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Preliminary capacity utilization analysis of the WCPO purse seine fleet using Data Envelopment Analysis (DEA)

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Abstract

WCPFC has noted concern over the size of WCPO fleets relative to available fishing opportunities. An example process to identify excess-capacity was presented to SC11. In this paper a more sophisticated analysis is performed to identify relationships between vessel fishing capacity and fishing effort for the WCPO purse seine fleet. First, Data Envelopment Analysis (DEA) is applied to identify potential fleet over capacity. This approach compares each vessel against others to evaluate annual output levels (total tuna catch) relative to the potential output if all vessels performed optimally (the ratio being the level of capacity utilisation) for given inputs (fixed input being vessel age, variable inputs being days fished and number of sets). Second, the potential numbers of vessels within optimally performing fleets are estimated based upon recent effort levels and levels consistent with effort limits in the WCPO, and compared to actual fleet sizes. Finally, to identify factors affecting vessel capacity utilisation and suggest appropriate metrics for fishing capacity, estimates are regressed against vessel characteristics and external factors (e.g. fuel prices).

The results suggest a degree of inefficiency and excess capacity within the WCPO purse seine fleet, which has increased over time. In 2014 the fleet was operating at approximately 60% of its maximum potential, compared to earlier years where on average the fleet was operating at 75%, excluding a time series high of 87% in 2002. The results imply in 2014 that this fleet could have caught 61% more or caught the same with 38% less vessels. The potential number of fully utilised vessels consistent with different effort levels (days fished), was estimated. A total of 160 fully utilised vessels was consistent with overall effort levels in 2014; a total of 192 vessels was consistent with combined WCPFC and PNA effort limits. These represent between 23% and 40% fewer vessels than in 2014.

In terms of factors affecting a vessel's efficiency, vessel length and fuel price were found to be significant covariates. In the case of vessel length, a 10m increase in length resulted in ~8% increase in capacity utilisation. An increase in fuel price by $10 per barrel resulted in a 1% decrease in capacity utilisation. Output in terms of production may be reduced or increased in the purse seine fleet via effort control and/or vessel length restrictions. Therefore this preliminary analysis can assist managers towards any desired potential fleet structural adjustments. However, gaps and inconsistencies in vessel characteristic information hindered analyses.

Therefore, we invite the WCPFC-SC to:
- Note the importance and implications of this research and consider its prioritization within the SC work plan for WCPO purse seine/longliners;
- Note the differences in vessel characteristics from 3 of the regions' databases (in: concluding remarks), and consider approaches to developing pooled expertise and resources to produce a comprehensive, accurate and verified database to support future work in this and related fields.

Introduction

Within the tropical Western and Central Pacific Ocean (WCPO), the level of purse seine fishing is currently managed through effort limits, with additional area and gear management interventions. These effort limits are in terms of fishing days. However the unit of effort production is ultimately the purse seine vessel, as it needs to have a specific number of fishing days during a year to remain profitable. This raises the issue of balancing the capacity of a fleet of vessels to produce effort with the fishing opportunities available over time.

Capacity utilisation (*CU*) is defined as the ratio of the current output (catch) to potential output (for examples see Herrero and Pascoe, 2003). Differences in that potential output can be attributed to short term changes in market conditions (e.g. cost and prices) and stock abundance, but also differences in the technical efficiency (*TE*) of vessels (e.g. skipper/crew skill). It is important to separate out these differences as a fleet of vessels of the same size (e.g. engine horse power, vessel length, etc.) that all fish during the same year will have different catches which may be due to the number of days fished (e.g. *CU*) or their skipper/crew skill (*TE*) (Pascoe *et al.,* 2001a). The *CU* measure may therefore be downward biased because the observed output may not necessarily be produced in a technical efficient manner. This bias can be corrected if the *TE* measure is known and is defined as unbiased capacity utilisation *CU**. The production capacity of a fishing vessel can be measured in 2 ways: a) by its potential output, where production capacity is measured with respect to the output (catch) given a set of inputs (days fishing), and b) on the basis of physical inputs such as the size of the fleet in terms of a vessel number target as a management objective or for example, total horse power (hp) of the fishing fleet.

Potential output, and hence capacity utilization, cannot be estimated with absolute certainty, as that potential output for a given input cannot be observed. Thus capacity must be estimated as a relative term based on a time series of inputs and outputs from other vessels. Data Envelopment Analysis (DEA) is a non-parametric method (see Farrel, 1957; Charnes, Cooper and Rhodes, 1978) which can be used to assess the potential output of a vessel. The method assumes the production function (how outputs change within inputs) is unknown and compares each production unit (vessel) against all other production units (Copper *et al.,* 2000). The approach identifies the "frontier" which represents the most efficient combination of various input and output variables for the vessels in question (Greene, 1993). All else being equal any vessel of similar characteristics should be able to achieve the same. The process is deterministic and produces an efficiency index (input or output) for that vessel which produces single or multiple outputs based on a selection of inputs. It should be stressed that there are other methods to calculate *TE/CU* in fisheries such as Stochastic Production Frontier (SPF) (Aigner, Lovell and Schmidt, 1977), however DEA is preferred when examining multiple species outputs (see Pascoe *et al.,* 2007).

To gain a better insight into fishing capacity, this paper estimates the capacity utilisation and technical efficiency of the purse seine fleet fishing on tropical tunas (skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*) and bigeye tuna (*T. obesus*)) between 20°N - 20°S and 120°E to 150°W (Figure 1). The study uses two methods to assess the recent history of tropical purse seine capacity:

1. TE and unbiased *CU** are estimated using DEA at the individual vessel level to identify potential over capacity within the WCPO purse seine fleet;
2. The potential numbers of vessels within optimally performing fleets are estimated based upon recent effort levels and levels consistent with WCPFC and PNA effort limits in the WCPO, and compared to actual fleet sizes. These are broken down into full time (>=250) and part time (<250 days) vessels;
3. To identify factors affecting vessel capacity utilization and suggest appropriate metrics for fishing capacity, explanatory variables are regressed against the unbiased CU using a Tobit regression.
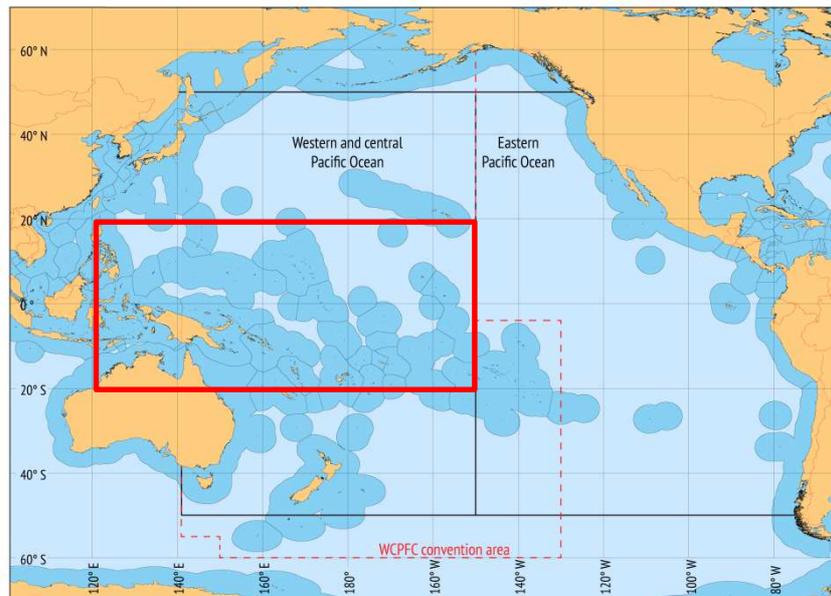

Figure 1.The study area of the WCPO highlighted in red.

Methods

Data

For the period 1993-2014, vessel level purse seine catch and effort data, and vessel characteristic data (from the Pacific Islands Forum Fisheries Agency (FFA) vessel register) were databased for all vessels fishing between 20°N - 20°S and 120°E to 210°W. The fleet register contains information on vessel characteristics such as engine power (hp), storage capacity, gross tonnage, and vessel length. While other vessel-related characteristics were also available, they were either absent for some vessels or did not span the time series, and hence were omitted from the analysis (n=62). Vessels were excluded from the analysis where they fished less than 25 days in a year (n=34). Domestic fleets and vessels fishing in archipelagic waters were also excluded.

Estimated values of biomass for the skipjack, yellowfin and bigeye were obtained from the most recent stock assessments (skipjack: Rice *et al.* 2014; yellowfin: Davies *et al.,* 2014; bigeye: Harley *et al.,* 2014, Figure 2).

To evaluate the value of key outputs, Bangkok prices (US$ per metric tonne) of skipjack and yellowfin tuna (1995-2014) were acquired from the Pacific Islands Forum Fisheries Agency (https://www.ffa.int/contact); bigeye prices were assumed equal to those for yellowfin. To reflect the cost of inputs, US gulf oil prices (US$ per barrel) were obtained from the US energy information administration http://www.eia.gov/petroleum/data.cfm.
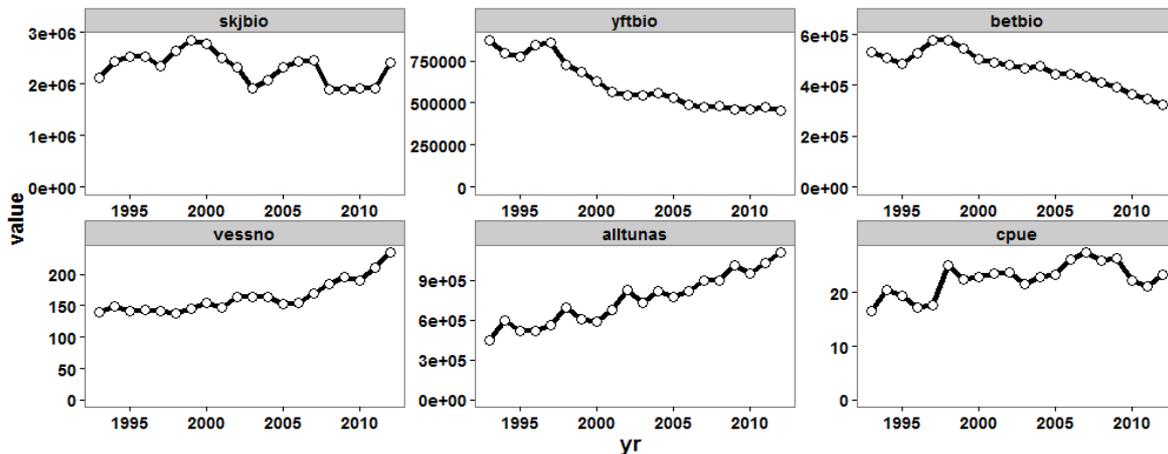

Figure 2.Top left to right: Annual total skipjack, yellowfin and bigeye biomass (mt). Bottom left to right: number of vessels; total tuna catch (mt); and CPUE (total of skipjack, yellowfin and bigeye catch t.day^{-1}) for the vessels used in this analysis. Time series through to 2012 only, representing the last year of the stock assessment.

Data Envelope Analysis (DEA)

An output-oriented DEA-approach is used to measure vessel efficiency. Current input levels are fixed and the model assesses to what extent the output could be increased given those input levels. The DEA method measures efficiency by comparing each individual production unit (fishing vessel) against all other vessels given a set of input and output variables. The algorithm compares observations from those production units relative to a 'production frontier'. The production units situated on the frontier are assigned an efficiency score (θ) of 1, and the subsequent units within that optimal frontier <1 (representing distances from the frontier). For example, an efficiency score of 0.75 implies that a vessel could in theory increase its outputs (that is, its catch per unit effort (CPUE)) by 33% while keeping inputs the same if it performed as well as its best-performing peers. By estimating the Technical Efficiency and Capacity Utilisation components, the unbiased capacity utilisation measure is calculated. See Appendix for detailed equations.

In the analysis, the age of the vessel was used to represent the fixed input, i.e. a vessel's 'capital stock' (the total physical capital existing in the fishery at any moment of time). Based upon Tidd et al. (2015), it is assumed that a higher age represents a comparatively less efficient vessel and a more costly one to run, thus affecting technical efficiency.

When evaluating the variable input levels and the output levels, an assumption may be that fishers will act to maximize their profit (i.e. their rent per trip). Ideally, therefore, analyses should be based upon individual revenue and cost data. As vessel-specific economic data

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were not available, fishing effort (days and number of sets) was used to represent variable input measures (i.e. reflecting inputs dependent upon the level of fishing effort), and total tuna catch the output level. It should be noted that outputs could be highly variable in a multi-species fishery dependent on whether vessel catch weights or revenue are used, especially if there were a mix of high and low valued species. For instance a vessel described as inefficient based on the catch weight maybe be considered efficient based on revenue, or vice versa. To properly model for revenue maximising behaviour, vessel level species and size composition data are needed, since price per unit weight varies by both species and size class. As vessel-specific economic data were not available, catch weight is felt to be a good indicator of maximizing behavior as skipper and crew are paid on the basis of catch in this fishery (Hampton pers. comm.).

While changes in catch may relate to changes in stock biomass levels rather than any change in the productivity of the fleet, here the DEA is calculated on an annual basis. It was not therefore necessary to account for differences in biomass over time under the assumption that vessels were exposed to the same stock in a year. For illustrative purposes the estimates of biomass within the tropical region of the WCPO are shown in Figure 2. Catches, total sets and days fished etc. were aggregated over year at the vessel level.

Technical efficiency (TE)

Technical efficiency is the differences in potential output that can be attributed to the degree to which output can be reached given fixed and variable inputs observed remain stable. It is a scalar where $\theta \geq 1$. Technical efficiency (eqn 1) of a vessel is:

$$TE = \frac{1}{\theta_1}$$

(1)

When calculating technical efficiency within the DEA, assumptions must be made about the 'returns to scale' as this effects the efficiency score θ. Returns to scale influences how outputs change within an increase in input. For example if constant returns to scale (CRS) model is assumed, a doubling of input will lead to a doubling of output. If variable returns to scale (VRS) are assumed, the change in output can be greater, equal to, or less than the change in input (this is the general approach adopted in fisheries). CRS is said to overestimate capacity output and underestimate capacity utilization while VRS is generally a more conservative estimate of capacity output and of capacity utilization (see Cooper *et al.,* 2000).

Technical efficiency (eqn 1) of a vessel can be calculated as the ratio of observed output relative to achievable output under a TE_{crs} assumption and then TE_{vrs} to calculate scale efficiency. Scale efficiency (*SE*; eqn 2) is the degree to which a production unit is operating at optimal scale. This ratio is less ≤ 1 (see appendices for detailed equations):

$$SE = \frac{TEcrs}{TEvrs}$$

(2)

Capacity utilization (CU)

When calculating the technical efficiency, we assume that the variable inputs (fishing days, etc.) remain at their observed level. If we assume that a vessel can adjust its variable inputs (e.g. fishing days) to increase output, while fixed inputs like vessel size or engine power remain constant, we can calculate the capacity utilization as:

$$CU = \frac{1}{\theta_2}$$ (3)

where $\theta \geq 1$.

This capacity utilization measure may be negatively biased because the observed output may not necessarily be produced in a technically efficient manner (as identified in the calculation of TE above). To correct for this bias, the results of the technical efficient model and the capacity utilization model can be combined. The unbiased capital utilization measure can be calculated as:

$$CU^* = \frac{CU}{TE}$$ (4)

The DEA linear programming model developed in R software benchmarking (Bogetoft and Otto, 2011) was used to implement the above analysis.

Estimation of fleet capacity

The DEA analysis identifies the relative performance of vessels to the 'optimally performing' vessel within a year. Noting that vessels that are removed from a fleet over time are likely the least efficient vessels, and that new vessels are likely to be better performing, over time the fleet will become more 'optimal'. Therefore we use the outputs of the DEA to examine the likely inputs/outputs for a fleet of fully effective vessels, and hence identify potential capacity levels. We define each existing vessel as operating full time (>=250 days) or part time (< 250 days, representing either part time fishers, or i.e. those vessels operating both inside and outside the WCPO within a year). We estimate the total number of optimally performing vessels consistent with annual effort levels, and estimate the number of full- and part-time vessel equivalents.

For each year (1993-2014) the average unbiased capacity utilization is used to identify annual fleet sizes and resulting effort/species catches where that 'optimal performing' fleet achieved the total annual fishing days in that year. The number of days fished in that year by a vessel is scaled by its unbiased capacity utilization (days fished/CU*). The resulting scaled days of vessels with the highest to lowest CU* are removed from the effort limits sequentially until the day limit is reached, and the number of optimally performing vessels within that fleet then identified.

Noting that the DEA is performed on a sub-set of total tropical WCPO effort, given that vessels fishing less than 25 days are excluded, the number of vessels within an optimally performing fleet consistent with two alternative effort levels is also examined:

1. Where effort was 49,617 days (corresponding to the effort fished within latitudes 20°N to 20°S within waters under national jurisdiction and in international waters in the WCPFC-CA, excluding Indonesia and Philippines fleets and archipelagic waters; see WCPFC12-2015-IP02_rev. 1); and
2. Where effort was 58,021 days, equivalent to the total tropical purse seine effort limits defined under WCPFC management measures and through the PNA purse seine Vessel Day Scheme, and excluding archipelagic waters (see Pilling and Harley, 2015).

Characteristics influencing vessel performance - Tobit analysis

To explain differences in the output efficiency scores ($CU*$) from the DEA analysis and to ascertain what factors may affect unbiased capacity utilization, a censored regression (Tobit model; Tobin, 1958) was chosen. This type of model can be used to estimate linear relationships in cases where values are 'censored' at a threshold value (here the threshold is 1; i.e. efficiency scores values ranging between 0 and 1). As some species are not always present in the catch, this approach allowed the capacity output to be at 0. Within the regression, the efficiency scores were the dependent variables and a variety of variables that could explain the deviations between vessels were examined as regressors. Those variables were selected ensuring they were as far as possible not correlated with inputs into the DEA; most vessel characteristics were correlated and had a Pearson's correlation coefficient greater than 0.70 (p <0.001). Resulting factors included price by species, vessel length, fuel price, number of vessels in the fleet within a year, year and quarter. Vessel engine horsepower (hp) and tonnage (GRT) were excluded from the analysis as they were highly correlated with vessel length. Due to the number of correlated variables the regression was limited to 3 variables. The unbiased capacity efficiency model for vessel i is therefore:

$$CU*_I = \beta_0 + \beta_1 Length + \beta_2 fuel + \beta_3 number\_vessels \quad\quad\quad (5)$$

Results

Results of the DEA

The results from the DEA are presented in Figure 3. The scores for unbiased capacity utilization ($CU*$), Technical Efficiency (TE) and Capacity Utilization (CU), averaged across vessels, show a general decline across the time period, during which vessel numbers increased (see Figure 2). The pattern suggests a degree of inefficiency within the tropical purse seine fleet, and that excess capacity (1-$CU*$, and defined as a short term occurrence whereby fishers produce less than under normal operating conditions because of changes in market conditions (e.g. cost and prices) and stock abundance) is evident. For example, $CU*$ in 1994 is at 0.75, and falls to 0.62 in 2014, noting a time series high of 0.87 in 2002. The results imply in 2014 that this fleet could have caught 61% (1/0.62) more or caught the same with 38% less vessels (1-0.62). TE and CU scores are also dissimilar, suggesting a degree of inefficiency. Scale efficiency (1 being where the vessel is operating optimally) is generally high, at around 0.9, indicating that fishing performance is close to optimal.
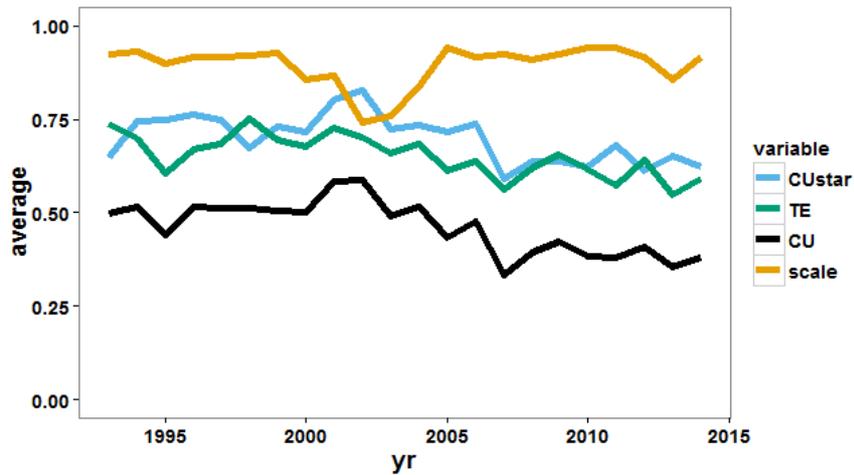
Figure 3. Results of the multi-output DEA analysis. Average annual, unbiased capacity utilization = CUstar (CU*), technical efficiency = TE, capacity utilization = CU and scale efficiency.

Capacity utilization (*CU**) and technical efficiency both declined with increasing vessel age (Figure 4), i.e. a fleet increasingly comprised of older purse seiners will show a reduction in fishing efficiency and technically efficiency, while replacement with newer vessels will increase technical and fishing efficiency. A 25% reduction in capacity utilization between vessels from age 1 to 40 results in a 66% reduction in capacity output that it could potentially achieve (i.e. a vessel capacity output (1/0.75) - (1/0.5) what it could achieve when new) is estimated. However, there is only a marginal decline in efficiency between age 1 and age 20. Technical efficiency shows a greater decline over the first 20 years, but there is large variability in technical efficiency between vessels of the same age.
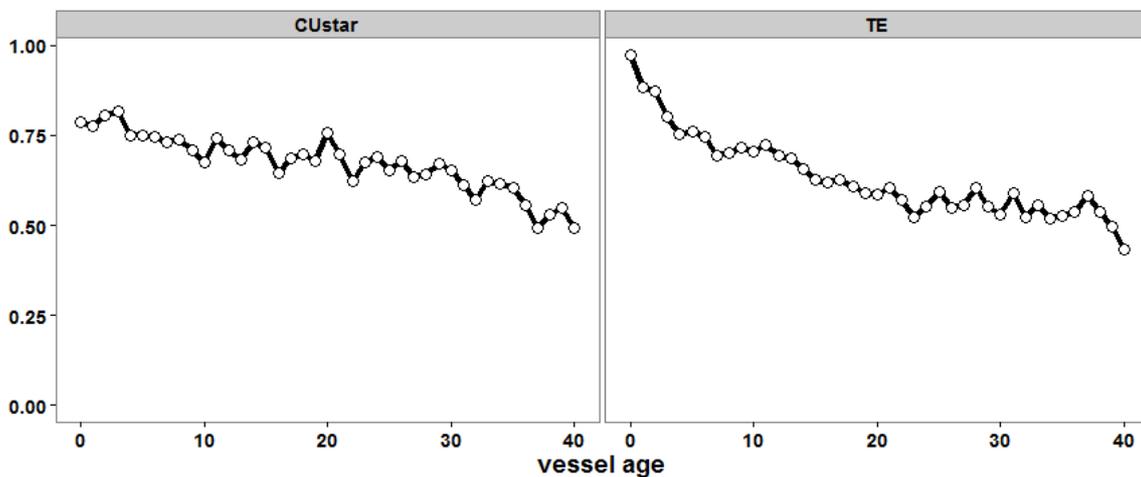

Figure 4. Average annual unbiased capacity utilization (*CU*star; *CU**) and technical efficiency (*TE*) versus vessel age.

Estimation of fleet capacity

To examine the likely inputs/outputs for a fleet of fully effective vessels, and hence identify potential capacity levels, the results of the DEA were used to identify annual fleet sizes and resulting effort/species catches where that 'optimal performing' fleet achieved a target total

of annual fishing days or species catch (Table 1). This was estimated for the effort and catch in each year (1993-2014) for the vessels examined (which excluded vessels fishing less than 25 days in a year), as well as for the two set effort levels: a) 49,617 days and b) 58,021 days.

In the examined tropical WCPO region in 2014, 45,911 fishing days were fished by the 243 vessels used within this analysis. Based upon the unbiased capacity utilization (*CU**), an optimally performing fleet of 147 tropical purse seine vessels would have utilized the same number of days (Table 1) and caught 21% more skipjack compared to the actual catch achieved, along with 24% more bigeye and 19% yellowfin respectively.

Noting that this analysis was based upon a subset of vessels (due to the removal of vessels fishing less than 25 days and where vessel characteristics were missing), extrapolating the analysis to the estimate of total fishing days within the WCPO in 2014 (49,617 days; see Table 1; row 2014a) 160 optimally performing vessels would achieve that effort, catching 24% more skipjack compared to the actual catch achieved and 30% more bigeye and 23% more yellowfin respectively.

Effort equivalent to current WCPFC and PNA limits (58,021 days) is consistent with 192 optimally performing vessels in the tropical WCPO (catching 32% more skipjack, 36% more bigeye and 36% more yellowfin respectively).

Examining key vessel characteristics of the fully utilized vessels, average engine horse power, grt, length and age have all increased over the period 1993-2014 (Figure 5), along with fleet size and catch per unit effort (Figure 2). In contrast, *CU** and *TE* have decreased (Figure 3) along with stock biomass (1993-2012 only; Figure 2).

Using the definition of full (>=250 days) and part time (<250 days) vessels, the number of fully utilized vessels (i.e. vessels assumed to be performing maximally at the frontier, with a value of 1) operating within a particular year was divided into those two categories (Table 1; Figure 6). Generally, full time vessels had higher unbiased capacity utilization (*CU**) levels than part time vessels. The number of fully utilized full time vessels has generally increased over time, while the number of part time vessels has fluctuated over the period, but sharply increased since 2010.
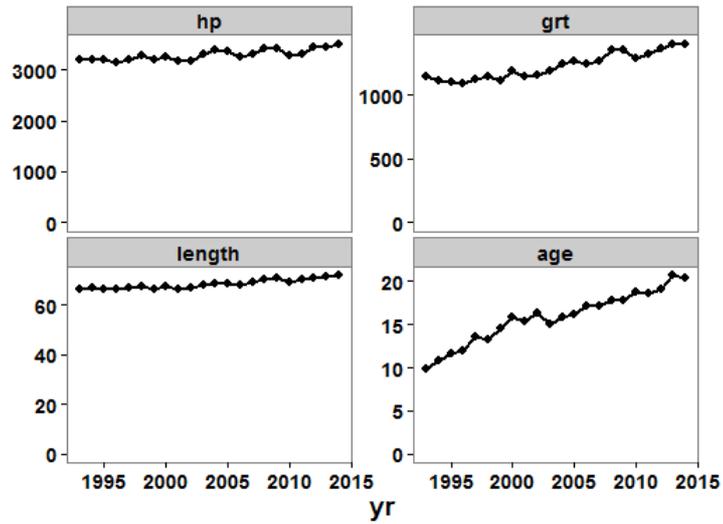
Figure 5. Vessel characteristics of fully utilized purse seine fleet (147 vessels), average, hp=horse power, grt=gross registered tonnage, length=length of vessel (m), and age.
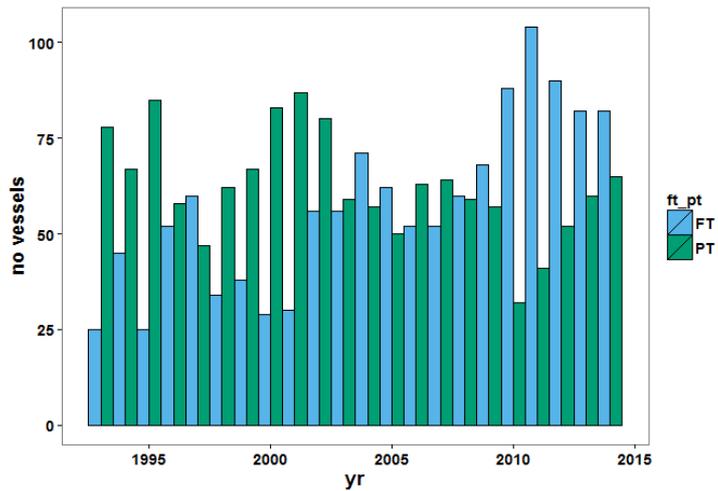

Figure 6. Number of fully utilized vessels (Table 1, column 'vessno') working FT=full time and PT=part time.

Table 1. Number of fully utilized vessels from DEA unbiased capacity utilization (CU*) consistent with defined total fishing days (day depicted by a *), and corresponding % increase in catch at full capacity relative to the actual catch achieved in that year. Days* for years 2010-2014 represent effort (days) of the fleet examined in the analysis (see Figure 2). 2014a represents total WCPO effort levels estimated for 2014. 2014b represents agreed total WCPO and PNA effort limits. Full time* and Part time* represent the number of vessels within the fleet examined in the analysis defined as full time (>=250 days fishing) and part time.

yr	vessno	days*	skj	bet	yft	Full time*	Part time*
2010	120	42128	24	16	22	89	102
2011	145	48151	19	17	20	106	106
2012	142	47250	24	22	20	90	147
2013	142	40831	14	14	15	82	135
2014	147	45911	21	24	19	82	161
2014a	160	49617	24	30	23		
2014b	192	58021	32	36	36		

Characteristics influencing vessel performance

Examining those factors (vessel characteristics, external parameters) that could explain vessel-specific differences in unbiased capacity utilization, and noting that limited un-correlated vessel characteristic information was available, the best model was chosen based on the lowest AIC score with that particular vessel characteristic (Table 2). Vessel length and fuel price were highly significant ($p < 0.001$). In contrast, the total number of vessels in a particular year (a proxy for a 'crowding' effect, representing potentially increasing competition between vessels) was not significant at the 5% level. The marginal effects (the expected change in unbiased capacity utilization with a change in the individual explanatory variable) indicated that if vessel length was increased by 10 meters the corresponding $CU*$ would increase by 8%, while an increase in fuel price by $10 would result in a 1% decrease in $CU*$.

Table 2. Results from Tobit analysis relating unbiased capacity utilization to vessel characteristics and external factors. Log(scale) ensures a positive outcome (see Appendix)

	Estimate	Std. Error	z value		Marginal effects
(Intercept)	0.286	0.0557	5.139	***	0.2458
Vessel length	0.00896	0.0005	16.443	***	0.0076
Fuel price	-0.0012	0.0003	-3.791	***	-0.00099
Total vessel numbers	-0.0006	0.0003	-1.862	.	-0.00052
Log(scale)	-1.2269	0.0129	-94.76	***	

Statistical significance at '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1.

Discussion

While the Western and Central Pacific Ocean fish stock biomass levels have declined (Figure 2) it is apparent purse seine effort has not (Williams and Terawasi, 2015). This 'can' lead to over-capacity, and a race to increase economic return, with investment in bigger and more powerful vessels to achieve this.

The unbiased capacity utilization scores (*CU**) for the tropical purse seine fishery suggest that throughout the time period the fleet on average has been underutilized, i.e. they are not performing at optimum. The excess capacity in the fleet as demonstrated by the calculated capacity outputs in each year (Table 1) suggesting that in 2014 the fleet was operating at around 60% of its maximum, compared to earlier years where on average the fleet was operating at 75% (Figure 3). To some extent it is important to have excess capacity in the fleet due to operational reasons i.e. maintenance issues such as breakdowns or engine refits, and/or changes in weather (e.g. *El Niño* and *La Niña* events) so that whereas in some years there is excess, in others there is just enough. Observations from the early years show that excess capacity was present in a younger fleet (average fleet age was lower). Reduced technical efficiency over time is concurrent with increases in average fleet age, and may reflect higher maintenance costs and repair periods (Figure 4; Figure 5). Eggert (2001) similarly found that vessel age had a significant impact on TE. Nevertheless Figure 2 would suggest that combined species catch rates have improved over time even with an average fleet vessel age greater than 20 years old, suggesting that the relationship is weak, or that fishers may be finding other ways to improve by implementing new technology such as advanced fish-finding devices (see Tidd *et al.,* 2015). Keeping up with such technologies, i.e. "learning by doing" can however result in technical inefficiencies in the fleet (Squires and Kirkley, 1999; Squires and Reid, 2004).

Examining the capacity of fleets relative to existing effort levels and effort limits (Table 1) a fleet of fully efficient vessels would represent between 40 and 23% fewer vessels than present in 2014 (e.g. 1-(WCPO number of vessels/actual number of vessels) = 1-(160/243)). This suggests that the fleet is currently utilising less effort than it potentially could if operating at a maximum level (dependent of course on a number of factors such as stock size etc.) and as such the catch is less than what it could be. While the number of full time vessels shows no clear trend over time (Figure 1, Figure 6), the increasing trend in part time vessel numbers will reduce the days fished per vessels and hence result in a lower *CU**.

Examining potentially improved capacity metrics beyond vessel numbers or a fishing day, and noting that most of the purse seine fleet examined within the analysis was within the 70-80m length category, length still had an effect on capacity close to unity. Therefore, a 1m change in length approximates to a 1% increase in capacity utilization. The length of a purse seiner is important as it is related to its grt and engine hp. The results suggest that purse seine fleet output in terms of production (catch) could be controlled via effort control and/or vessel length restrictions, potentially in some composite form (e.g. vessel length, grt and hp). This approach is comparable to the EU's Vessel Capacity Units (VCU) system, where if 1 boat leaves the fishery it must not be replaced with a vessel of greater VCU [overall length × breadth of vessel (both in m) + engine power (kW) × 0.45] (see Pascoe *et al.,* 2001b)). However it would be necessary to continue to document all technological changes

to a vessel as any adoption of capacity and effort limitations may still increase due to the increase in catchability arising from new technologies.

Concluding remarks and next steps

This paper presents an initial examination of capacity 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). Further, information on costs and revenues would complement such an analysis but we note this comes with data confidentiality issues.

While databases available to SPC contain fields for vessel characteristics of interest, there were clear information gaps (e.g. freezer or storage capacity, vessel breadth, 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. As an example comparison, the information contained within three vessel characteristics databases (WCPFC, PNA and FFA registers) for vessel storage capacity and GRT show considerable differences (Table 3) for three purse seine vessels.

Table 3. Vessel characteristic information (vessel storage capacity (VSC, m³) and GRT (tonnes)) for three purse seine vessels contained within three available regional databases.

Vessel	PNA VDS		WCPFC		FFA	
	VSC	GRT	VSC	GRT	VSC	GRT
1	1282	850	1282	1339	1395	1339
2	1906	1205	1300	1012	Absent	1012
3	1485	1000	1591	1179	1738	1179

SC11 noted that fleet capacity analyses are an important contribution to the development of a purse seine capacity management scheme for the WCPFC and supported further work to identify patterns of participation by full-time and part-time vessels within the fishery. Also noted was the need to relate both participation and effort creep (Tidd *et al.,* 2015; see also Tidd and Pilling, 2016 MI-WP-08) to vessel characteristics and to assist the Commission when considering measures on fleet capacity.

Therefore, we invite the WCPFC-SC to:
- Note the importance and implications of this research and consider its prioritization within the SC work plan for WCPO purse seine/longliners;
- Note the differences in vessel characteristics from 3 of the regions' databases (in: concluding remarks), and consider approaches to developing pooled expertise and resources to produce a comprehensive accurate and verified database to support future work in this and related fields.

Acknowledgements

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Appendix: Equations

Technical efficiency (TE)

$Max\theta_1$

subject to :

$$\sum z_i y_{im} \geq \theta_1 y_{jm} \qquad \forall m$$

$$\sum z_i x_{in} \leq x_{jn} \qquad n \in F_x \cup V_x$$

$$\sum z_i = 1$$

$$z_i \geq 0 \quad \forall i, \qquad\qquad\qquad\qquad\qquad\qquad\qquad\text{(A1)}$$

Where θ_i is the capacity score of vessel i, y_{jm} is the amount of output m produced by vessel j, F_x and V_x are the sets of fixed and variable inputs (x) respectively, x_{jn} is the amount of input n used by vessel j where (z_i) weighting factors measure the optimal linear combination of peers (frontier observations) that give the optimal performance of the unit in question.

By including the constraint $\sum z_i = 1$, we assume that the returns to scale are variable (VRS), however if the equation is changed to $\sum z_i < 1$ it would be assumed as decreasing returns to scale (DRS) and if $\sum z_i > 1$ then increasing returns to scale (IRS) while CRS is equal to constant returns to scale, double inputs and outputs are doubled.

The technical efficiency (TE) is calculated as:

$$TE = \frac{1}{\theta_1} \qquad\qquad\qquad\qquad\qquad\qquad\qquad\text{(A2)}$$

Capacity utilization (CU)

While calculating the technical efficiency, we assume that the variable inputs (fishing days, etc) remain at their observed level. If we assume that a vessel can adjust its variable inputs (e.g. fishing days) to increase output, while fixed inputs like vessel size or engine power remain constant, we can calculate the capacity utilization. The model is then changed to:

$Max \theta_2$

subject to :

$$\sum z_i y_{im} \geq \theta_2 y_{jm} \qquad \forall m$$

$$\sum z_i x_{in} \leq x_{jn} \qquad n \in F_x$$

$$\sum z_i x_{in} \leq \lambda_{jn} x_{jn} \qquad n \in V_x$$

$$\sum z_i = 1$$

$$z_i \geq 0 \quad \forall i, \qquad \lambda_{jn} \geq 0 \quad \forall j,n \tag{A3}$$

Where λ_{jn} is the input utilization rate by vessel j of input n.

The capacity utilization can be calculated as:

$$CU = \frac{1}{\theta_2} \tag{A4}$$

This capacity utilization measure may be negatively biased because the observed output may not necessarily be produced in a technically efficient manner (as identified in the calculation of TE above). To correct for this bias, the results of the technical efficient model and the capacity utilization model can be combined. The unbiased capital utilization measure can be calculated as:

$$CU^* = \frac{CU}{TE} \tag{A5}$$

Where scale efficiency is degree to which production unit is operating at optimal scale i.e. TE_{crs} constant returns to scale relative to TE_{vrs} variable returns to scale equation. This ratio is ≤1 and gives an indication of moving to optimum scale.

$$SE = \frac{TEcrs}{TEvrs} \tag{A6}$$

The Tobit model is as follows for observation i:

$$y_i^* = \beta' x_i + \varepsilon_i$$
$$y_i = y_i^* \; if \; y_i^* > 0 \; \text{and} \tag{A7-9}$$
$$y_i = 0 \, \text{otherwise}$$

where ε_i is the error term and x_i and β_i are vectors of explanatory variables and unknown parameters, respectively. The y_i^* is a latent variable (inferred through the model) and y is the inefficiency score. The likelihood function (L) is maximized in order to solve β_i. During the maximization step the routine uses a log scale to ensure a positive outcome instead of

modelling on the original scale in order to ensure a positive estimation on the limited response variable.