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Examining productivity changes within the tropical WCPO purse seine fishery

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Executive summary

The Western Central Pacific Ocean (WCPO) is one of the most productive tuna fisheries in the world and catches by weight of tuna are dominated by the purse seine fleet.

The tropical WCPO purse seine fishery is primarily managed through effort limitations (limits on the number of fishing days per year). However, constant innovation leading to more efficient ways to find, catch and process fish, can result in an increase in productivity e.g. the amount of catch per fishing day . Increasing fleet productivity is a key feature of concern in effort/input controlled fisheries, as it can have detrimental effects to health of the stock if not properly accounted for.

This paper reflects our first examination of potential evidence for historical productivity increases within the WCPO tropical purse seine fishery. Results show that purse seine catchability (as estimated within the MULTIFAN-CL assessment of the WCPO skipjack stock) has increased by 3.0-5.0% per annum, which if solely attributed to increase in purse seine productivity suggests that a day fishing in 2011 is 19-34% more effective than a day fishing in 2005. Increases in the number of sets made per day were also found, likely reflecting fewer days where no set was made. Over the period 2005-2011, the rate of free school setting increased by 1.6% per annum, while FAD sets increased by 0.7% per annum. Set rates have been near constant in the most recent period (2011-2013), with only small increases in free school sets. More efficient purse seine vessels tended to be younger, and this was linked to vessel size (being larger, even within a 50-80m size category) and greater engine power.

The analyses above have identified potential evidence for productivity increases within the tropical purse seine fleet. Further work is suggested to help improve our knowledge of productivity change within WCPO fisheries. We invite the WCPFC-SC to:

- Note the importance and implications of this research and consider its prioritisation within the SC work plan;
- Note that there is evidence from several sources that purse seine vessels have increased their efficiency relative to the effort metrics being used to manage the tropical purse seine fishery. This needs to be taken into account when developing management measures and maintaining stocks relative to TRP biomass levels.

Introduction

With constant innovation developing more efficient ways to find, catch and process fish, catchability (*q*) in wild fisheries tends to increase. Fleet size limits and effort limits tend to accelerate the increase in productivity because they create incentives to maximise outputs per vessel or per fishing day. For successful management of fisheries, particularly where stock abundance is declining, understanding how productivity changes over time (where productivity is the level of outputs for a given level of inputs within the production process) and the factors that drive those changes is required. Increased productivity can result from developments to existing vessels or the addition/substitution of newer vessels, with for example more efficient and powerful engines, larger nets, improved radar technology, and use of sonar buoys on FADs.

Understanding the scale of productivity increases is especially important in fisheries managed using effort (input) controls as opposed to catch (output) controls. An example is the WCPO tropical purse seine fishery, which is managed primarily through limits on the number of fishing days each year. In this fishery, increases in productivity would relate to an increase in fishing mortality that a vessel could impose on the stock during a fishing day (also known as 'effort creep'). An effort-based management system that does not take into account and adjust for this increase will not achieve its objectives (e.g. maintaining a stock at the desired target reference point level or avoiding a limit reference point with an acceptable level of risk; MOW3-WP/03).

Policy and regulatory changes can also affect vessel fishing power, and affect fleet productivity. For example, the FAD closure periods within the WCPO tropical purse seine fishery may have reduced fleet productivity in recent years, while sub-regional management arrangements allowing the pooling of fishing days or increasing transferability of days from less productive regions to more productive ones could increasing productivity. However, such management intervention may lead to further innovation within fleets through a commercial drive to improve profitability within those management constraints. For example, the FAD closure period may have increased the speed of adoption and use of sonar buoys on FADs as a commercial response to optimise benefits from available FAD fishing periods, and this might counteract any reduction in fishing power resulting from the FAD closure. Separating out these influences is not straightforward, but the potential aggregate effect of increases in productivity on the fish stock is of primary interest here.

This paper reflects our first examination of potential evidence for historical productivity increases within four key fleets of the WCPO tropical purse seine fishery (the United States, Korea, Chinese-Taipei and Japan). We also investigate the purse seine vessel attributes that might contribute to identified changes in productivity in the fishery using available information. In undertaking this exercise, we examine the results from the skipjack stock assessment, and catch and effort data at both the fleet and individual vessel level.

How do trends in purse seine CPUE track trends in skipjack abundance?

Fisheries models are based on the concept that catch rates (CPUE) are directly related to the abundance of the stock being fished. However, vessel/fleet productivity increases could maintain or increase CPUE in the face of stock abundance declines. In turn, in schooling stocks like tuna, CPUE may remain high in the face of stock abundance declines ('hyperstability') (see also SC11-MI-WP-04). There are two key mechanisms that could maintain or increase CPUE: 1) improved technology leading to increased productivity over time; and 2) fishers ability to find schools of skipjack does not decrease in proportion to stock size declines.

A comparison of estimated tropical adult skipjack biomass from the most recent skipjack assessment (Rice *et al.,* 2014; Figure 1, top) to the nominal overall catch rates (mt per day) of key purse seine fleets (Japan, Korea, Chinese Taipei and the US) over the same period (Figure 1, bottom) shows that the trends in these sets of data are very different. While tropical skipjack abundance has generally declined over the period 1992-2012 in all regions, purse seine catch rates over that period have generally increased; i.e. fishing success (CPUE) has not tracked underlying skipjack abundance.

The fleet-specific catch rate information (Figure 1, bottom) indicates variability in the trends between fleets. While in recent years (2008-2012) trends have been comparable (e.g. relatively low catch rates in 2011 across fleets, with that CPUE recovering in 2012), the increase in CPUE by the Korean and Chinese Taipei fleets since 1992 has been much larger than that for the US fleet, for example. While there is some commonality in the trends for the Japanese, Korean and Chinese Taipei fleets over time, that for the US fleet has been different, with notable declines in CPUE in the early 2000s. In recent years, the average annual CPUE by the Korean fleet has been consistently higher than all others. The overall increasing trend in CPUE suggests some improvement in productivity over time. Factors that may be related to those trends will be examined throughout this paper.

Within the MULTIFAN-CL stock assessment model, the fishery specific 'catchability' parameter can be related to fleet productivity. It estimates the impact of a single unit of effort of a given fishery on the stock, translating the level of fishing effort into the level of fishing mortality. Within the stock assessments catchability is allowed to vary over time, and enables the model to adjust the impact of fishing on stocks due to processes including improved fleet productivity.

The resulting time series of catchability estimates for the four main grouped tropical purse seine fisheries within the 2014 skipjack stock assessment are shown in Figure 2. We exclude estimates for 2012, as they are considered uncertain. While estimates of catchability within tropical purse seine fisheries do not increase year-on-year, they are estimated to have increased across the time period 2001-2011. Examining overall trends in catchability from the recent period of 2005-2011 for each fishery, the slopes of the linear relationship are shown in Table 1. Annual increases in catchability ranged from 3.0 to 5.0% per annum, which suggests that a day fishing in 2011 was 19-34% more effective than a day fishing in 2005. It is important to note that these estimates assume that the assessment is completely correct with respect to recent trends in abundance, and do not provide information on what developments might be driving these trends. We also note that catchability in the most recent years is estimated to have levelled off (Table 1). Whether this is related to e.g. recent management measures within the purse seine fishery (e.g. annual FAD closures), reductions in the effect of technical advances, and/or a feature of the MULTIFAN-CL estimation process, cannot be identified.

Are there trends in the number of sets per fishing day?

Increases in the number of sets made per fishing day may reflect increased purse seine vessel productivity. To examine this, the numbers of drifting FAD and free school sets made per fishing day across the period 2000-2013 were evaluated from logsheet data. Figure 3 shows the resulting pattern of mean sets-per-day-fished by set type for four key fleets combined, and by fleet.

Trends in the number of sets per day by fleet and set type varied prior to 2006. From that year, trends were more consistent across fleets, with the number of sets per day generally increasing. This was particularly clear in the number of free school sets per day. In the most recent period, set rates were near constant, with small increases seen in free school set rates. Over the period 2005-2011 the rate of free school setting increased by 1.6% per annum, with FAD sets increasing by 0.7% per annum (Table 2).

Are fleet-average changes in productivity seen at the vessel level?

Trends in purse seine productivity, in terms of their catch rates over time, and changes in the number of sets made per day, vary between fleets (Figure 1, Figure 3). These data also indicate considerable variability within fleets. Performance at the individual vessel level may show similar patterns to their associated fleet average, or may vary around that average. We examine vessel-specific patterns of annual productivity in two ways.

Vessel-specific productivity trends are examined for the period 2001-2013 as ratios of that vessel's average skipjack CPUE (mt/day) in 2000, by fleet (Figure 4a). Only those vessels for which data were available for the complete period 2000-2013 were included within this analysis. The resulting ratios showed notable inter-annual variability at the individual vessel level. Some year-specific patterns were visible (e.g. the Chinese-Taipei and Korean fleets in 2009 tended to show relatively higher CPUE than in neighbouring years). The data tend to show upward trends, with ratios relative to the 2000 CPUE trending above 1 over time. It is also clear that particular vessels show consistently higher catch rates over time compared to other vessels within the fleet.

The general trend in vessel-specific CPUE relative to that achieved in the year each vessel entered the fishery is shown in Figure 4b, by fleet. Using a lowess smoother to indicate the general weighted trend in these ratios, the CPUE of all fleets increased the longer a vessel remained in the fishery, relative to their 'starting' CPUE. For example, after 20 years in the fishery Korean vessels' CPUE was on average up to three times greater than that in their first year. For some fleets, the increase in CPUE appeared to reach an asymptote (e.g. the Chinese-Taipei fleet after 15 years in the fishery). However, these trends are influenced by the lower number of vessels that have been in the fishery for more than 15 years.

Examining the fleet-specific general trends over time, Figure 4c indicates the annual fleet CPUE range between 2000 and 2013, and the average annual CPUE of vessels entering the fishery in a year relative to that distribution. If new vessels entering the fishery had relatively better performance than long-term vessels, those vessels would be expected to be in the upper part of the fleet-specific CPUE range. Generally, new boats entering the fishery were below the fleet average. However, Chinese-Taipei vessels entering the fishery in the most recent period 2010-2013 appear to show higher average CPUE. It is important to note that the new vessels weren't new *per se*, but were new to the fleet. Examining this in more detail, Figure 5 presents the proportion of each fleet by age category. Based upon this data, the Chinese-Taipei vessels that joined the fishery in recent years were in fact older than 11 years. Although the source of these vessels is not clear from the available information, the relatively high CPUE would suggest that these vessels may have had more up to date technology and/or experienced crew than the majority of the fleet.

It is important to note that the analysis does not account for changes in skipjack biomass. Doing so may imply greater productivity changes than suggested here, given that tropical biomass is assessed as having declined over time.

What vessel characteristics may drive these efficiency changes?

The analyses indicate fleet-specific trends in productivity, with particular fleets showing greater increases than others. In turn, vessels appear to improve their productivity over time, while some vessels tend to achieve consistently higher CPUEs. The latter trend suggests that vessel-specific characteristics influence productivity.

At the vessel level within the four key fleets, vessel characteristics that tend to result in higher catch rates, and hence can contribute to increases in productivity, were examined. Data were from the period 2010-2013. For this analysis we focussed solely on vessels with lengths between 50 and 80m to reduce the impact of vessel size, which is already known to influence productivity (at the gross scale for example, the largest 'super' purse seiners in the fishery are known to have relatively high catch rates). We excluded vessels that fished fewer than 25 days in at least one year from the analysis. Individual vessels across the four purse seine fleets were ranked in terms of their average annual total tuna catch rates across 2010-2013 (Figure 6). The top 30 performing vessels were predominantly from Korea. The bottom performing 30 vessels tended to be from Chinese-Taipei, the US and Japan.

Available vessel characteristics (e.g., vessel age, vessel size, engine horse power, storage capacity; this information was available for 2010-2011 only) were related to the rankings to identify those factors that tended to distinguish one group from the other (Figure 7). More effective vessels tended to be newer, and this appeared linked to vessel size (being larger, even within the 50-80m size category) and greater engine power.

Discussion

The productivity or harvesting power and catchability of fishing vessels tends to increase over time due to technological improvements (e.g. fish finding and fishing gear developments) and the skill of the fishers (e.g. the crew and the fishing skipper). The simple exploratory analyses used here indicate that catching efficiency has improved over time in the tropical purse seine fishery. Pinpointing the factors driving that increase in productivity is complicated by the limited available data set of factors that might influence the changes. However, this exploratory analysis provides results to prompt discussions for future work in this important area of research.

Skipjack catch rates in the WCPO have tended to increase over time, even though the exploitable biomass is assessed as having declined over that period (Figure 1). Non-proportionality between CPUE and stock abundance suggests that fleets are better at finding concentrations of fish rather than by fishing randomly (see Harley *et al*., 2001; Hilborn and Walters 1992; SC11-MI-WP-04; "Hyperstability").

Identified increases in the number of sets made per day (1.6% per annum over 2005-2011) do not necessarily mean that all vessels have started to make multiple sets per day. These patterns were primarily driven by a reduction in the number of days spent fishing without a set being made (i.e. fewer days were spent purely searching). This could be related to the resurgence in helicopter use leading to increased free school fishing success. There is also the potential for 'smart' FADs to reduce days without a set (e.g., when a FAD is visited, but found to be empty) thereby reducing search time and hence potentially fuel costs. Sonar-FADs could also allow vessels to better select those FADs associated with larger fish aggregations.

Patterns were also identified at the individual vessel level (Figure 4b) where the time spent in the fishery resulted in productivity increases compared to the year it entered the fleet. This varied between fleets, with that for the Korean fleet increasing notably over 20 years within the fishery, while that for other fleets tended to asymptote at around 15 years within the fishery. Although data were not available to examine potential causes of this in detail, it may suggest that fishing success is related to skipper/crew experience of the fishery, coupled with the time taken to learn how to best exploit 'new' technologies.

New vessels in earlier years of the study generally had a lower CPUE (see figure 4c). Some of those 'new' vessels may represent vessels reflagged to a fleet, and hence do not reflect 'improved' technology. More recently, however, vessels entering the fishery appear to be more productive, e.g. for the Chinese-Taipei fleet. Nevertheless out of the 4 fleets examined, the Chinese-Taipei was shown to have only 3 vessels in the top 30 performing vessels over the period 2010-2013, with more vessels featuring in the bottom 30. The Korea fleet appeared to have the most vessels in the top 30 rank (Figure 5).

Observing vessel attributes for the comparison between the 30 'best' and the 30 'worst' performing vessels, the top performing vessels appear to be newer (younger), larger in length and more powerful in terms of engine power (Figure 6). It was also interesting to note that fish storage capacity did not appear to be a significant indicator of efficiency, despite being a very common measure of fleet capacity.

We note that the vessel characteristics used within this analysis represented a short term (2010-2011) summary of those characteristics, and how they varied relative to vessel rankings. When examining vessel-specific productivity over time (e.g. Figure 4), to identify covarying factors requires a time series of how vessel characteristics have changed. We discuss this further below.

We highlight that the last years of this analysis are influenced by misreporting of fishing effort within logsheets (SPC, 2013; see also Appendix 1). This may exaggerate trends seen for some fleets in the most recent years, and will affect the overall estimates for the most recent period.

Next steps

This paper presents an initial examination of potential increases in productivity within the tropical purse seine fishery. To extend these analyses, up to date time series of information on vessel and crew characteristics is needed (e.g. key potential factors such as crew history, information on gear and technological changes over time).

While databases available to SPC contain fields for vessel characteristics of interest, there were information gaps or fields that were no longer being completed or entered (e.g. information on the types of sounders and dopplers in use, freezer capacity etc.), in addition to fields which did not contain details of the measurement units to accompany the values (e.g. fields for storage capacity, fuel capacity, net depth and length, etc.), which reduced their utility and hindered analyses.

A key area for future analysis is identifying those factors driving changes in vessel productivity, in order to identify appropriate metrics for productivity change (e.g. as opposed to a fishing day as currently used in management measures, an aggregate of individual components into a composite measure of effort such as a 'kilowatt fishing day' might be more appropriate in the situation where engine power and engine refits were found to drive vessel productivity). For future analyses it will therefore be important to include a time series of vessel changes as they occur (consistent with the WCPFC "Record of fishing vessels and authorization to fish", CMM 2013-10 part B 7b)). Ensuring a comprehensive and up to date database of the time series of regional vessel history characteristics will facilitate future analyses into identifying potential factors that contribute to composite measures of fishing effort.

To enhance analyses further, incorporation of Electronic Monitoring (EM)/VMS/observer data and hence incorporation of more precise information on time spent actually fishing, would be beneficial. It will also be important for future studies to research other factors (e.g. bycatch and the social-economic implications of FAD closures or other management regulations, economics in the form of fuel costs, market prices and interest rates) to see how exogenous variables affect productivity.

The potential consequences of increases in fleet productivity need to be taken into account when developing management measures and maintaining stocks relative to TRP biomass levels. Therefore, we invite the WCPFC-SC to:

- Note the importance and implications of this research and consider its prioritisation within the SC work plan;
- Note that there is evidence from several sources that purse seine vessels have increased their efficiency relative to the effort metrics being used to manage the tropical purse seine fishery.

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Hilborn, R. & Walters, C.J. (1992). Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. New York: Chapman and Hall, 570 pp.

SPC (2013). Purse seine effort. A recent issue in logbook reporting. WCPFC-TCC9-2013-18.

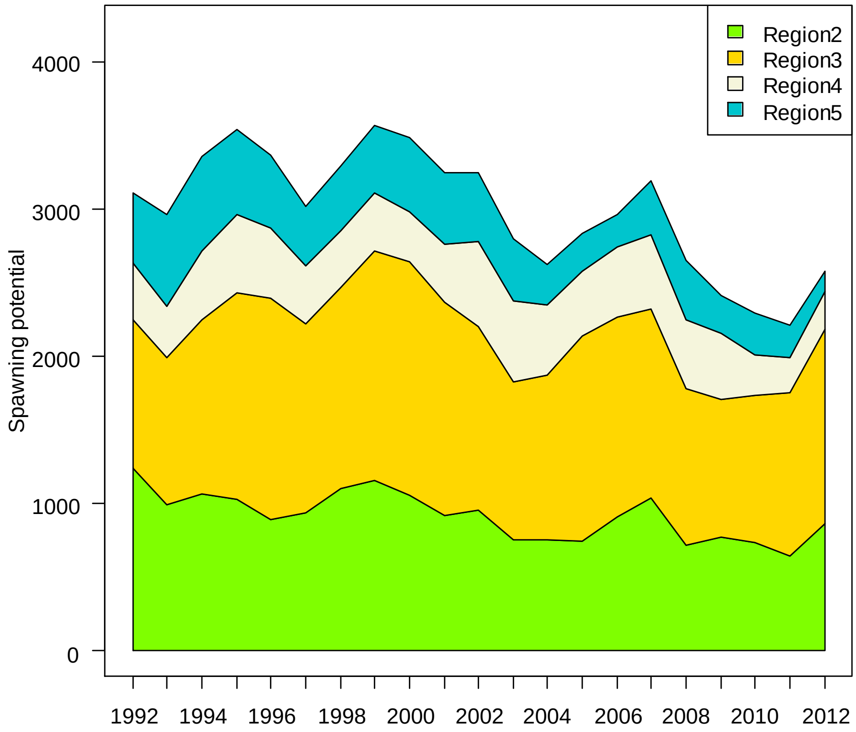
Rice, J., Hampton, J., Davies, N., and McKechnie, S. (2014). Stock assessment of skipjack tuna in the western and central Pacific Ocean. WCPFC SC10-SA-WP-05, Majuro, Republic of the Marshall Islands, 6 – 14 August 2014.

Table 1. Average annual increase (2005-2011) in purse seine vessel efficiency estimated from the 2014 skipjack stock assessment.

Fishery	% increase per annum (2005-2011)	% increase per annum (2009-2011)
Western free school	3.0%	0.6%
Western FAD	3.0%	-0.1%
Eastern free school	5.0%	0.3%
Eastern FAD	4.3%	-0.9
Average	***3.8%***	***-0.03%***

Table 2. Average annual increase in purse seine vessel efficiency estimated from the number of sets made per day.

	% increase per annum	
Set type	2005-2011	2011-2013
Free school	1.6%	0.1%
FAD	0.7%	0.0%



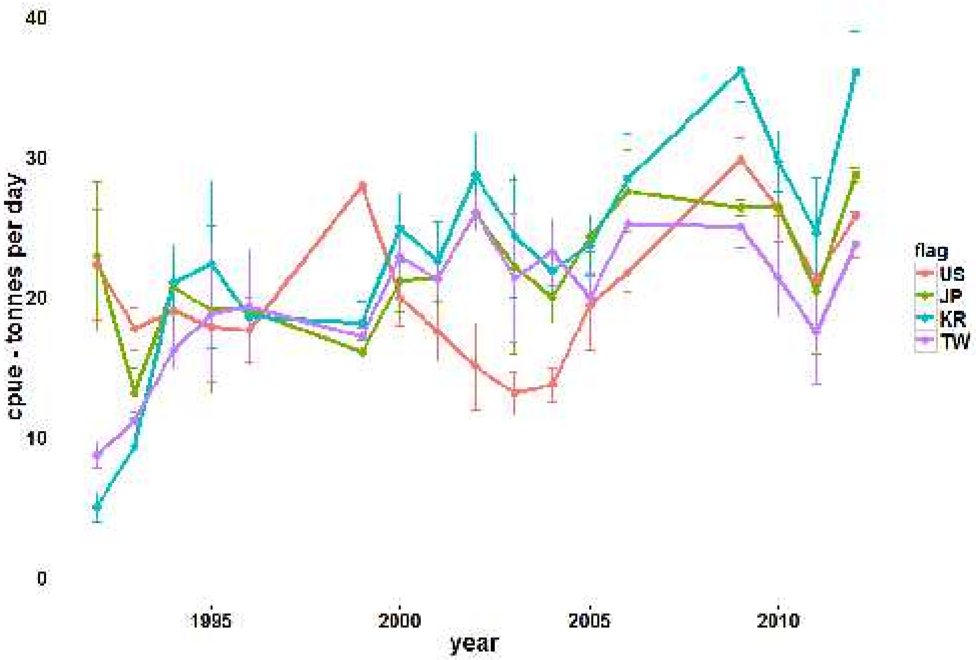


Figure 1. Estimated skipjack spawning potential (adult biomass, '000 metric tonnes) by tropical model region for the period 1992-2012 (top); and average tropical purse seine skipjack catch per day by year and flag over that period (bottom). Error bars represent variability across quarters of the year. Flags: US – USA; JP – Japan; KR – Korea; TW – Chinese Taipei.

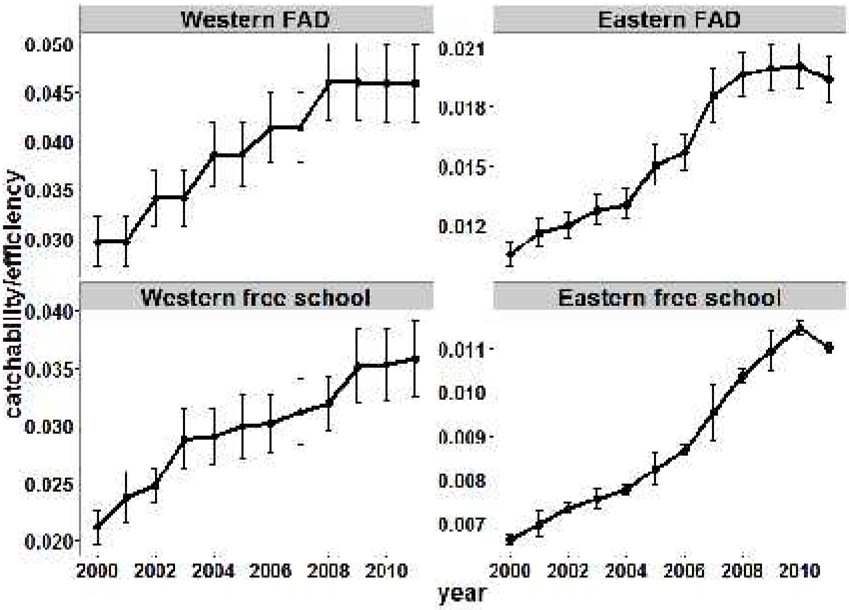


Figure 2. MULTIFAN-CL estimates of changes in catchability for the four tropical purse seine fisheries within the skipjack assessment model. Bars indicate variability in quarterly catchability estimates.

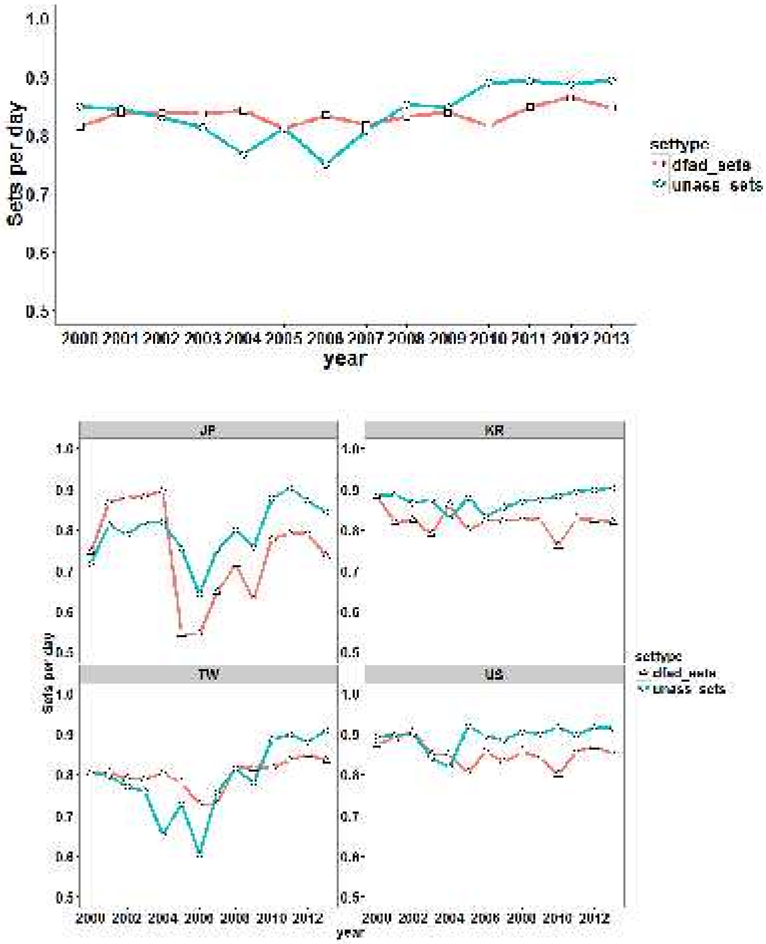


Figure 3. Number of sets per day (unassociated and associated) over time for all purse seiners combined within PNA waters (top) and by flag for four key fleets (bottom).

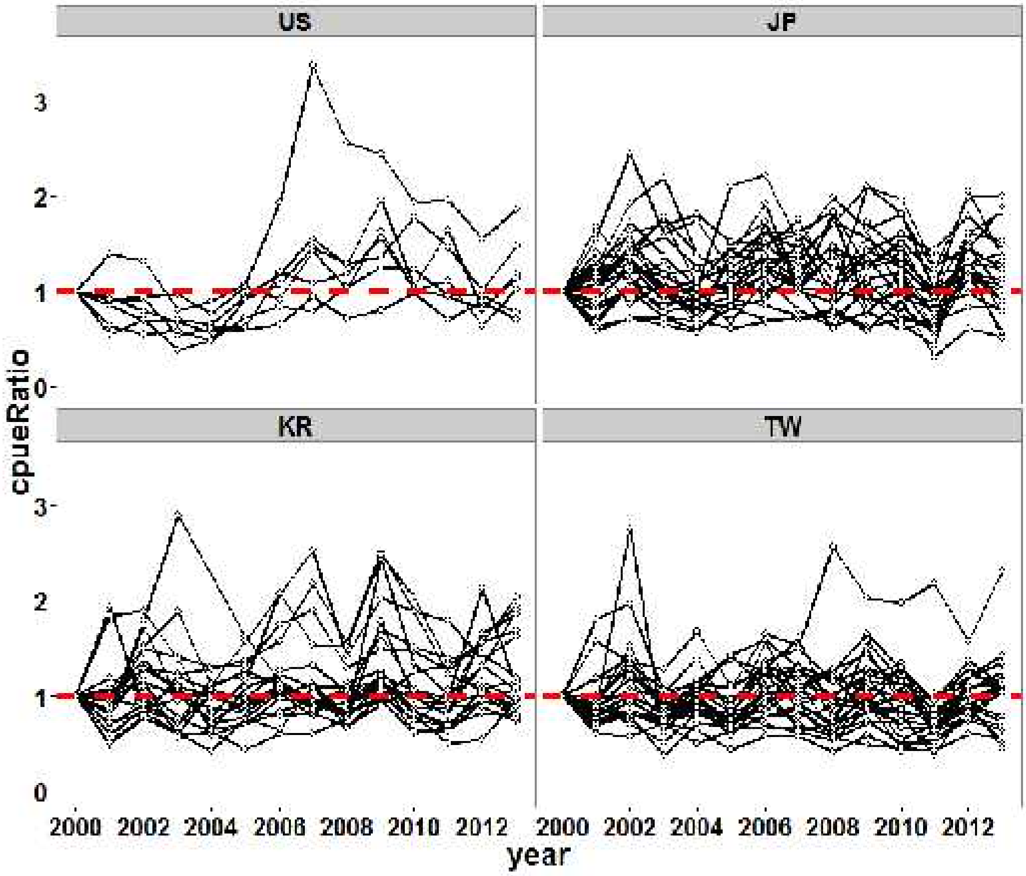


Figure 4.a) Annual CPUE trend (skipjack metric tonnes per day) for each vessel over the period 2000 to 2013, relative to the CPUE achieved in 2000 by that vessel. Note only vessels that were present for all of the period were included.

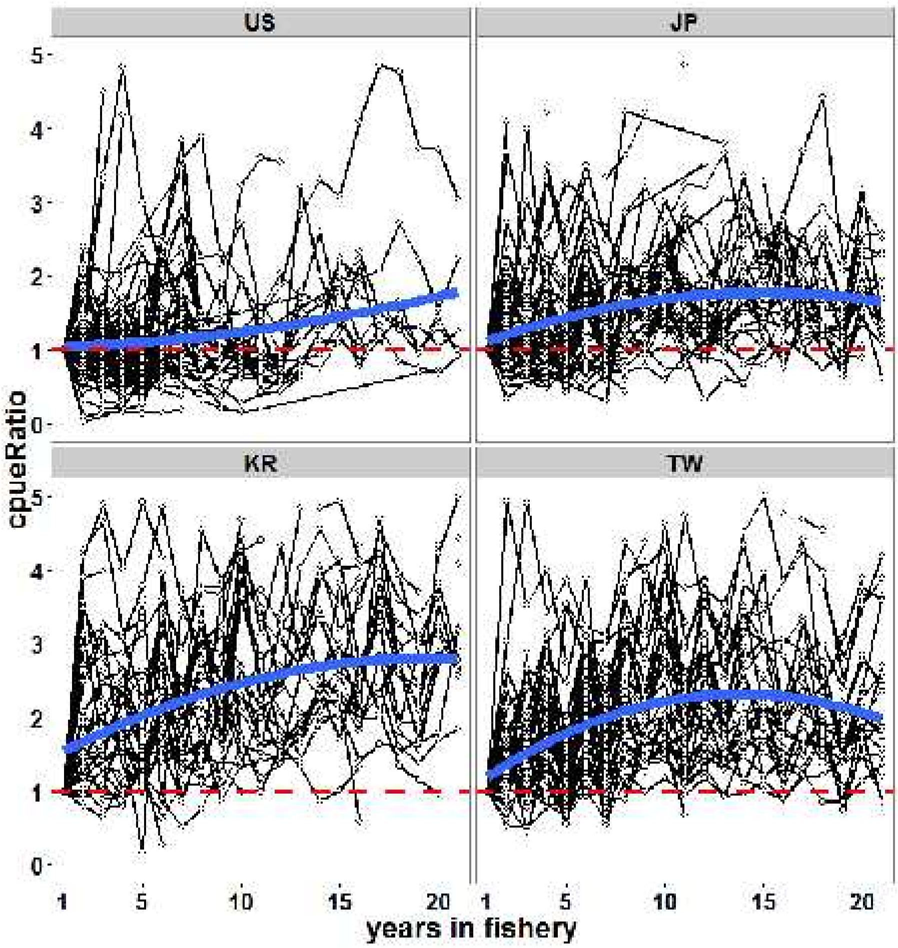


Figure 4.b) Annual CPUE (skipjack metric tonnes per day) achieved by each vessel across the years that vessel was in the fishery, relative to the CPUE achieved in its first year. Note each line represents a vessel and the blue line a smoother fitted to all data.

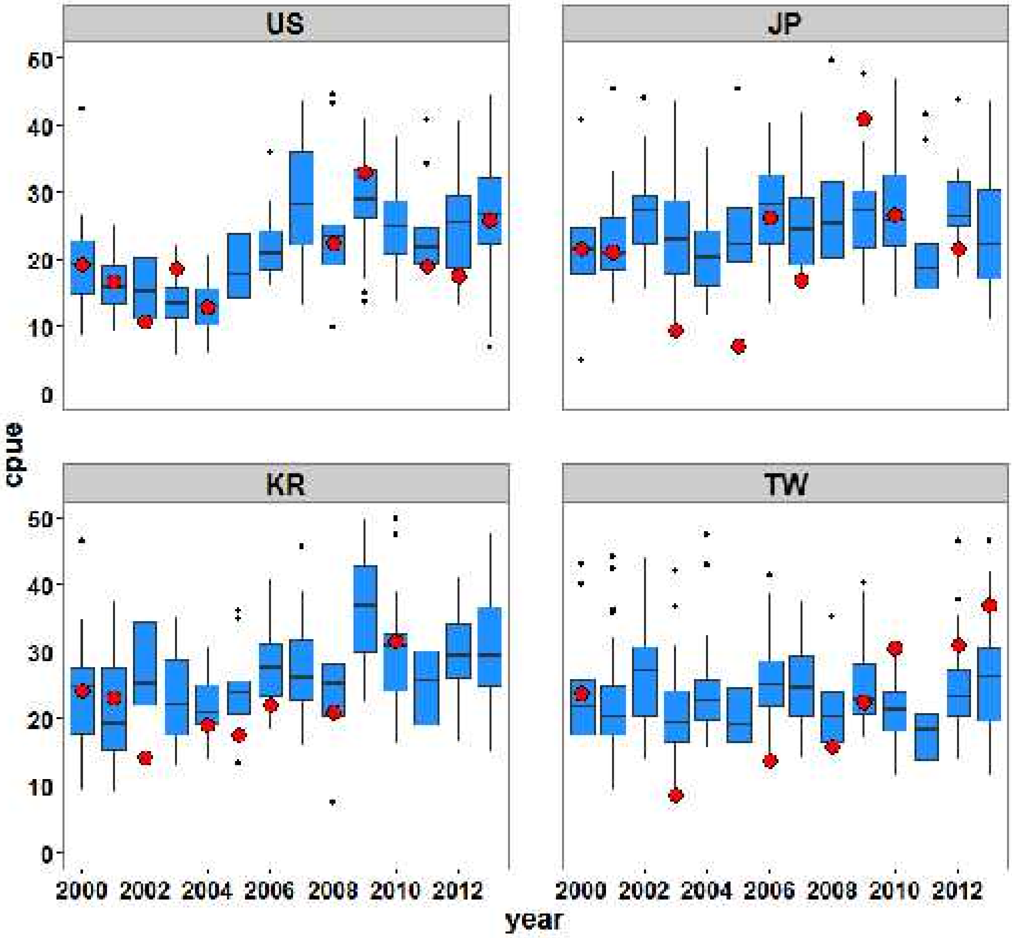
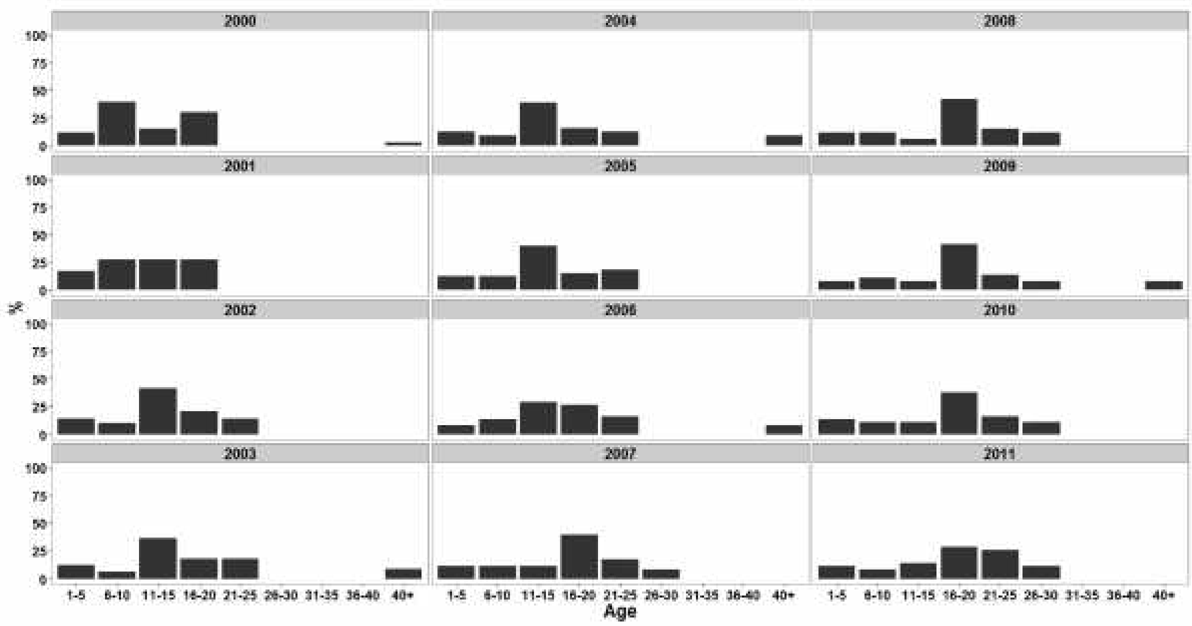
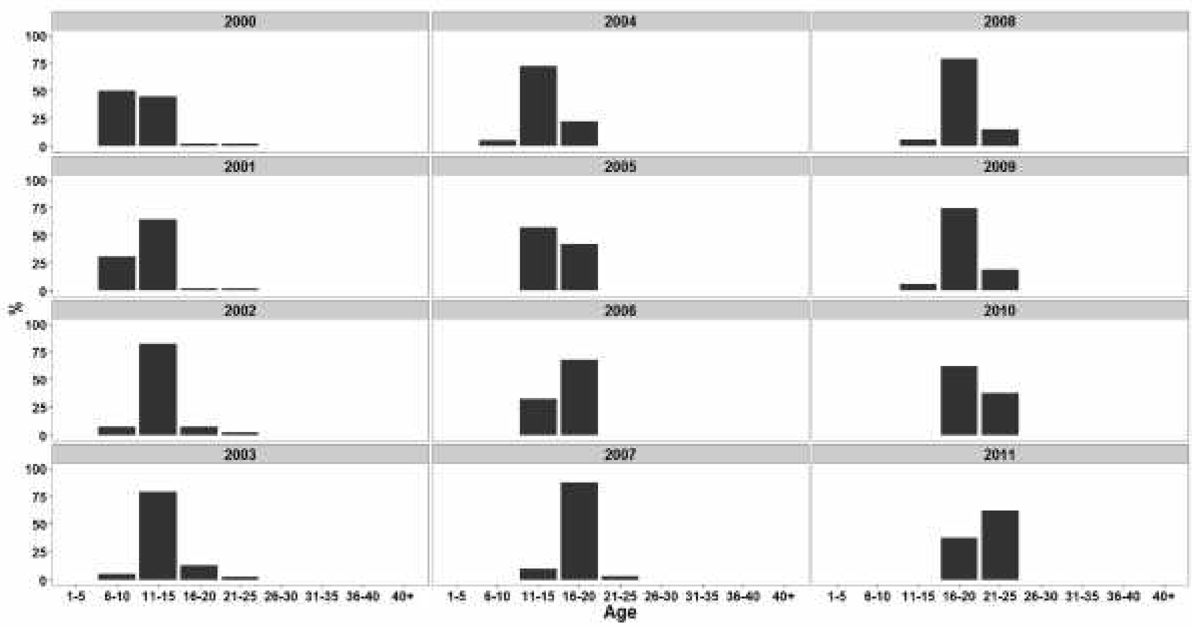


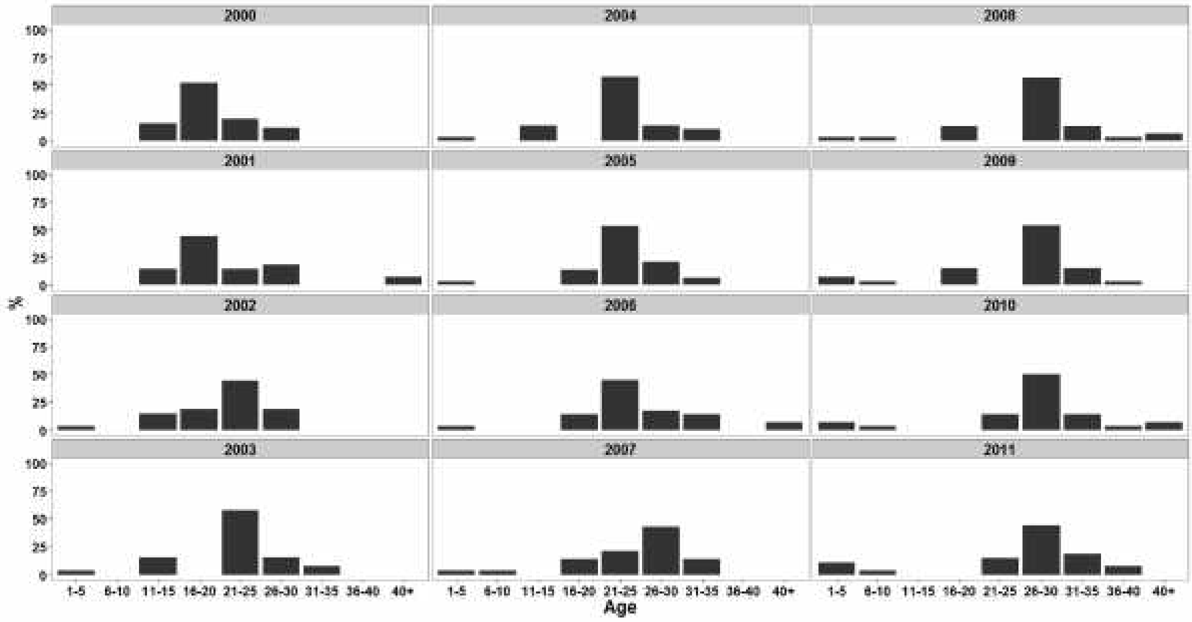
Figure 4.c) Box and whisker plots depicting CPUE by fleet over the period 2000-2013. The red dot represents mean CPUE of new vessels entering the fishery.



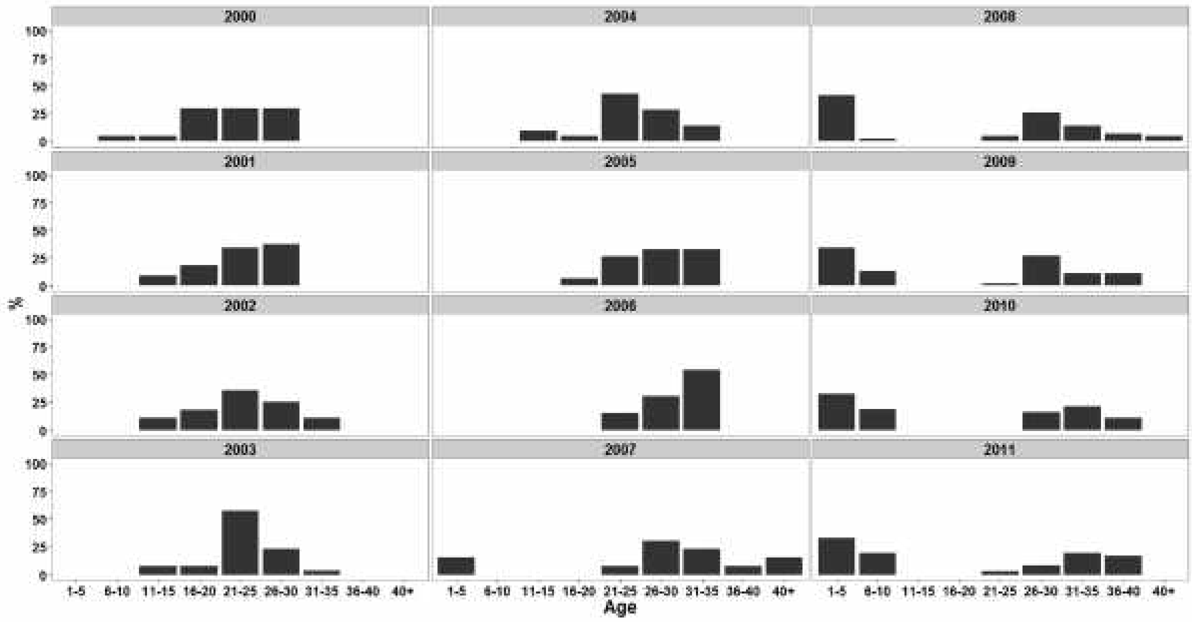
Japanese fleet: % fleet by age by year.



Chinese Taipei: % fleet by age by year.



Korea: % fleet by age by year.



US: % fleet by age by year.

Figure 5. Distribution of vessel age by fleet and year over the period 2000-2011.

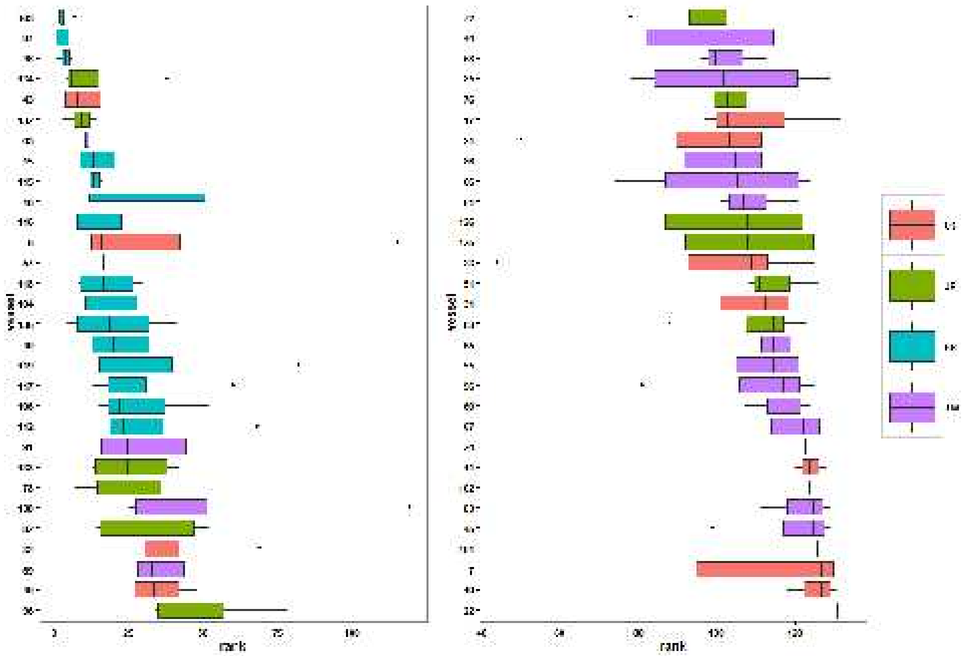


Figure 6. The top thirty (left) and bottom thirty (right) vessels operating within PNA waters. Rankings based on annual total tuna catch rates over the period 2010-2013. Horizontal bar represents the median rank across years, left and right of the box = 75th and 25th percentiles. The four different fleets are colour coded.

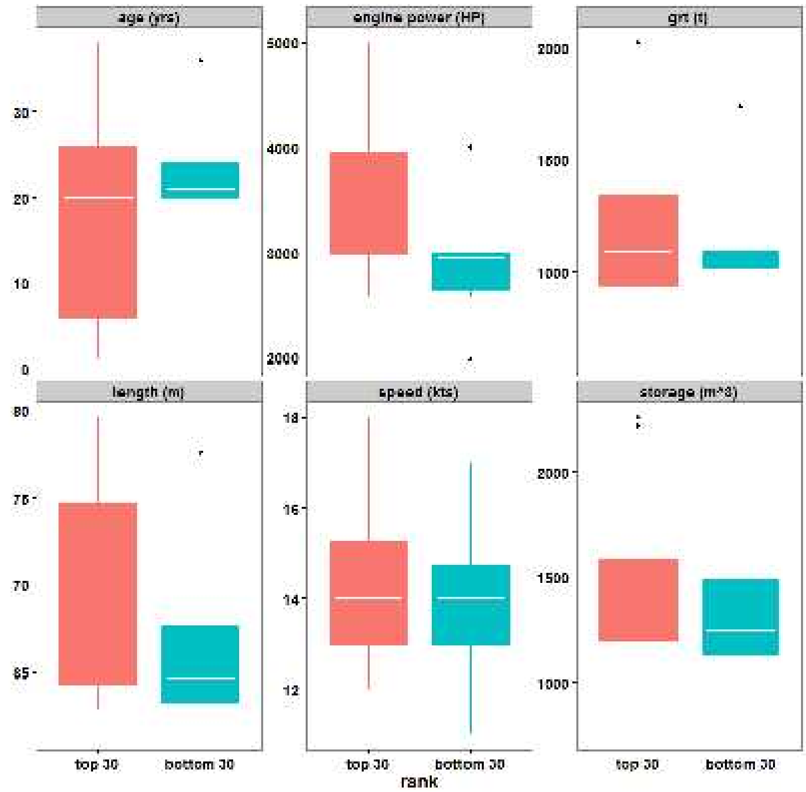


Figure 7. Characteristics of the thirty top (red) and bottom (blue) ranked vessels. Horizontal white line represents the mean characteristic for each group, top and bottom of the box = 75th and 25th percentiles.

Appendix 1. Latest information on patterns of effort reporting within purse seine logbooks

SPC_OFP paper WCPFC-TCC9-2013-18 noted that in recent years, there has been evidence of a change in how purse seine effort was reported in logbooks by some vessels. It was evident that the main change in behaviour was for some vessels to report what was previously considered to be '**a day when a set was not made, but any part of that day was spent searching for fish**' as '**a day in transit**', with the latter not included in the purse seine measure of effort used in the scientific work conducted by the SPC.

Figure A1 updates time series trends in the proportion of logsheet days per month reported as transit days for the four fleets examined within this paper. The assumption made is that we expect 2 days transit from the departure date from port to fishing and 2 days transit before the arrival to port in the majority of fleets, and these days are excluded from the calculations. For the Japanese fleet, 4 transit days are assumed, given the greater distance travelled to fishing grounds from a Japanese home port.

It is clear that rates of reporting of days in transit on logsheets has increased in three of the fleets (JP, KR, TW) over the recent period, from a historical level of <10% of days to 10-30%, dependent upon the fleet. In contrast, the pattern of reporting by the US fleet appears to have remained consistent.

Note that no correction for logsheet coverage has been attempted; proportions are calculated based upon the available logsheets by fleet within the tropical region each month. Note also that the length of the time series differs between fleets, due to varying availability of operational (logsheet) data.

As noted in the OFP paper to TCC, the ramifications of the change in purse seine effort reporting are obvious and include the following:

I. Inconsistency in historical purse seine effort time series (recent effort levels will appear to be lower than reality);
II. Inconsistency in tuna catch per unit CPUE time series trends that used the purse seine day as the unit of effort (recent CPUE levels will appear to be higher than reality);
III. Divergence in the estimated non-transit effort determined from VMS data and the effort reported on logbooks;
IV. Monitoring of purse seine effort for management purposes (effort levels will be lower than reality).

Points I, II and IV will affect the analyses undertaken in the main paper.

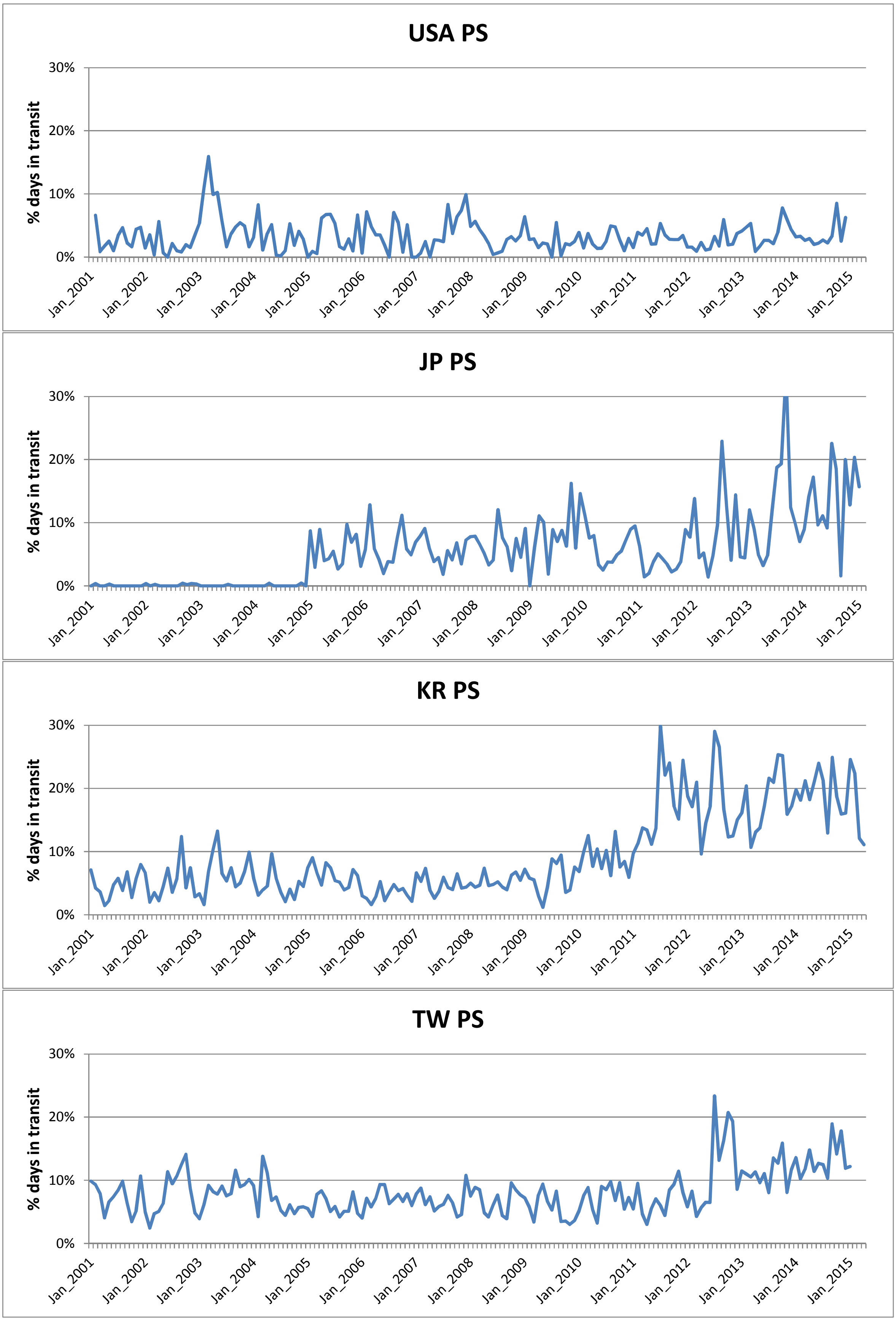


Figure A1. Monthly trends in the proportion of transit days reported on logbooks by purse seine fleet fishing the tropical WCPO, 2001- 2015.