with respect to total fishing effort over time, within the region. 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. Free-school sets are made throughout the day, and given effort constraints, there may be incentives to make additional sets within a fishing day, even if the aggregations are small, to maximize harvest within a vessel's allocated fishing days. Between 2015-2016 and 2017-2018, the average number of sets per year increased by 20% and 6%, inside and outside PNA EEZs, respectively. Over the time series (2007-2018) the linear regressions indicated positive trends in sets per year of approximately 4% and 6%, inside and outside PNA EEZs, relative to sets per year in 2007 (Table 1).

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

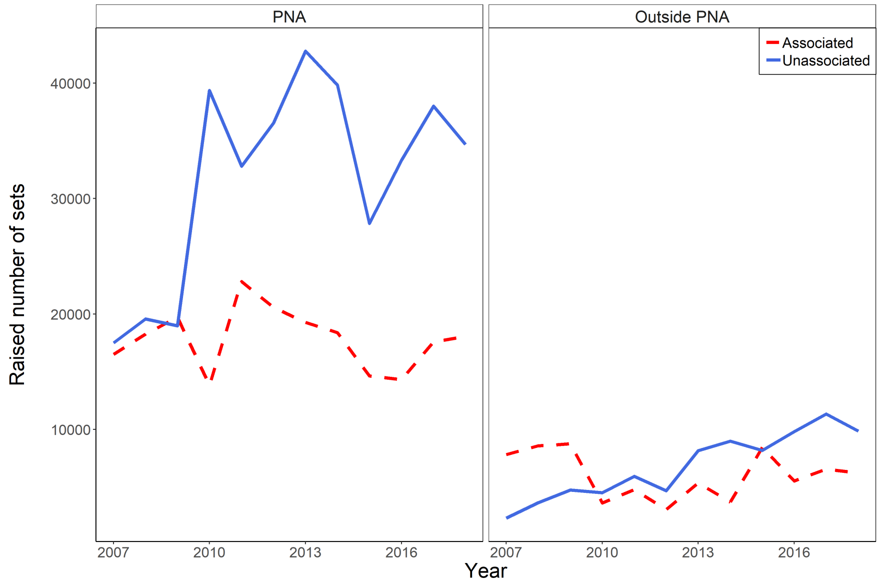

Figure 1: Time series of total raised purse seine sets per year, for associated and unassociated set types, inside (left) and outside (right) PNA EEZs from 2007-2018.

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 (Figure 2). The number of sets made per fishing day has generally increased since 2007 for unassociated (free school) sets while the number of associated sets has stayed relatively constant within the PNA, and has generally decreased outside of the PNA. The average sets/day inside PNA waters from 2017-2018 relative to 2015-2016, increased by 5% for associated sets and 1% for free school sets (3% increase combined), with a combined long-term increase in sets/day of 3% over the time series, relative to 2007 (Table 1). Outside PNA waters, free school setting rates increased by 2% while associated sets decreased by 21% (8% decrease combined), with a 2% increase over the time series. The substantial decline in associated sets/day from 2015/2016 to 2017/2018 outside PNA EEZs was due to the unusually high set rate observed in 2015.

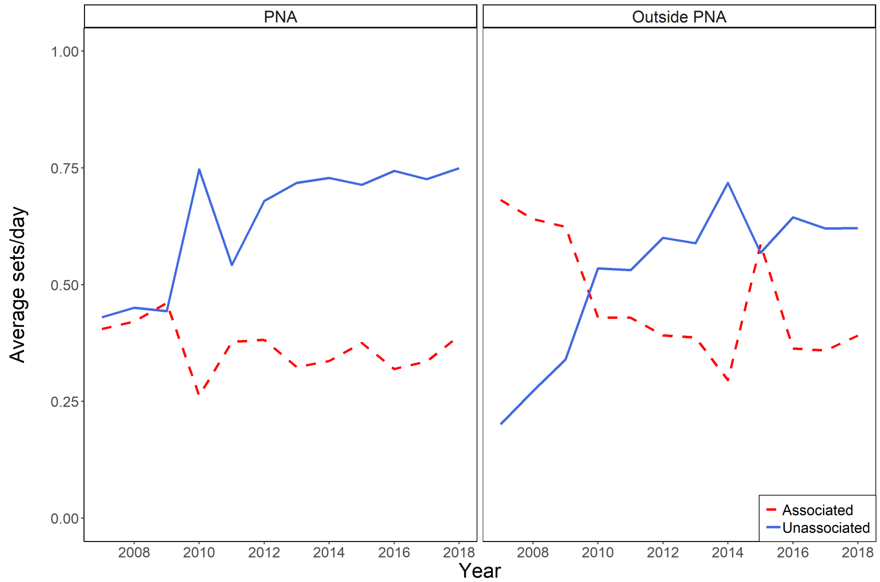

Figure 2: Time series of setting rate (sets per fishing day) for associated and unassociated set types, for inside (left) and outside (right) PNA EEZs, from 2007-2018.

Purse seine CPUE inside and outside PNA EEZs

Trends in the nominal CPUE were measured as total tuna (mt) caught per day fished, and per 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 3. The majority of the catch (69-88%) was comprised of skipjack (Figure 5), which drives these trends.

Catch rates within PNA EEZs have been consistently higher than for areas outside PNA EEZs (Figure 3). CPUE inside and outside PNA EEZs have shown similar trends in the recent period, although the catch rates outside PNA EEZs are considerably more variable. The drop in CPUE outside the PNA EEZs in 2010 appears consistent with closure of key high seas areas, implying that the remaining fishing areas were of lower suitability to purse seine fishing (Pilling et al., 2016). A comparison of average CPUE from 2017-18 to the average from 2015-2016 showed a decrease of 13% per set and 10% per day inside PNA EEZs, and decreases of 25% and 31%, respectively, outside PNA EEZs. These trends are largely driven by the high catch rates observed in 2015 for associated and unassociated sets, inside and outside of PNA EEZs, with the long-term trends suggesting more moderate changes with a 1% decline in mt/set and a 1% increase in mt/day inside PNA EEZs. Over the CPUE time series for the waters outside PNA EEZs, there has been a 4% and 3% decline in mt/set and mt/day, respectively. While catch per day inside PNA EEZs showed a slight positive trend, the catch per set has modestly declined (Figure 3). The opposing trends in catch/day and catch/set are attributed to the increase in number of sets performed per fishing day over the time series inside PNA EEZs.

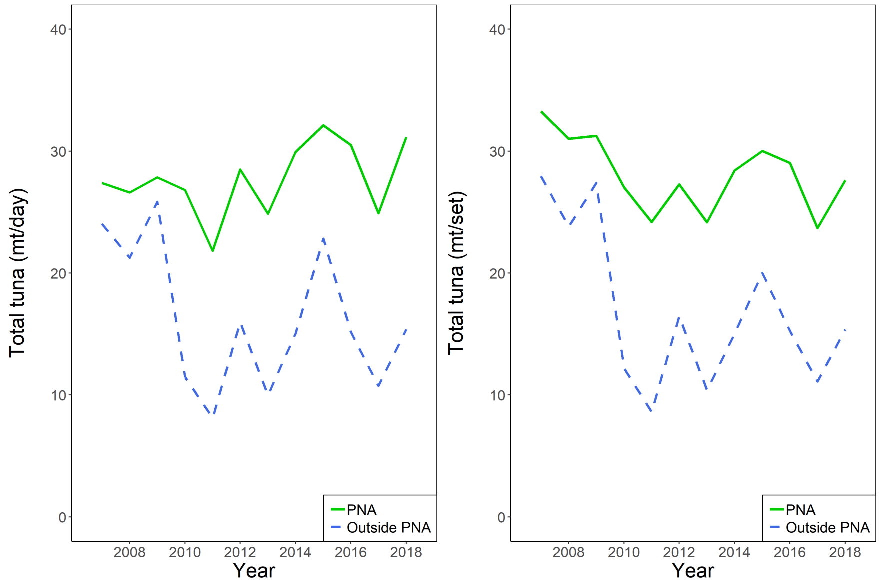

Figure 3: Time series of nominal purse seine total tuna CPUE in terms of mt/day (left) and mt/set (right) inside and outside PNA EEZs, from 2007-2018.

The long-term trends in tuna catch rates from the regression analyses, by set type, indicate that associated set CPUE inside and outside PNA EEZs has fluctuated without trend since 2007 (Figure 4). The unassociated (i.e. free-school) CPUE showed a steep decline from 2007 to 2010 inside and outside PNA EEZs, after which the the trends are generally positive, but with high variability in areas outside of the PNA EEZs. When evaluated over the most recent period (2015-2016 compared to 2017-2018), catch rates by set type and region, suggested overall declines, with a 9% and 1% decline in total tuna mt/set for associated sets inside and outside PNA EEZs, respectively, and a 17% and 47% decline for free-school sets, inside and outside PNA EEZs (Table 1). These changes are again, largely driven by the high catch rates observed in 2015, with the regression analyses over the full time series indicating more modest declines in CPUE (mt/set), ranging from no trend for associated sets in PNA waters to a 5% decline for free school sets outside PNA EEZs (Table 1).

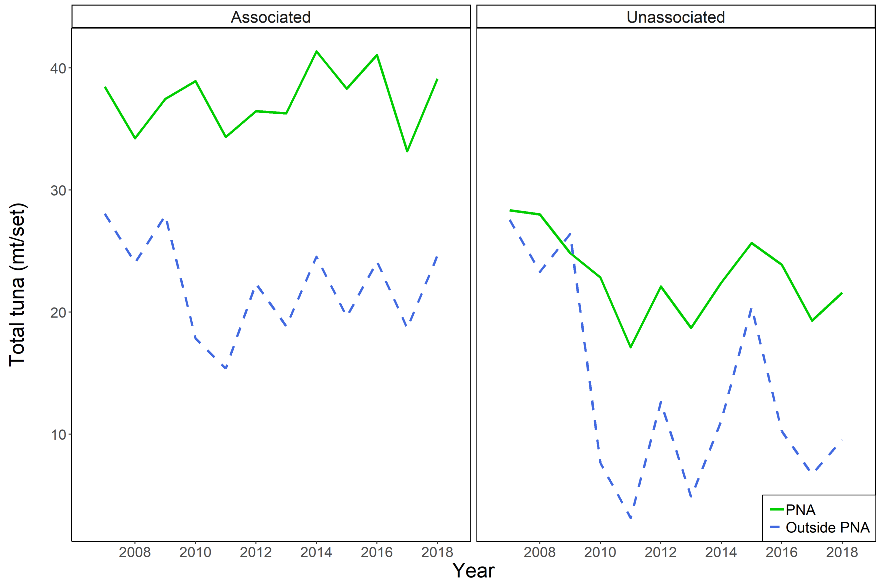

Figure 4: Time series of nominal purse seine total tuna CPUE (mt/set) for associated sets (left) and unassociated sets (right) inside and outside PNA EEZs.

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 given 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.

More detailed information of 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 FAD tracking information, it was estimated that at the scale of the WCPO there were 30,700−56,900 FAD deployments in 2016 and approximately 44,700−64,900 in 2017, and 26,200−37,300 active FADs in 2016 with an increase to 38,000−48,200 in 2017. The mean number of active FADs per vessel was estimated to be 102 in 2016 and 163 in 2017. 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.

Aggregate purse seine catches inside and outside PNA EEZs

Within PNA EEZs, average 2017-2018 total tuna catch increased by 4% relative to the 2015-2016 average, with a fairly stable long-term trend (Figure 5). Outside PNA EEZs, 2017-2018 average tuna catch decreased by 21%, this value being strongly influenced by the high 2015 catch associated with a strong El Niño event, and the corresponding shift in fishing effort to the east. The positive trend in free-school sets is influenced by the increase in number of sets made per day. The species catch composition in both associated and unassociated sets has remained consistent through the years, and remains dominated by skipjack. The FAD sets tend to catch a higher proportion of bigeye tuna than the free-school sets, while free-school sets have a slightly higher proportion of yellowfin tuna (Figure 5). Total catch serves as an important proxy indicator, but can be directly influenced by factors unrelated to effort creep such as the number of vessels participating in the fishery; and therefore, CPUE may be a more informative indicator of effort creep.

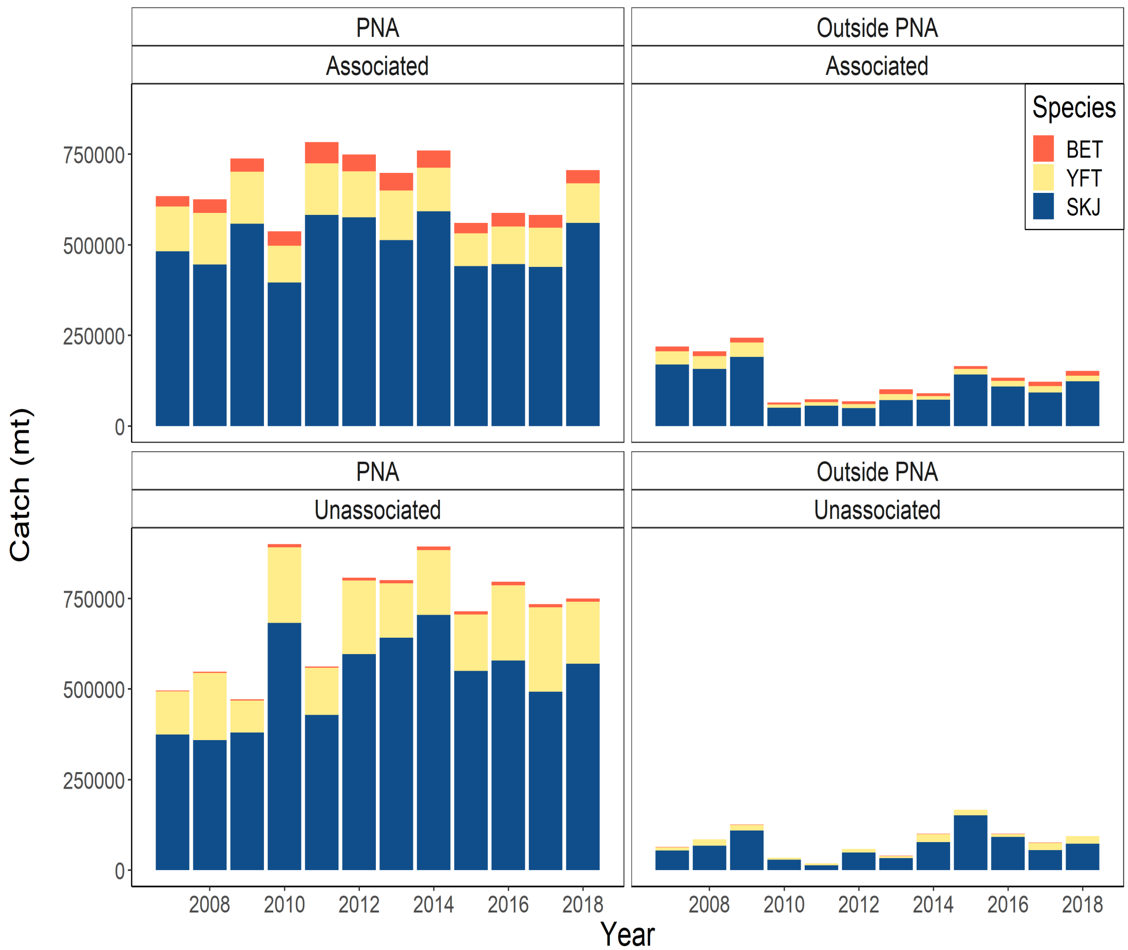

Figure 5: Time series of purse seine catches inside (left) and outside (right) PNA EEZs, for associated (top) and unassociated (bottom) sets from 2007-2018.

Changes in vessel characteristics within the purse seine fishery

To the extent that effort creep is driven by the size of vessels or other specific vessel characteristics, changes in these features 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. Information is also available from observer records of vessel characteristics.

The accuracy of information in these vessel registers still need 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 6 shows the evolution of average vessel length (m), gross registered tonnage (GRT), and engine horsepower for vessels on the FFA Register. A long-term increase is seen in these characteristics, and more recently these indicators have changed by about 0-1% (Table 1). We note that estimates reflect vessels that may operate in specific tropical WCPO areas.

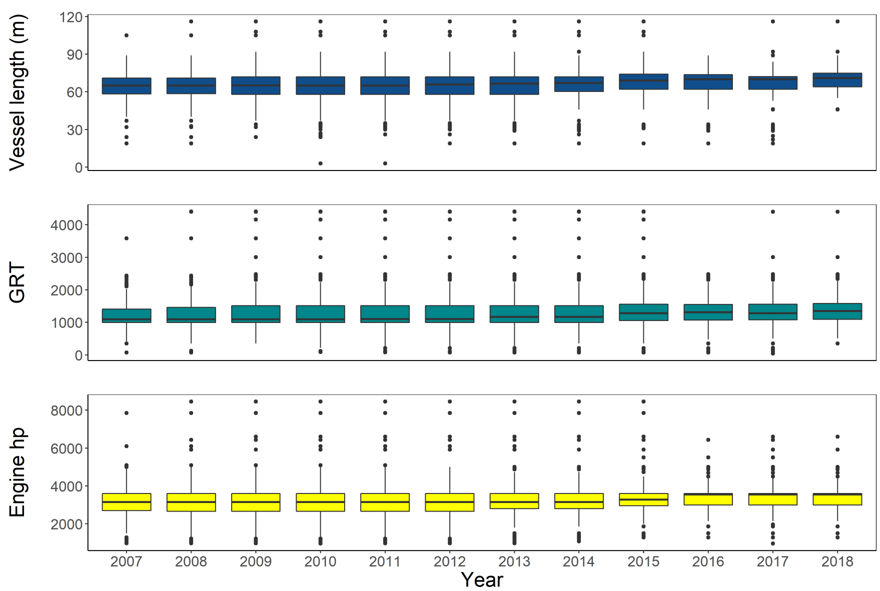

Figure 6: Boxplots illustrating the distribution of vessel size characteristics of purse seine vessels registered annually on the FFA Vessel Register in terms of length overall (m; top); gross registered tonnage (GRT; middle); and engine horsepower (bottom).

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, 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. A challenge 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 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. 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 such as vessel length, or a suite of characteristics in a simple combination, can act as a suitable proxy.

Estimated catchability trends

Within the MULTIFAN-CL stock assessment model, the fishery-specific parameter 'catchability' 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), as well as effort creep.

Skipjack tuna

Catchability estimates for skipjack tuna from the four main tropical purse seine fisheries have increased throughout the time series (1972-2018; Figure 7), 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[7]
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%

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

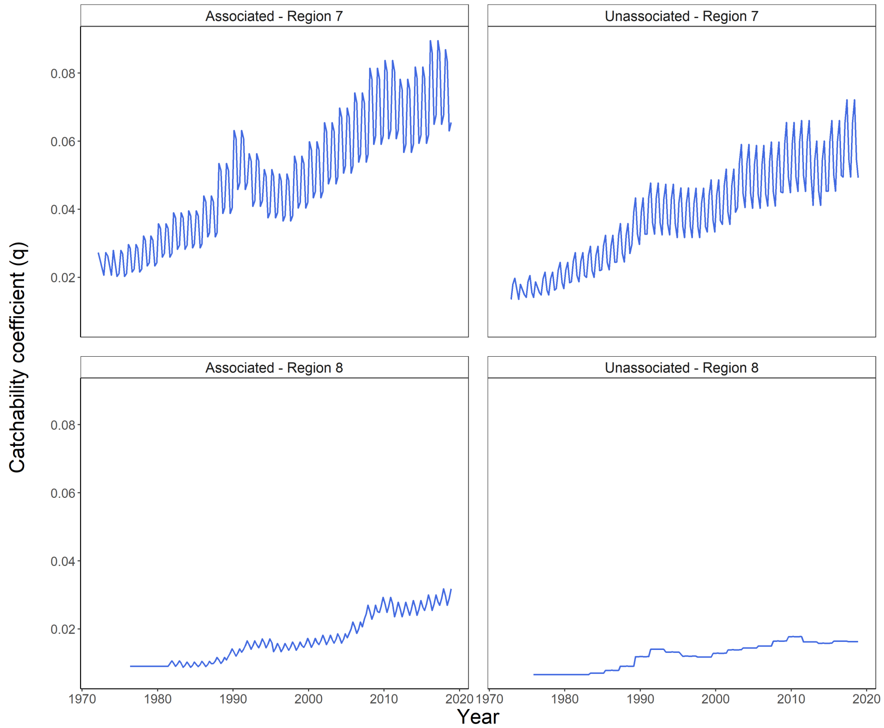

Figure 7: MULTIFAN-CL quarterly time series estimates of tropical purse seine fishery catchability within the 2019 skipjack stock assessment model (Regions 7 and 8; 1972-2018).

Yellowfin tuna

Yellowfin tuna catchability estimates from the most recent (2017) yellowfin stock assessment (Tremblay-Boyer et al., 2017), also showed a general positive trend from the beginning of the time series (1968), until approximately the early 2000s, in Regions 3 and 4 (Figure 8). 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.

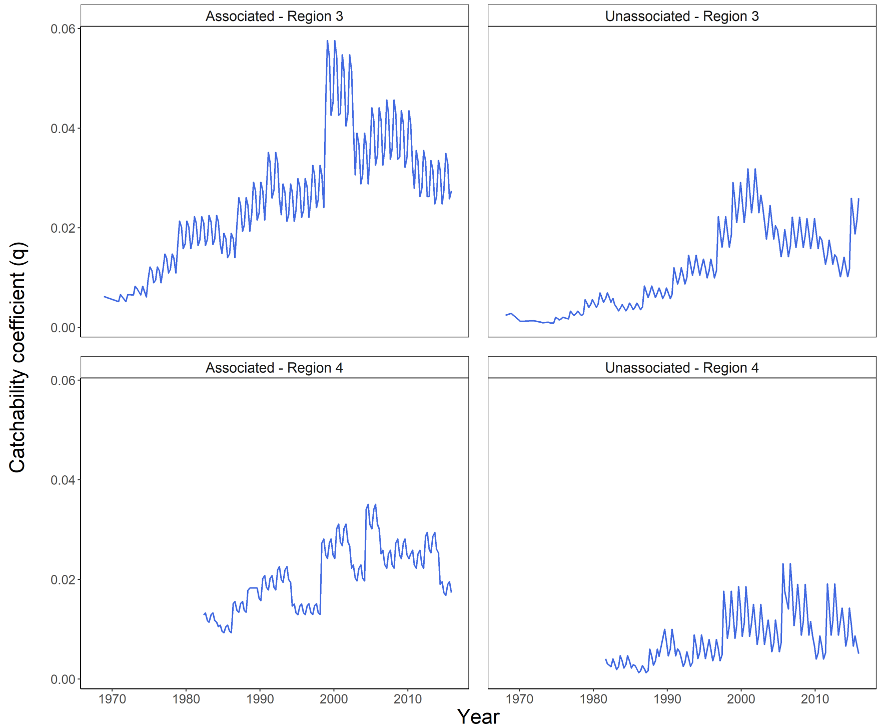

Figure 8: MULTIFAN-CL quarterly time series estimates of tropical purse seine fishery catchability within the 2017 yellowfin stock assessment model (Regions 3 and 4; 1968-2015).

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**[8]
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%

Catchability as an indicator of effort creep

In theory, catchability estimates should be amongst the best indicators of effort creep, as they measure the aggregate effect of changes in vessel efficiency on fishing mortality and they 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.

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 proxies and effective effort may not be linear and the influence on effective effort may be indirect or ephemeral. 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, changes in the biomass tend to be detected long after the biomass has declined to a point at which significant management action is required to rebuild it. 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 felt 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., acoustic sounders 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 (i.e., vessel length, GRT, and engine horsepower); however, analyzing changes in catch rates with respect to changes in vessel characteristics or technologies employed

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

may improve our ability to assess effort creep. Continued research into the development of suitable effort creep indicators will focus on these integrated analyses. Similar challenges are identified for the use of catch levels, and therefore, at this point, a combination of the indicators provided may be most appropriate.

We note that the majority of the candidate effort creep catch-based indicators (e.g., CPUE indices) have shown decreases over the recent period within the WCPO when examined both within and outside PNA EEZs, while vessel-based indicators have 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 remains unclear. Ultimately, the effectiveness of potential effort 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 SC15 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
- note the importance of developing quantitative metrics of effort creep for management use and development of harvest control rules.

Acknowledgments

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