SCIENTIFIC COMMITTEE
TWELFTH REGULAR SESSION

Bali, Indonesia
3-11 August 2016

Examining indicators of effort creep in the WCPO purse seine fishery

WCPFC-SC12-2016/MI-WP-08

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Abstract

Effort creep has implications for maintaining stocks around target reference points, and can affect vessel profits. A better understanding of effort creep, and identification of both indicators that reflect it and mechanisms through which managers can appropriately adjust for its impacts, are needed. This paper summarises trends in potential effort creep indicators for the tropical purse seine fishery, and their suitability for adjusting WCPO effort limits (Table 1). The majority of indicators have shown increases over the recent period within the WCPO when examined both within and outside PNA EEZs.

The number of sets made per day has gradually increased over time, reflecting an increase in effective effort within fishing day limits. While catch per set has generally declined, increased setting rate has more than compensated for this and has led to general increases in catch per day, although short-term changes are affected by operational patterns. While recent changes in catch and CPUE may reflect the ultimate consequences of effort creep, we note that purse seine CPUE is considered relatively insensitive to changes in underlying fish biomass due to the schooling behaviour of fish, and influenced by oceanography, fishing location and logsheet misreporting, for example.

Vessel characteristics, which may better reflect the drivers of 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.). The relationship between the change in a characteristic and the level of effort creep may not be linear. Identifying characteristics that influence CPUE, and then modelling their combined effects, taking the stock size into account, may help identify the overall level of effort creep, and whether a single characteristic or a simple combination can act as a suitable proxy.

Catchability estimates from stock assessments should be the 'best' indicators of effort creep, as they measure the aggregate effect of changes in vessel efficiency on fishing mortality when estimating stock size and trends. However, their utility as indicators must be considered, noting practical challenges that include their timeliness. This may limit their utility for year-on-year use, but they may be adequate for less frequent adjustments to effort limits and validation of other approaches.

Once an appropriate link between an indicator and effort creep has been established, development of transparent decision rules for desired effort limit adjustment is recommended. These should define the period of data used for the adjustment, the frequency with which adjustment is considered, and potentially a minimum change within an indicator before effort limit adjustments are made. Noting year-on-year fluctuations in indicators, trends between short-term averages should be examined. Ultimately, the approach should be tested for effectiveness within Management Strategy Evaluation.

We invite WCPFC-SC12 to:

- consider the importance of this field of research and its prioritisation within the SC work plan;
- discuss the appropriateness of candidate indicators of effort creep, and their pros and cons;
- note the trends in FAD (associated) fishery metrics, and the need to ensure related information is available to understand the potential influences on effort creep;
- note the importance of developing consistent and complete information on vessel characteristics;
- consider how trends in indicators might be evaluated (averages, standardisation);
- discuss potential decision rules for implementing any approach.

Table 1. Summary of relative trends in different indicators (average 2014-15 vs 2012-13) and notes on their application for effort limit adjustment.

Signal	PNA	Outside PNA	Notes
Sets/day	+2%	+8%	• Useful to monitor, but affected by misreporting of effort (days fished) • Increases in setting frequency may be countered by a higher proportion of unsuccessful sets
Total tuna CPUE (mt/day)	+11%	+25%	• Can be broken down for specific regions • Inter-annual fluctuations need to be considered, e.g. use recent averages • Changes in fishing practices may be driven by market forces (e.g. fuel price, fish prices) • Purse seine CPUE is unlikely to be directly related to stock size • Short lags in data availability, will be improved through e-reporting • Affected by oceanographic influences, fisher effects, misreporting • These could – in theory - be adjusted for
Total tuna CPUE (mt/set)	+9%	+16%	
Catch (total tuna / skipjack)	-3% / +0%	+98% / +120%	• Can be broken down for specific regions • Directly relates to the overall fishery impact on the stock • Total tuna catch not affected by species composition uncertainty, but adjusted skipjack estimates are more directly relevant to the TRP • Short lags in data availability, will be improved through e-reporting • Inter-annual fluctuations need to be considered, e.g. use recent averages • Affected by oceanographic influences • When modelling, influenced by regional biomass • Changes in fishing practices may be driven by market forces (e.g. fuel price, fish prices)
Vessel length	+2%	+2%	• Vessel size data are relatively good and readily available, but not perfect, while other characteristics may also influence effort creep • Estimating fishing power change through changes in vessel characteristics is technically good, but relationships must be developed • Changes in characteristics, such as size, may not directly relate to effort creep levels; combined effects of characteristics must be understood • Other vessel characteristics within regional vessel registers need to be validated • Specific metrics, such as the number of deployed and actively monitored FADs, may monitor specific aspects of purse seine effort creep
Vessel GRT	+4%	+4%	
Vessel HP	+3%	+6%	
Vessel storage	+4%	+5%	
Vessel age	-13%	-10%	
Vessel crew nos.	+3%	+2%	
MFCL assessment catchability trend	-	-	• Theoretically preferable as it takes stock/biomass changes into account • Most recent catchability estimates are uncertain • Updated only with a new assessment, not for year-by-year adjustments • Assumes assessment correctly estimates abundance • Does not break down trends into specific regions beyond those of the assessment model • Estimates will integrate over fleets, depending on the model's fishery definitions. • Estimates will include effects related to the distribution of effort in relation to the distribution of fish at a spatial scale finer than that being modelled. • May allow validation of other approaches

Introduction

Effort creep describes the situation where fishing vessels improve their ability to catch fish over time within an effort-managed system, and hence catch more per fishing day. This may create economic benefits through increased efficiency. However, effort creep becomes a problem if:

- Adjustments are not made to management systems to take into account the resulting increases in fishing mortality per 'fishing day', in which case stock management targets would not be met (e.g. the skipjack stock would fall below the adopted interim target reference point level[1]; see Scott et al., 2016a). In time, this phenomenon will be a key element of consideration for harvest control rules; or
- Incentives created within management systems to increase vessel efficiency distort the patterns of investment in the fleet and lead to vessel designs or operations that are not optimal.

Effort creep can result from improvements to existing vessels with investment in better fishing technology and more powerful engines, or the addition/substitution of newer vessels. Removing less effective vessels from the fishery means available fishing days can be fished by more efficient vessels, thereby increasing effective effort and also leading to effort creep. Policy and regulatory changes can also affect the rate of effort creep. For example, FAD closure periods within the WCPO may have reduced fishing power in recent years, although increased FAD fishing and FAD deployment outside the closure may have negated that. Separating these influences is not straightforward.

To assist in the sustainable management of WCPO tuna stocks, an increase in our understanding of effort creep and identification both of indicators that reflect the degree of creep, and mechanisms through which fishery managers can appropriately adjust the fishery for its impacts in light of those indicators, is needed. The Pacific Community (SPC) presented an examination of productivity changes within the tropical WCPO purse seine fishery to SC11 (WCPFC-SC11-2015/MI-WP-06). The current paper builds upon work undertaken at the request of the Parties to the Nauru Agreement (PNA) to advise on approaches to adjust purse seine effort limits to take effort creep into account. It presents a summary of potential effort creep indicators, both inside and outside the PNA fishery, and examines their suitability for monitoring and adjusting WCPFC limits for effort creep or for identifying the specific factors causing effort creep that could then be managed directly. The appropriateness of indicators will be influenced by potential approaches through which effort limits may be adjusted.

What is the objective of adjusting for effort creep?

First, the objective for adjusting purse seine effort limits within the WCPO in light of effort creep needs to be defined. The assumption is made that this is to ensure the skipjack stock remains around the adopted interim target reference point in order to achieve stated management objectives (e.g. stability in yield, relatively high CPUE, minimising additional impacts on other tuna stocks, etc.). A defined objective for effort adjustment also helps to identify the most relevant indicators of effort creep, which can be used to identify by how much the effort limit needs to be adjusted.

[1] We note that a challenge in effort control systems is managing an individual species to a desired level within a multispecies fishery.

Alternative indicators of 'effort creep' in the WCPO purse seine fishery

To appropriately adjust WCPFC effort limits, indicators of the level of effort creep are needed to identify the required level of adjustment. The utility of recent trends in relevant indicators that can act as a proxy for effort creep are examined here:

- Trends in tuna catch levels, catch rates, and alternative fishing effort values;
- Estimates of trends in vessel size and other characteristics;
- Trends in estimated 'catchability' from WCPFC stock assessment models.

Examination of trends in catch, catch rate and effort

Examining overall catch, catch rates and effort levels might be a simple way of adjusting effort limits for effort creep. To examine their utility, these values were estimated within and outside PNA EEZs (where PNA are PNA Parties + Tokelau) using aggregate (1°x1°) raised logsheet data, summarised by approximate EEZ/high seas area for the WCPFC Convention Area within the latitudinal range 20°N-20°S. Effort and catch within archipelagic waters are included within estimates due to the nature of the aggregate data used. Trends are examined over the last 11 years (2005-2015). Given the impact of management interventions such as the implementation of the PNA Vessel Days Scheme and closure of the high seas pockets, and the 'poor' fishing year of 2011, trends are developed by taking ratios between average effort, CPUE, and catch in 2014-15 and 2012-13.

Purse seine effort (sets per day) inside and outside PNA EEZs

Fishing days in the WCPO tropical purse seine fishery are generally limited through the PNA VDS, EEZ-nominated effort and skipjack catch levels, and high seas effort limits (e.g. Pilling and Harley, 2015) noting that overall, the overall limits allow some increase from current effort before they are theoretically reached. In cases where fishing days are limiting, however, 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 1). The number of sets made per fishing day has increased over the recent 11 year period for both associated and unassociated sets. The rate of increase in free school sets per day over this period has been greater than FAD sets. However, examining the average set/day over the period 2014-2015 relative to that over the period 2012-2013, inside PNA waters free school set rates have remained constant while FAD sets increased by 3% (2% combined). Outside PNA waters free school setting rates increased by 8%, while FAD sets increased by 5% (8% combined).

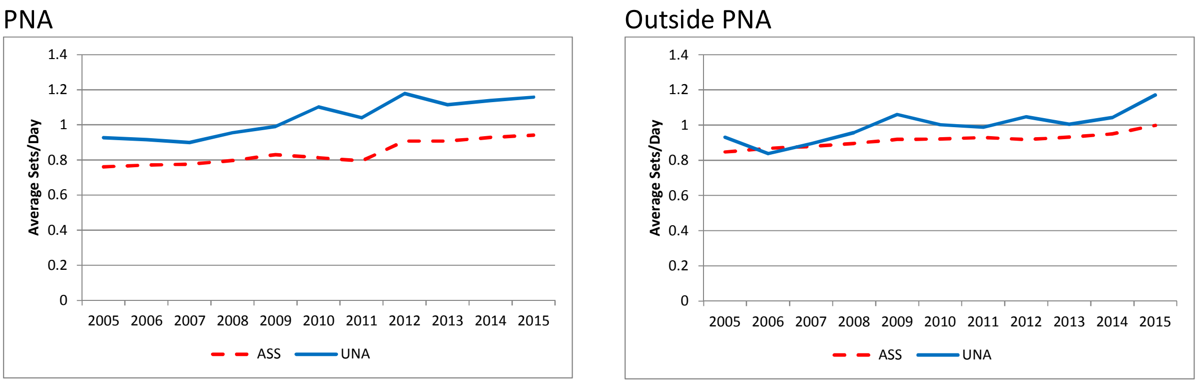
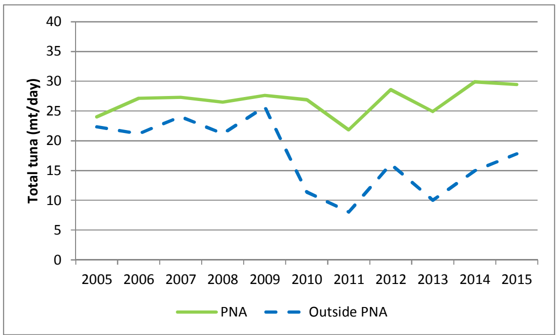


Figure 1. Time series of setting rate (sets per fishing day) for associated and unassociated set types, for inside (left) and outside (right) PNA EEZs.

Purse seine CPUE inside and outside PNA EEZs

Trends in the nominal CPUE (total tuna (mt) per day fished and per set, the latter to account for increases in sets made per day seen above) are presented in Figure 2. The majority of the catch (70-80% in recent years) was skipjack (Figure 4) which drives these trends. We note that, in general, skipjack biomass has declined over the period examined (e.g. Rice et al., 2014).

CPUE within PNA EEZs has been consistently higher than outside. The drop in CPUE outside the PNA EEZs in 2010 appears to be consistent with closure of key high seas areas, implying that the remaining fishing areas were of lower suitability to purse seine fishing. CPUE inside and outside PNA EEZs have shown similar trends in the recent period. Comparing average CPUE over 2014-15 to the average over 2012-13, these have increased by 9% (per set) and 11% (per day) inside PNA EEZs, and by 16% and 25% respectively outside PNA EEZs. While catch per day inside PNA EEZs has generally increased, the catch per set has declined slightly in the longer-term, corresponding with increases in the number of sets made per day (Figure 1). However, the increased set rate per day appears to compensate for any reduced catch rate per set, as the mt/day has increased over time. Outside PNA EEZs, the overall trend is downwards. This is significantly influenced by the closure of the high seas and relatively poor fishing in 2011, with an increasing trend after that year in mt/day and mt/set.



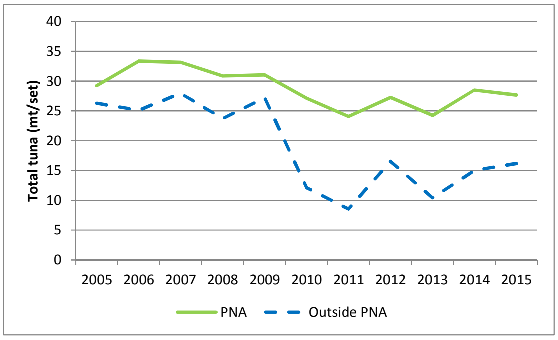


Figure 2. Time series of nominal purse seine total tuna CPUE in terms of mt/day (left) and mt/set (right) inside and outside PNA EEZs.

The long term trend in associated catch rates has been constant or increasing, while unassociated catch rates have tended to decline (Figure 3). We note that there has been an increase in the number of unassociated sets in recent years. However, when evaluated over the more recent period, catch rates in all set types and regions has increased, by 4% and 19% within PNA waters (associated and unassociated sets, respectively), and 9% and 33% outside PNA waters.

As noted, the number of sets made per day has increased over time (Figure 1) while the average nominal catch rate per set has declined (Figure 2). This may suggest that vessels that have already made one set in the day (e.g. a FAD set) are attempting to maximise the value gained within a fishing day by conducting another (potentially free school) set, even when the marginal benefit of that extra set may be small. How this affects the economics of the fishery is not currently known.

The potential for new FAD technology (e.g. increased use of sonar FADs, allowing for 'optimal' deployment of effort on FADs with higher biomass beneath them), and the suspected increase in the number of FADs deployed, will influence the CPUE trends in the associated set time series. This is discussed further below.

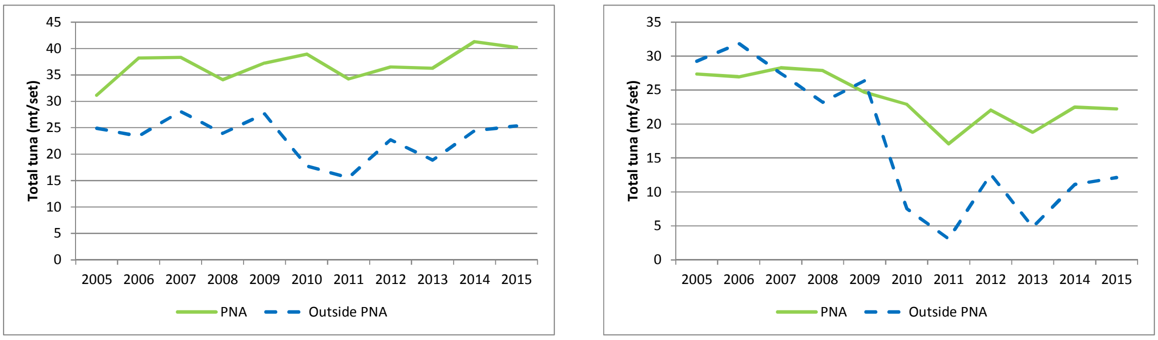


Figure 3. Time series of nominal purse seine total tuna CPUE (mt/set) for associated (FAD) sets (left) and unassociated (free school) sets (right), inside and outside PNA EEZs.

Aggregate purse seine catches inside and outside PNA EEZs

Total tuna catch within PNA EEZs has increased over the 11 year period, with a reduction in the provisional catch for 2015 (Figure 4). Catch outside PNA EEZs fell notably in 2010, consistent with closure of key high seas areas, and has increased since that time to pre-closure levels. Catch within the PNA EEZs has fluctuated from year to year since 2010. Within PNA EEZs, average 2014-15 total tuna catch decreased by 3% relative to the 2012-2013 average. Outside PNA EEZs, 2014-15 catch increased by 98%, this figure is strongly influenced by the 2015 catch level. This increase resulted mainly from increased fishing in the eastern high seas and in some non-PNA EEZs as a consequence of the strong *El Niño* event in 2015.

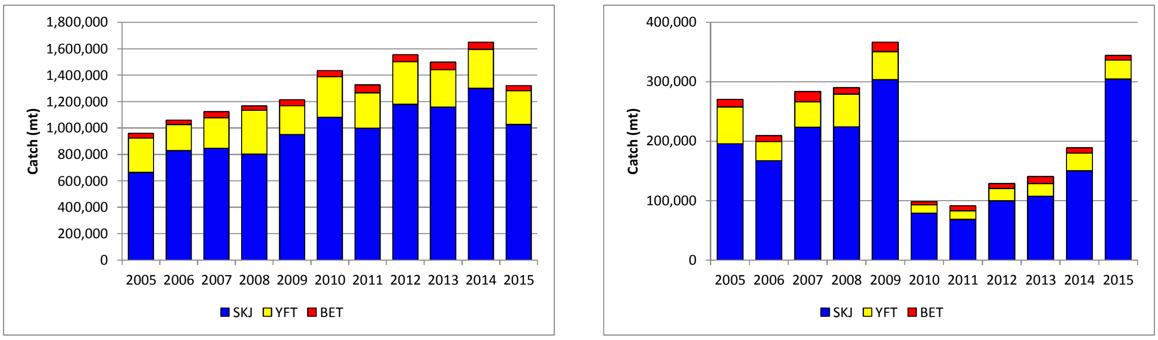


Figure 4. Time series of purse seine catches inside (left) and outside (right) PNA EEZs (2005-2015). Note different y-axis scales.

Changes in vessel characteristics within the purse seine fishery

To the extent that effort creep is driven by increases in the size of vessels or other 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. These are: the WCPFC Record of Fishing Vessels; the FFA Vessel Register; and the PNA VDS Register. Information will also be available from observer records of vessel characteristics.

The accuracy of the information in these Vessel Registers needs to be verified and standardised, as comparison between Registers indicates inconsistencies in both the measurements used (e.g. the option for hold space to be declared in m^3 or mt) and in submitted characteristics for a given vessel, as well as absent information for some fields (as also noted in Tidd et al., 2016a). This raises challenges for evaluating trends in vessel characteristics of relevance as potential drivers of effort creep.

We first examine vessel size data to see whether management regimes within the WCPO have influenced the pattern of vessel construction. Figure 5 shows the available annual time series of the average length of vessels built in each year. While the average length of new vessels has increased over time, it has been relatively stable since 2011 (the 2010 mean length being slightly lower). It is interesting to note that the maximum size of vessels built since 2010 has been in the 79-80m range. Fourteen out of fifty vessels built during 2010-2015 were in the 79-80m range (28%), compared to 13% in this range for the period 2004-2009. No vessels have been built larger than 100m in length since 2004.

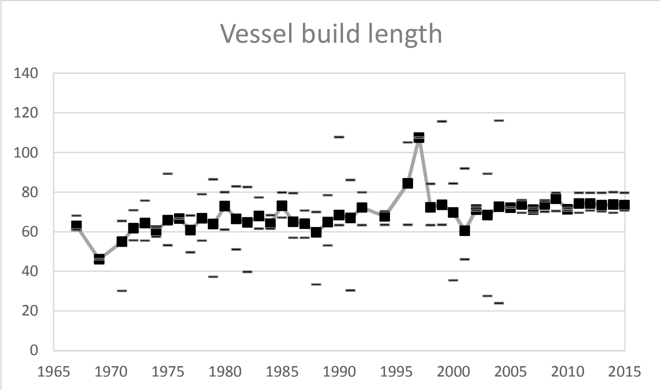


Figure 5. Average length of vessels built by year from vessel registers. Horizontal bars indicate minimum and maximum vessel sizes build in year.

Figure 6 shows the average length, GRT, engine power and storage capacity of vessels on the FFA Register. A long-term increase is seen in characteristics, and more recently have grown by around 2-4% in PNA EEZs (comparing the 2014-15 average to that from 2012-13), with slightly greater increases calculated for outside PNA EEZs (2-6% over the same period; see Table 1 for details). We note that these estimates reflect vessels that may only operate in specific areas of the tropical WCPO.

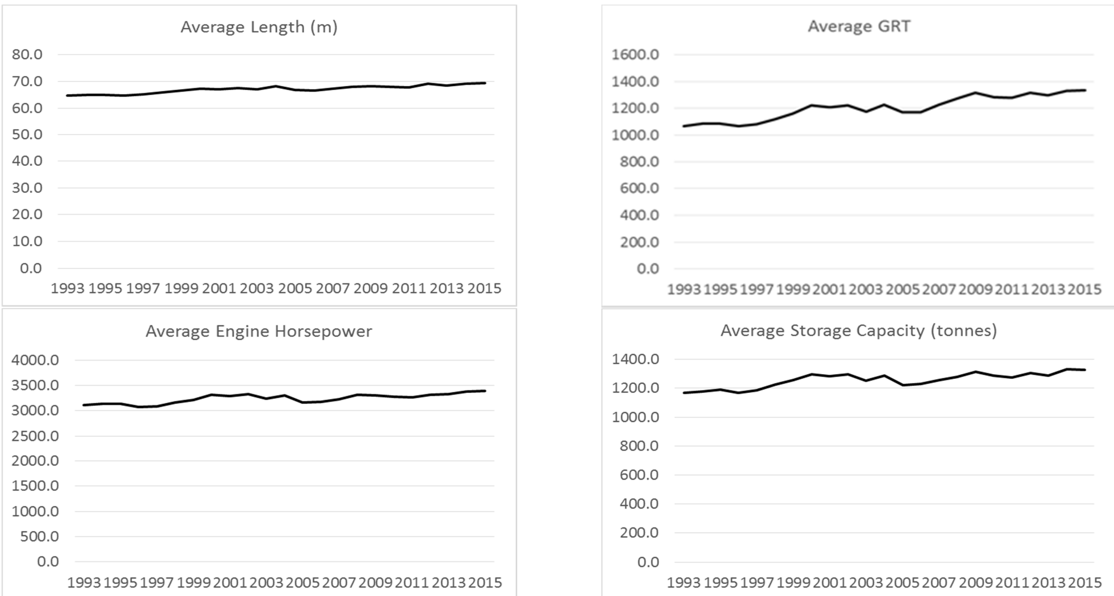


Figure 6. Average vessel size characteristics of purse seine vessels registered annually on the FFA Vessel Register in terms of average a) length overall (m); b) gross registered tonnage (GRT); c) engine horsepower and d) storage capacity (m^3).

To identify whether trends in vessel size and associated characteristics lead to higher CPUE, the analysis of the influence of purse seine vessel characteristics on nominal CPUE presented in Tidd et al. (2015) was updated to include all fleets and for the period 2012-2015 (Appendix 1). Results indicate that vessels with higher CPUEs are larger (length and GRT), newer, and in contrast to the results of previous analyses on a restricted range of fleets, have larger storage capacities. This suggests that the most recent vessels, despite being smaller than 80m in length (Figure 5), are likely more efficient. We note that the number of vessels within the fishery appears to have increased in the last 10 years (e.g. Figure 2 of Tidd et al., 2016a). Noting that effort limits are applied to the fishery, this has implications for fleet capacity (Tidd et al., 2016a).

Examining this further, nominal vessel catch rates achieved in the period 2012-2015 were plotted within vessel length categories (Figure 7). A general increasing trend in both nominal skipjack CPUE and total tuna CPUE (mt/day) are seen with vessel length. Step-changes in CPUE with length appear at around 51-55m and 86-90m, while a general increasing trend in CPUE is seen between 51 and 80m length, and for vessel sizes above 85m. This is consistent with the findings of Tidd et al. (2016a) where vessel length was significantly related to purse seine capacity utilisation.

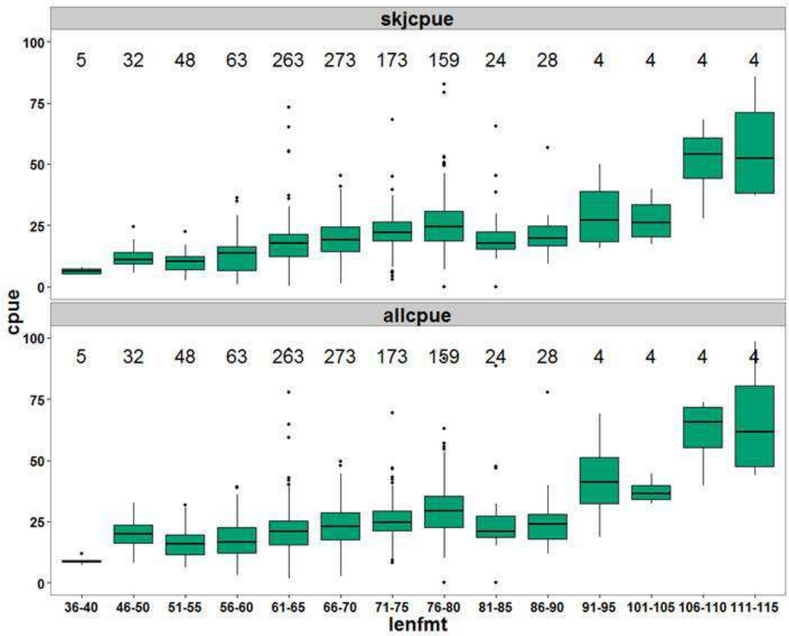


Figure 7. Nominal CPUE (top: skj mt/day; bottom: total tuna mt/day) for purse seine vessels operating within the tropical WCPO over the period 2012-2015, by length class. Numbers indicate the number of vessels contributing to the distribution.

There has been considerable discussion on the role of FADs, and in particular their associated electronics, within the fishery. The number of FAD sets per day has increased over time, inside and outside PNA waters (Figure 1). This may reflect increased FAD deployment within the WCPO and hence one element of effort creep within that component of the purse seine fishery. In turn, although we currently lack sufficient information to quantify its effects, the perception has been that this technology has significantly changed the way that vessels within the WCPO operate, and that it may contribute to catch increases. If we presume an artificial operational ceiling of 1 FAD set per day, the increased use of FADs equipped with sonars may allow effort creep to continue. This assumption is based upon anecdotal industry information that suggests vessels can target FADs known to have larger aggregations beneath them, based upon acoustic information provided by the FAD's sonar system. This may also influence the increasing trend in associated set CPUEs seen in recent years (e.g. Figure 3). More detailed information on FAD deployments, FAD technology, the influence of the FAD closure period, and associated CPUE changes is needed. In particular, the number of deployed and actively monitored FADs could be a key vessel characteristic responsible for effort creep.

Estimated 'catchability' trends in skipjack and yellowfin stock assessments

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 allowed to vary over time to adjust the impact of fishing on stocks due to processes such as effort creep. The resulting pattern for the four main tropical purse seine fisheries within the skipjack and yellowfin stock assessments are shown in Figure 8.

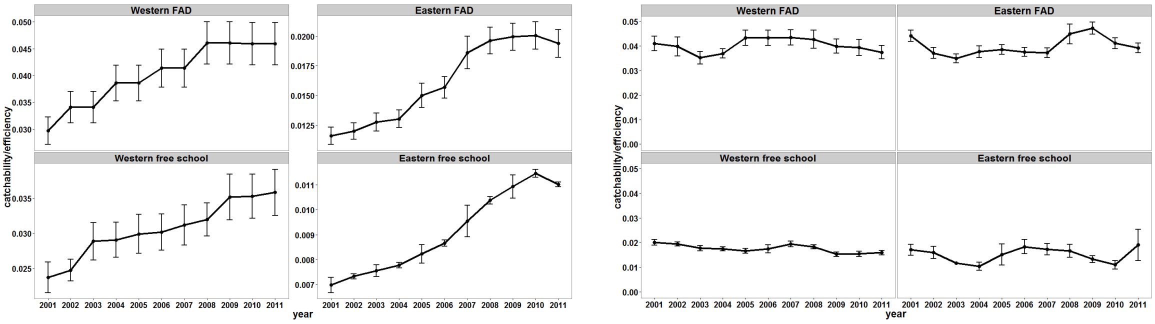


Figure 8. MULTIFAN-CL time series estimates of tropical purse seine fishery catchability within 2014 skipjack (left) and yellowfin (right) assessments. Bars indicate variability in quarterly catchability estimates.

Catchability estimates for skipjack within tropical purse seine fisheries have increased across the time period, with some stabilisation in the final years. Estimated yellowfin catchability across the same period has been relatively stable. Examining the trends from the recent period of 2005-2011 and 2009-2011 (ignoring estimates for 2012 which are uncertain), slopes of the relationships are shown in Table 2.

Table 2. Average annual increase in purse seine vessel efficiency estimated from the 2014 skipjack and yellowfin stock assessments.

Fishery	**Skipjack** % increase per annum		**Yellowfin** % increase per annum	
	2005-2011	2009-2011	2005-2011	2009-2011
Western free school	3.0%	0.6%	-0.9%	0.9%
Western FAD	3.0%	-0.1%	-2.9%	-1.3%
Eastern free school	5.0%	0.3%	4.7%	7.5%
Eastern FAD	4.3%	-0.9%	0.4%	-3.7%
Average	**3.8%**	**-0.03%**	**0.3%**	**0.9%**

How to apply indicators of effort creep

The majority of candidate indicators of effort creep have shown increases over the recent period, both within and outside PNA EEZs. How well indicators relate to effort creep, their ease of monitoring and the timeliness of the availability of information will influence their utility. Here we use as an example the approach of adjusting for effort creep by simply reducing WCPFC effort limits. We note that an alternative approach, identifying specific factors driving effort creep and addressing them directly, is equally applicable.

To operationalise the use of indicators to adjust WCPFC effort limits, for example, the following is recommended:

- selecting indicators most appropriate for whichever management approach is defined to adjust limits for effort creep;
- develop decision rules to transparently identify:
    - when an adjustment needs to be made;
    - how large that adjustment needs to be.

Selecting indicators

The pros and cons of the different indicators are detailed in Table 1. Perhaps the most obvious starting point for adjusting overall effort levels for effort creep is to use recent changes in CPUE. 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 behaviour of fish. Separating effort creep effects from this hyperstability is challenging. In turn, other influencing factors that would need to be considered (but which could be modelled) include:

- the effect of oceanographic conditions and geographic location, with for example recent strong El Niño events shifting fishing effort to the east of the fishery, which can influence CPUE achieved;
- the increased ability of fishers to catch fish over time (e.g. learning to use new technology and knowledge of good fishing areas, and communication between vessels (cooperation versus competition), rather than technology-based effort creep *per se*; Hilborn and Walters, 1992);
- the implications of market forces and management regulations on patterns of fishing (e.g. FAD closure, increasing fuel costs, fluctuations in market prices, which may have both positive and negative outcomes for productivity); and
- the effect of logsheet misreporting, noting that there is evidence to suggest an increase in the reporting of 'days spent steaming' within logsheets, which are not currently included within estimates of fishing effort (SPC-OFP, 2013).

Similar challenges are identified for the use of catch levels, although changes in that indicator perhaps indicate the ultimate impact of effort creep. A combination of these indicators may be appropriate.

Monitoring vessel characteristics may allow the technical drivers of effort creep to be identified. Those characteristics could be tracked through regional vessel registers, as well as through the information observers collect on the fishing gear used by each vessel on each trip (see also Tidd et al., 2016a). That effect may be specific to set-type. For example, more powerful blocks, larger net mesh, and knotless mesh may increase the effectiveness of free school fishing, while as noted above the adoption of echo-sounders on FADs may increase the effectiveness of FAD fishing. However, we note that the information currently available can be inconsistent between Registers, absent, or contains potential errors. There is a need to improve the information available if this field of research is to be continued (see also Tidd et al., 2016a).

A challenge is to identify a limited suite of characteristics that directly (or indirectly) influence effort creep. Trends in different characteristics are likely correlated (i.e. larger vessels have greater hold capacities, etc.; see also Appendix 2). 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. For example, 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, 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. The influence of vessel characteristics on fleet capacity is examined in Tidd et al. (2016a). In turn, identifying vessel characteristics that influence catch rates through modelling may prove challenging, due to natural variability, characteristics that may not be regularly captured in Registers (but that may be available through observer reports), and other factors that cannot easily be modelled, which may ultimately prove more influential.

'Production frontiers' can be used to identify increases in vessel/fleet/fishery performance, by monitoring the change in that frontier over time (see Tidd et al., 2015). The overall change in impact on the stock can be estimated for given effort levels, thereby providing an overall measure of increases in fishery or fleet productivity, and hence effort creep. This approach combines consideration of vessel characteristics with catch and effort data. Tidd et al. (2016b) identified a 3.8% average annual increase in fishing power over the period 1993-2010 for four key purse seine fleets operating within PNA EEZs. This approach can be readily extended, for example through stochastic multi-output production function methods.

In theory, catchability estimates should be the best indicators of effort creep among the options considered in this paper, as they measure the aggregate effect of changes in vessel efficiency on fishing mortality which for example vessel length measures do not, and they take into account changes in stocks which catch and catch rate indicators cannot do easily. However, the model-based estimates will also integrate over fleets, depending on how fisheries are defined in the assessment model. They will also include effects related to the distribution of effort in relation to the distribution of fish at a spatial scale finer than that being modelled. In turn, the utility of catchability estimates for monitoring the fishery for effort creep and adjusting effort limits must be considered, with practical challenges including:

- Timeliness: catchability estimates are only updated when assessments are performed. Estimates in the final years of the assessment are considered the most uncertain as those years have limited information available to estimate catchability and hence estimates are more strongly influenced toward the 'prior mean' for the catchability parameter. Combined, in the worst case these issues may mean the most recent usable estimate may be five or more years old.
- Accuracy: catchability estimates assume that the assessment is completely correct with respect to recent trends in abundance.

The utility of catchability estimates for year-on-year use is therefore limited. Less frequent changes to effort limits based on catchability estimate trends may be more appropriate. In turn, the values may offer a useful validation of other approaches.

Developing decision rules

Transparent decision rules for adjusting effort limit levels are recommended. These should define the period of data used for the adjustment, the frequency with which re-adjustment is considered, and potentially a minimum level of change in an indicator within an adjustment period before action is taken.

There are considerable year-on-year fluctuations in the indicators (e.g. due to changes in the underlying stock size, oceanographic influences on fishing location and catch, market forces, etc.) that need to be taken into account if these indicators are to be used for adjustments. Using a specific single year as a baseline against which the level of changes is evaluated would potentially lead to bias, and the option of examining trends between short-term averages, of the type used in the evaluations in this paper, is recommended.

The change in an indicator may be considered too small to warrant an adjustment. As an example only, it may be considered that an adjustment only occurs if the indicator changed by 2% or more relative to the baseline period. Once an adjustment was made, the baseline period would need to be modified accordingly.

The situation where effort creep indicators decline should also be considered. Declining catch or CPUE should be viewed in light of the stock assessment and other scientific analyses, as they may be indicative of declining stock sizes rather than 'negative' effort creep, and should not automatically lead to increases in effort limits for example. Declines in certain vessel characteristics may be indicative of a shift to a more efficient approach to fishing or due to market forces, rather than reductions in effort creep. Care must be taken when interpreting trends for any decision rule.

Implications for the development of harvest control rules

As noted above, the increase in fishing mortality per fishing day resulting from effort creep will mean that stock management targets are unlikely to be met if effort limits are not adjusted appropriately.

Approaches described within this paper focus on the potential use of trends in indicators to allow effort limit adjustment by managers. In theory, however, those effort reductions could be controlled through appropriate formulation of a harvest control rule (HCR; e.g. Scott et al., 2016a). Such a harvest control rule could include, for example:

- trends in indicators could be incorporated within the HCR as part of the internal setting of future effort levels. An example is the addition of a catch-level trigger within 'HCR5' of Scott et al. (2016a), which required an additional effort reduction if a specific annual catch level was exceeded in two consecutive years[2]. A similar approach could be taken based upon trends within specified effort creep indicators; or
- adjustment of effort levels through the HCR based upon the assessed status of the skipjack stock. If effort creep were occurring, the skipjack stock size would be expected to fall below the TRP at recent effort levels, and with the correct HCR formulation would lead to specified reductions in effort to compensate. The potential disadvantage of this approach is that the management system would be reacting to the consequences of effort creep, rather than pre-empting the effect. This may lead to continued effort reductions if the HCR were unable to reduce effort limits sufficiently to counteract the actual level of effort creep experienced. The use of indicators as suggested in the first bullet would in theory avoid this, if the correct indicators could be identified.

We note that the necessary scale of adjustments for effort creep remain uncertain, because the extent to which effort creep is occurring in the fishery, and the nature of the change, is not clear. Ultimately,

[2] We note that due to strong autocorrelation in recruitment, a longer period that smooths out the resulting variability in catch may be better.

the approach selected can be tested for its effectiveness within Management Strategy Evaluation (see Scott et al., 2016b) to ensure that any proposed management approach is robust to this uncertainty.

We invite WCPFC-SC12 to:

- consider the importance of this field of research and its prioritisation within the SC work plan;
- discuss the appropriateness of candidate indicators of effort creep, and their pros and cons;
- note the trends in FAD (associated) fishery metrics, and the need to ensure related information is available to understand the potential influences on effort creep;
- note the importance of developing consistent and complete information on vessel characteristics (see also Tidd et al., 2016a);
- consider how trends in indicators might be evaluated (averages, standardisation);
- discuss potential decision rules for implementing any approach.

Acknowledgements

The study was carried out with financial support from the World Bank (DGF 107515), and by program funding to SPC Fisheries, Aquaculture and Marine Ecosystems (FAME) through the Australian Government DFAT Partnership for Pacific Regionalism and Enhanced Development. Thanks to Steve Brouwer for his review of an early draft of this paper.

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Appendix 1. Vessel characteristics driving efficiency change

At the vessel level for all fleets operating within the WCPO, vessel characteristics that tend to coincide with higher catch rates, and hence could contribute to effort creep, were examined for the period 2012-2015. The analysis was broken down into two ‘fleets’: PNA Party flags; and all other flags. Vessels that fished fewer than 25 days in at least one year were excluded from the analysis. The available vessel characteristics for the top and bottom 30 performing vessels (in terms of mt/day) were examined to identify those factors that tended to distinguish one group from the other (Figure 9). In both cases, although the absolute levels differed, more effective (top 30 performing) vessels tended to be newer, and this seemed to be linked to vessel size (being larger and of higher GRT), greater engine power and storage capacity.

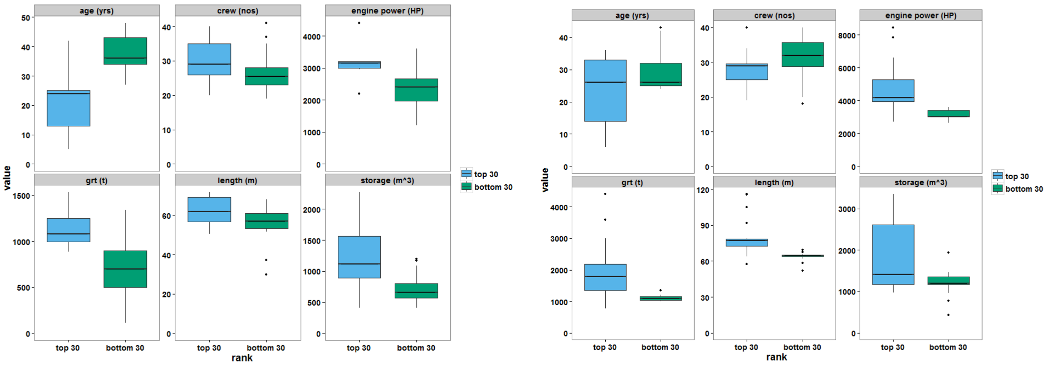

Figure 9. Characteristics of the thirty top and bottom ranked vessels for PNA-flagged vessels (left) and non-PNA flagged vessels (right).

Note that while the results are similar to previous analyses (Tidd et al., 2015), these results are not limited to the four flags examined previously, and are for a more recent time period.

Appendix 2. Trends in nominal purse seine CPUE with vessel characteristics.

NOTE: the number of vessels for which information on a specific characteristic was available varied.

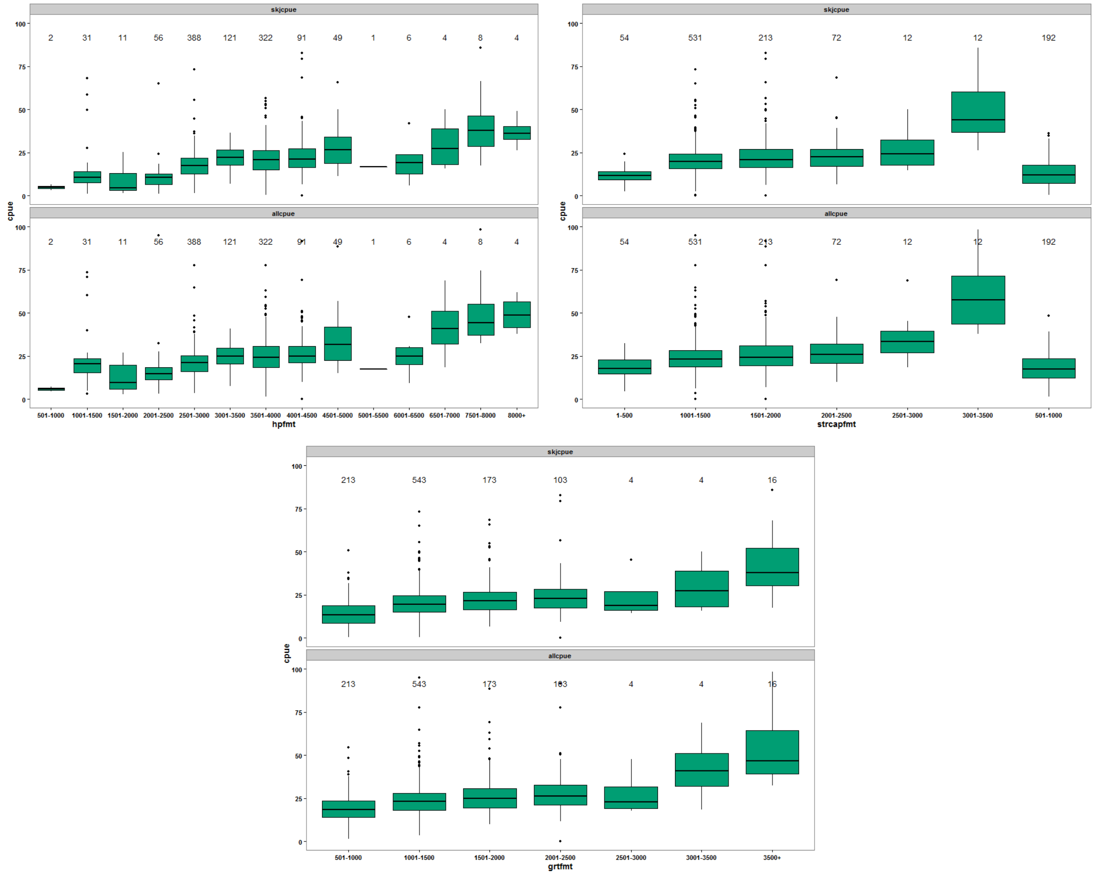

Figure A1. Nominal CPUE (top: skj mt/day; bottom: total tuna mt/day) for purse seine vessels operating within the tropical WCPO over the period 2012-2015, by engine horse power (top left), storage capacity (m^3; top right) and vessel GRT (bottom). Numbers indicate the number of vessels contributing to the distribution.