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Developing a bioeconomic model for WCPO tuna fisheries to assess potential economic outcomes under alternative management options

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C H Kirchner[1], A M Berger[1], R Banks[2], C Reid[3], J Hampton[1], G Pilling[1], and S Harley[1]

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[1] Oceanic Fisheries Programme, SPC, B.P. D5, 98848 Noumea Cedex, New Caledonia
[2] Poseidon, Aquatic Management (Pty) Ltd, Port Douglas, Australia
[3] Pacific Islands Forum Fisheries Agency, PO Box 629, Honiara, Solomon Islands

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Executive Summary

Globally, the value of including economic information in the management of fisheries is being increasingly recognized. For most fisheries, the long-term maximum economic yield (MEY) that can be achieved occurs at higher biomass levels than the long-term maximum sustainable yield (MSY), therefore providing a buffer against scientific uncertainties to help ensure ecological sustainability of the resource as well as providing higher economic returns.

The purpose of this paper is to present a preliminary bioeconomic model for WCPO tuna fisheries. The model will allow both an examination of management limits that maximize a specified economic outcome (e.g., fleet profitability), and a comparative analysis of economic outcomes by gear for any set of management options. Also, the model allows for the analysis of biological consequences of fishery conditions that achieve various economic outcomes.

The 2014 MULTIFAN-CL stock assessments for bigeye, skipjack and yellowfin tunas and the 2012 assessment for south Pacific albacore are used as the basis of the biological and fishery dynamics. For the economic component, the net present value (NPV) of profits is calculated over a 20-year time horizon in order to provide a measure of the relative economic outcomes of different management options. In the projections, effort for four defined fisheries – tropical longline, southern longline, and associated (fish aggregation device and floating log sets) and unassociated (free-school sets) purse seine – was varied individually between +25% and -50% of 2012 levels. Future recruitment was assumed to follow the long-term spawner-recruitment relationship. Some examples of the types of patterns found in these preliminary results include:

- Catch revenue can be expected to fall under 2012 effort levels, with southern and tropical longline fleets becoming unprofitable. Profits are predicted to exist only in the purse seine fishery;
- There is scope for increasing profits through reductions in effort. Increased stock sizes are expected to increase profits through increased catch per unit effort, but this conclusion is based on standard catch / abundance relationships and developing alternative models of the relationship between abundance and fishing success will be crucial to determining robustness of results; and
- Positively, the abundance of all four species is predicted to increase under scenarios that maximize NPV of profits.

As the bioeconomic model is further developed, there are many applications and extensions that could be possible, e.g.:

- Economic evaluation of the trade-offs between FAD and free school fishing approaches within the purse seine fishery;

- The incorporation of additional economic strata so that the model reflects not just the fishing fleets but other economic units such as coastal states within whose EEZs fishing activity takes place and who gain economic benefits from the selling of access rights and/or on-shore processing and other related industries.
- The inclusion of other economically important species for which stock assessments are available.

We invite SC10 to consider the inclusion of this work in the scientific research plan of the Committee, and to encourage industry collaboration to ensure the most accurate economic information is available for inclusion.

1. Introduction

Catches of tuna taken in the Western Central Pacific Ocean (WCPO) account for 60% of global tuna supply (Figure 1) (Hamilton et al., 2011). Annually, about 2.6 million tonnes of tuna are landed (Figure 2) and in 2012 the estimated delivered value of this catch was about US$7.2 billion (Williams and Terawasi, 2013), making it one of the world's most valuable natural living resources. The Western and Central Pacific Fisheries Commission (WCPFC) is the international authority responsible for the sustainable utilization of these tuna resources through the setting of Conservation and Management Measures (CMMs) (Langley et al. 2008). Tuna are exploited mostly by purse-seine, longline and pole-and-line vessels. Most of the purse-seine effort is concentrated within the exclusive economic zones (EEZs) of the tropical (20°N to 20°S) Pacific Island countries and expended mostly by distant-water fleets from the Republic of Korea, Chinese Taipei, Japan, USA, Philippines, as well as some vessels flagged by Pacific Island countries, including Papua New Guinea, Republic of the Marshall Islands, Federated States of Micronesia, Kiribati and Solomon Islands. In the longline fishery, Chinese, Chinese Taipei, Japanese and Korean fleets now take the highest catch (WCPFC, 2013a), but Pacific Island nations, including Fiji, Samoa, New Caledonia and French Polynesia, are also actively longline fishing. The longline fishery is further divided into a tropical longline fishery that targets mainly bigeye and yellowfin tuna (for the *sashimi* market) with some albacore bycatch, whereas the southern longline fishery targets albacore (for the canned tuna market).

Purse-seiners primarily target skipjack (*Katsuwonus pelamis*) by setting around a Fish Aggregating Device (FAD) or on free-swimming schools. Free-swimming schools of large yellowfin (*Thunnus albacares*) are also targeted. The catch taken from FAD sets comprises higher proportions of small skipjack, yellowfin and bigeye tuna (*T. obesus*) than those taken from free-schools sets (Langley et al. 2008). The latest catch estimates are available for 2013 (Williams and Terawasi, 2014). The purse-seine fishery as a whole caught 1.9 million tonnes (77% skipjack, 19% yellowfin, 4% bigeye) in 2013. The longline fishery, which targets either bigeye and yellowfin tuna in tropical waters, or albacore tuna (*T. alalunga*) in sub-tropical waters caught 303 thousand tonnes (33% albacore, 22% yellowfin, 21% bigeye and 25% other species). The pole-and-line fishery, which has been declining for many years, caught about 221 thousand tonnes (73% skipjack, 15% north Pacific albacore, 10% yellowfin and 2% bigeye), while the catch taken by troll gear and a variety of artisanal gears, mostly in eastern Indonesia and the Philippines, amounted to 279 thousand tonnes (59% skipjack, 33% yellowfin, 3% bigeye and 2% albacore) in 2013.

The purse seine fishery is currently managed by restricting fishing days to those fished in 2010, and through restricting the use of FADs through time-area closures of either 3 or 4 months (WCPFC, 2013a) or limiting the number of FAD sets. The FAD closure is in place primarily to decrease catches of small-sized bigeye in the purse seine fishery. Bigeye and yellowfin tuna catch limits have also been set for the longline fishery (WCPFC, 2013b). Management of the Pacific tuna fishery is complex, needing not only to address individual stock-specific sustainability issues but also interactions between fleets. For example, CPUE and revenue in the longline fishery could potentially be improved by reducing catches of yellowfin and bigeye by purse seine FAD sets, but this would possibly come at the cost of reduced skipjack catches (Langley et al. 2008). The estimated delivered value purse seine catches in 2013 was US$ 4 billion, whereas the longline and pole-and-line delivered value was lower at US$ 1.9 billion and US$ 0.6 billion, respectively (Williams and Terawasi, 2014). This leads to the question of tradeoffs; can a suitable balance be found that provides optimal ecological and economic exploitation levels between the different tuna species and the purse-seine and longline fisheries?

Globally, the value of including economic information in the management of fisheries has slowly been recognized and implemented in some countries (e.g., Australia; Dichmont et al. 2010). An account of the Australian success of implementing a maximum economic yield (MEY)-based proxy as a target reference point in their fisheries management has been discussed in Smith et al. (2013). Generally, the long-term MEY occurs at higher biomass levels than the long-term maximum sustainable yield (MSY), therefore providing a buffer against scientific and implementation uncertainties to help ensure ecological sustainability of the resource (Grafton et al., 2007).

There have been several studies that have documented the economic implications (vessel profitability) of alternative fishing effort levels in the WCPO, each with a unique set of model assumptions and methodological approaches. Bertignac et al. (2000) was the first published attempt at identifying conditions that might maximize resource rent from the WCPO tuna fisheries, and this study concluded that increased returns could be gained by decreasing the size of all fleets, with the possible exception of the tuna longline fleet based within Pacific Island Countries. Reid et al. (2006) confirmed this by showing that a 30% reduction of effort across all fleets would result in a possible overall increase in rent, but this would be unequal across different gear types and jurisdictions. Hannesson and Kennedy (2007) concluded that considerable increases in rent could be obtained if purse seine effort was reduced (in their words: “drastically”) for the benefit of the longline fishery that catches the more valuable product. Also, Kompas et al. (2010) published a biological and economic justification for decreasing fishing effort for the purse seine, frozen longline and fresh longline fisheries by 44%, 40% and 51%, respectively, for at least the 2008-2012 period to double the rent received from the WCPO tuna resource. Sumaila (2013) illustrated that significant gains could be made by reducing the use of FADs in the purse-seine fishery, because the longline fishery would then gain from the higher availability of large yellowfin and bigeye tuna.

This paper presents a preliminary bioeconomic model currently under development to allow for both an examination of management limits that maximize a specified economic outcome (e.g., fleet profitability) and a comparative analysis of economic outcomes by gear category under a given set of management options. The net present value (NPV) of profits calculated over 20 years was evaluated under different combinations of effort in purse seine and longline fisheries in order to provide a measure of the relative economic outcomes of different managed effort levels. Because the model is currently under development, the results presented in this paper are intended to illustrate the types of the analysis that can be undertaken using this modelling approach. The potential to further develop the model to assess the impact of management limits on different fleets and areas (e.g., within the EEZs and international waters) is also currently being assessed.

2. Methods and data assimilations

2.1 Biological model

Established stock assessment methods (MULTIFAN-CL, Fournier et al., 1998) are used by the Secretariat of the Pacific Community (SPC) to evaluate stock status of the main tuna species (skipjack, yellowfin, bigeye and albacore tuna) in the Western and Central Pacific Ocean (WCPO). The model is age and spatially structured. Catch, effort, size composition, and tagging data are used in the model and are grouped into fisheries. The assessments are run over quarterly time periods for skipjack, yellowfin and bigeye, and annual time periods for albacore. The last assessment for albacore was done in 2012 (Hoyle et al. 2012) and the other three tuna species were assessed in 2014 (skipjack – Rice et al. 2014; bigeye – Harley et al. 2014, yellowfin – Davies et al. 2014). The albacore, skipjack and yellowfin stocks remain above the spawning biomass at MSY (B_{MSY}) (Table 1), and are therefore considered not to be overfished. However, the bigeye stock is estimated to be overfished with recent spawning potential estimated to be 0.16 of unfished levels, which is lower than the agreed limit reference point of 0.2. Also, recent levels of bigeye fishing mortality are estimated to be 57% higher than the fishing mortality at MSY (Figure 3).

2.2 Economic model

To illustrate the economic valuation of the tropical tuna fishery in the WCPO, different levels of effort need to be appraised to determine an on-average economically optimal effort structure for longline and purse-seine fisheries over a certain time period for example 20 years. To explore this, projections using results from the latest stock assessments for each of the four species (albacore, bigeye, skipjack, and yellowfin) were conducted. According to the underlying population dynamics of the projection model, as the stock of the individual species increases, more catch is obtained for the same levels of effort and larger sizes of fish will be present on average in the catch. Hence, in this scenario the cost per unit of catch would decrease and the revenue would increase as the price of fish is size-dependent and larger fish typically fetch a higher price. If the extent of the CPUE increase for the purse-seine fishery is disproportionately smaller than the increase in stock size (Reid et al. 2006), i.e., a hyper-stable response, the benefits from e.g. effort reductions are likely to be less than model predictions that assume CPUE is proportional to stock size. In this paper, we have modelled only the standard responses of CPUE to changes in stock size, but will examine the impact of hyper-stable responses in further planned work. There is also the potential that reductions in effort, particularly in the purse seine fishery, may lead to higher fish prices and profit margins as a result of the impact of reductions in supply on tuna prices (Reid et al. 2006). We allow for this effect in the economic model through price elasticity terms in the revenue equations described below.

2.2.1 Fishing regions and fishery definitions

The WCPO area stretches from 40^0N to 40^0S and 110^0E to 150^0W. This area is divided into different assessment units for each of the four main tuna species. Bigeye and yellowfin tuna have the same regions, whereas skipjack and albacore tuna have different spatial stratifications (Table A.1). There were many reasons for these stratifications: habitats of the different species, the use of tagging information, historical patterns of fishing, and in some cases isolation of a specific fleet from others for selectivity or catchability parameterization purposes.

The WPCO tuna fishery is a diverse fishery consisting of numerous gear types, species and regions with different gears targeting different species and different species being targeted by the same gear in different regions. For each individual species stock assessment (MULTIFAN-CL), different fishery complexes are defined into homogenous groups by assessment region (assuming that the selectivity and catchability are the same within a group). For bigeye and yellowfin tuna, 33 different fisheries (Table A1.2) have been identified, 23 fisheries for skipjack (Table A1.3) and 30 fisheries for southern albacore (Table A1.4).

2.2.2 Stratification for the bioeconomic model

The bioeconomic model is a species combined model, which implies that common strata between these four species need to be assigned to allow the individual outputs of the biological models to be combined. In order for all the purse-seine and longline fisheries for the four tuna species to be pooled into common strata for the integrated analysis, *regions* for the bioeconomic model were specified. The region structure used was based on the stratification applied to the 2014 bigeye and yellowfin stock assessments, but excluded regions 8 and 9, which were pooled with regions 3 and 5 respectively (Figure 4).

For each stock, purse seine and longline fisheries were 'assigned' to a region to form 'economic strata', providing a common definition across all four stock assessments. The pole-and-line, domestic fleets (Indonesia, Philippines, and Vietnam), and all other fishing methods were not stratified into the regions, but pooled according to gear only. Table 2 shows the 17 economic strata used in the bioeconomic model and the grouping of the different fisheries within them. Purse-seine fishing includes skipjack, bigeye and yellowfin tuna, whereas the longline fishery includes albacore, bigeye and yellowfin tuna. One of the assumptions made when defining the economic strata was that southern albacore is caught only in LL5 and LL6 (Table 2). Albacore caught in LL1&2 form part of the northern albacore stock, which was not considered in this analysis.

The 17 economic strata were then pooled into 5 *effort groups* within which common future conditions were modelled: tropical longline (LLT), southern longline (LLS), unassociated purse-seine fishing, associated purse-seine fishing, and a final group consisting of all other strata (all tuna fishing in Indonesia, Philippines and Vietnam and also the pole-and-line fishery. The tropical longline fishery (LLT) normally targets either yellowfin or bigeye tuna, whereas the southern longline fishery (LLS) is mainly an albacore-based fishery, but also catches bigeye and yellowfin.

2.2.3 Simulation approach and assimilation of catches

The bioeconomic consequences of various scenarios of future conditions were evaluated through 20 year biological stock projections by effort group. While the intention in future is to incorporate uncertainty into this analysis through the use of alternative model runs from the respective stock assessments and through the use of stochastic future recruitments, the present analysis is based on deterministic simulations (i.e. no stochastic variability in future recruitment) using only the reference case for each of the four species assessments.

The effort used for the projections was based on the respective nominal effort reported by fishery group in 2012. Projections evaluated the consequences of conditions matching multiples of the 2012 levels of effort (‘effort scalars’) within each of the fishery groups in the range 0.5 to 1.25 (in increments of 0.25), where a scalar of 1.0 was equivalent to the 2012 level. All unique combinations across the four fishery groups were examined. Effort for the 'other' fishery group was kept constant at the 2012 level in all projections.

The projections estimated a catch number-at-age matrix for each fishery division for each of the 20 projected years and each effort combination. These catch-at-age data were converted into catch-at-size and split into 5 commercial weight bins for each species. The numbers of fish in each bin were converted into weight of catch per bin ($C^{sp}_{y,fd,ec,b}$), where the catch (C) is available per species (sp), by year (y), effort scalar (ec), weight per bin (b) and the fishery division (fd).

The fishery divisions were sorted into the economic strata (es) for each tuna species ($C^{sp}_{y,es,ec,b}$) according to Table 2.

2.2.4 Determination of bycatch for the longline fishery

Unlike the purse-seine fishery, the longline fishery commonly retains bycatch of billfish, tuna-like species and sharks, for commercial reasons. To indicate the importance of including the bycatch species in the analysis, the proportion of each species of the total average catch in each economic stratum is given in Table 3. In some areas high bycatch is taken or even targeted, at least historically, in particular the shark catch in LL1&2 and LL7 where sharks may contribute 25% and 36% respectively to the total catch.

To account for these as potential revenue sources, the catch of the main bycatch species (sp_b) have been estimated using regression coefficients from historical (1990-2013) longline catch data that related bycatch levels to the catch of a specific 'main' tuna species. The main tuna species were selected based on that which provided the best r-squared for that bycatch species for each of the economic strata. Resulting regression estimates were then used in the estimation of bycatch (Table 4). The bycatch was calculated using the following equation:

$$C_{y,es,sp_b,ec,b} = \left(\left(C_{y,es,sp_b,ec,b}\right)^{\ln(T\_b\_es)}\right) \times \exp(intercept)$$

where *T_b_es* is the coefficient of the regression of the tuna species used as the dependent variable for each strata and bycatch species, with the intercept being from the same regression (Table 4). Some of the resulting bycatch relationships were suspect, based on their low p-value, and for some, unrealistic coefficients were derived (those regression marked with grey in Table 4). These were excluded from the analysis. For these estimates, a constant average bycatch level was used. Future analyses will develop alternative relationships; e.g. by using effort instead of target species to regress against bycatch.

2.2.5 Catch and effort by fishing nation

It is highly likely that there is some consistency within fishing nations regarding fish pricing and vessel cost structures. To take this into account, the catch assimilated above (section 2.2.3) for a particular economic stratum was further separated into catch by fishing nation on the basis of the proportion of the total catch by species and flag (*fl*) for the longline fishery and the purse-seine fishery (split into associated and unassociated fishing) in each region. These proportions were calculated using catch and effort by flag, economic strata and species averaged over 2010-2013. Any of the fleets that expended less than 5% of the combined effort in any of the strata were pooled. Proportion of effort and species catch by economic strata and flag are presented in Appendix 2, Tables A2.1 - A2.4.

2.2.6 Revenue

In order to investigate profit made in the different areas by either longlining or purse-seine fishing, the multi-dimensional catch matrix calculated in Section 2.2.3 was summarised into two: longline fisheries (LL1&2, LL3, LL4, LL5, LL6, LL7) and purse-seine fisheries, pole-and-line and other fisheries combined (PS1, PSA3, PSU3, PSA4, PSU4, PSA7, PSU7, P&L, domestic and miscellaneous).

$$C^{ll}_{y,es,sp,ec,b} = C^{Sp_i}_{y,es,ec,b} \qquad \text{and} \qquad C^{ps}_{y,es,sp,ec,b} = C^{Sp_i}_{y,es,ec,b}$$

Therefore, when calculating revenue, a different approach was taken for the longliner versus purse-seiners. Whereas the value of the purse-seine catch is fish-size dependent, prices for longline catches, especially the tropical longliners, depend on the value chain of a specific fleet; the price ($P^{ll}_{sp,fl}$) for longline-caught fish differs between species and flags (Table 5).

The commercial category catch bins for the longline fishery were summed and the total catch weight by species, year, region and scalar was divided into the different fishing fleets (flags) instead ($C^{ll}_{y,sp,ec,es,fl}$) using the proportion calculated in section 2.2.5.

$$C^{ll}_{y,sp,ec,es} = \sum_{b=1}^{5} C^{ll}_{y,sp,ec,es,b}$$

$$C^{ll}_{y,sp,ec,es,fl} = C_{y,sp,ec,es} \times Cp^{ll}_{fl,sp,es}$$

Where *Cp* is the proportion of catch for the different flag-nations (*fl*) in the total longline catch (Appendix 2).

For purse seiners, the price ($P^{ps}_{sp,b}$) of the purse-seine catch (canning market) is weight and species-dependent (Table 6). For example, large yellowfin attract a higher price than large skipjack (or mixed yellowfin/skipjack lots) of the same size.

Prices were extracted from Customs and Excise data from Thailand (skipjack, yellowfin, bigeye and albacore)[4], Japan (bigeye and yellowfin)[5] and the USA (bigeye and yellowfin)[6]. Prices were reformulated from Carriage Including Freight (CIF) to ex-vessel to reflect market destinations and product form (frozen and fresh), carriage, processing costs and customs tariffs. The price differentials between sizes for the purse seine catch are based on Bangkok price differentials.

The revenue (R) for each year, by species, economic strata, weight bin and effort scalar was therefore calculated as follows:

$$R^{ps}_{y,sp,ec,es,b} = C^{ps}_{y,sp,ec,es,b} \times P^{ps}_{sp,b}$$

$$R^{ll}_{y,sp,ec,es,fl} = C^{ll}_{y,sp,ec,es,fl} \times P^{ll}_{sp,fl}$$

Given the importance of the WCPO tuna fisheries to the global market, changes in the level of supply from the region are likely to impact on global demand and for this reason price elasticity[7] of demand was incorporated in this bioeconomic analysis, in a similar fashion to that of Bertignac et al. (2000), Reid et al. (2003), Pan and Pooley (2004), Reid et al. (2006) and Kompas et al. (2010). The change in price when there is a 1% change in the quantity supplied on an annual basis is the inverse of demand elasticity (Table 7). The formulae below include the price elasticity for purse seine and longline calculations of revenue.

For purse seiners:

$$R^{ps}_{y,sp,ec,b} = \left(P^{ps}_{sp,b,(y-1)} - P^{ps}_{sp,b,(y-1)} \left(\frac{C^{ps}_{y,sp,ec} - C^{ps}_{(y-1),sp,ec}}{C^{ps}_{(y-1),sp,ec}} \right) / \varepsilon_{sp} \right) \times C^{ps}_{y,sp,ec}$$

where $P^{ps}_{sp,b,(y-1)}$ is the initial price of species; $C^{ps}_{(y-1),sp,ec}$ is the initial supply; ε_{sp} is the elasticity of demand for species; and $C^{ps}_{y,sp,ec}$ is total annual harvest of species for all purse-seine fleets (Kompas et al. 2010, Supplementary Material).

The revenue for the purse-seine fleet was summed over the bins and divided into the different nations/flags by using the proportion $Cp^{ps}_{fl,sp,es}$ calculated in section 2.2.5:

$$R^{ps}_{y,sp,ec,es} = \sum_{b=1}^{5} R^{ps}_{y,sp,ec,es,b}$$

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[4] http://www.customs.go.th/Customs-Eng/Statistic/StatisticIndex2550.jsp

[5] http://www.customs.go.jp/toukei/srch/indexe.htm?M=01&P=0

[6] http://www.st.nmfs.noaa.gov/st1/

[7] *"Price elasticity measures the responsiveness of the quantity demanded of fish to a change in price that arises from a change in harvest brought to market"* (Kompas et al., 2010, pg. 179)

$$R^{ps}_{y,sp,ec,es,fl} = R^{ps}_{y,sp,ec,es} \times Cp^{ps}_{fl,sp,es}$$

For longliners:

$$R^{ll}_{y,sp,ec,es,fl} = \left(P^{ll}_{(y-1),sp,fl} - P^{ll}_{(y-1),sp,fl} \left(\frac{C^{ll}_{y,sp,ec} - C^{ll}_{(y-1),sp,ec}}{C^{ll}_{(y-1),sp,ec}} \right) / \varepsilon_{sp} \right) \times C^{ll}_{y,sp,ec,es,fl}$$

where $P^{ll}_{(y-1),sp,fl}$ is the initial price of species caught by a specific longline fleet/flag; $C^{ll}_{(y-1),sp,ec}$ is the initial supply; ε_{sp} is the elasticity of demand for species; and $C^{ll}_{y,sp,ec,es,fl}$ is total annual harvest of species for all longline fleets/flags taken off the individual economic strata.

The total annual revenue for the purse-seine fishery and the longline fishery for each effort scalar was calculated as the sum for each gear group across species, economic strata and fishing nation:

$$R^{ps}_{y,ec} = \sum_{sp=1}^{n} \sum_{es=1}^{n} \sum_{fl=1}^{n} R^{ps}_{y,sp,ec,es,fl}$$

$$R^{ll}_{y,ec} = \sum_{sp=1}^{n} \sum_{es=1}^{n} \sum_{fl=1}^{n} R^{ll}_{y,sp,ec,es,fl}$$

2.2.7 Costs

Costs of fishing were based upon a specific unit of effort. Those costs had the potential to vary by fishing method, region and fishing nation.

Within the projection analysis, the effort expended in 2012 (E_{2012}; Table 8) by either longline fishing (hundreds of hooks;) or purse-seining fishing (days;) in each economic strata was multiplied by the scalar for each effort group. That effort was further stratified into fishing nations (Section 2.2.5), resulting in effort by flag, scalar and economic strata. To obtain the total costs per scalar/effort set of scenarios in the WCPO tuna fishery, the respective level of effort was multiplied by the costs per hook (*ch*) for each economic strata and flag for longline fisheries (Table 9) and by fishing costs per day (*cd*) for each economic strata and flag for purse-seine fisheries (Table 10). The costs used reflect the economic cost of producing a unit of effort and include cash costs, depreciation and a return on capital. Given this, profits estimated in this paper relate to economic profits often referred to as “super-profits” or “rents”. Costs do not include licence fees paid by foreign fleets fishing in EEZs. Cost estimates have been extracted from the data base of the Parties to the Nauru Agreement formulated from information received from the industry and other published sources (e.g., Miyake et al, 2010).

$$E_{fl,es,ec\,=\,ec_{es}} \times Ep_{fl,es} \times E_{es(2012)}$$

$$Cost^{ll}_{fl,es,ec} = ch_{fl,es} \times E^{ll}_{fl,es,ec}$$

$$Cost^{ps}_{fl,es,ec} = cd_{fl,es} \times E^{ps}_{fl,es,ec}$$

$$Cost^{ll}_{ec} = \sum_{fl=1}^{n} \sum_{es=1}^{n} Cost^{ll}_{fl,es,ec}$$

$$Cost_{ec}^{ps} = \sum_{fl=1}^{n} \sum_{es=1}^{n} Cost_{fl,es,ec}^{ps}$$

2.2.8 Net Present Value

The net present value (NPV) of profits were calculated over a given time horizon (20 years) in order to provide a measure of the relative economic impact of different management options. Comparative analysis of NPV provides a readily applicable approach for calculating quantities consistent with examining the concept of the MEY, and these can be used to guide biological and economic-based management of fisheries.

Identifying the appropriate discount rate for use within NPV analyses is a challenge; the lower the discount rate the more weight that is attached to future yields. High discount rates imply a short time horizon (and raise the incentive to overfish) as future catch is then worth little in today's prices. The risk caused by natural processes such as environmental variation is not considered in this process. The NPV was calculated for the longline and the purse-seine fisheries separately, by devaluing expected profit with a discount rate (*d*) of 3%. NPV was calculated for each scalar examined.

$$NPV^{ps} = \sum_{y=1}^{20} \frac{\left(R_{y,ec}^{ps} - Cost_{ec}^{ps}\right)}{(1+d)^{n}}$$

$$NPV^{ll} = \sum_{y=1}^{20} \frac{\left(R_{y,ec}^{ll} - Cost_{ec}^{ll}\right)}{(1+d)^{n}}$$

$$NPV = NPV^{ll} + NPV^{ps}$$

3. Results

Some preliminary results are presented to illustrate the potential use of this model.

The model estimated that under a continuation of 2012 fishing effort (business as usual; the BAU scenario, all scalars = 1) the indicative NPV of profits earned over the next 20 years would be US$17.00 billion (or on average 1.12 billion USD annually). This could be increased to a maximum of US$26.98 billion (or on average 1.81 billion USD annually) under the estimated optimum effort distribution (i.e., the effort conditions in each fishery group, noting that changes in effort were bounded by a maximum 50% decline and 25% increase; Figure 5), while using a discount rate of 3%[8] thereby placing a relative high value on future profits. It should be noted that these indicative values depend on the validity of the economic data and on the assumptions of the bioeconomic model. Therefore, it would be prudent to view them relative to one another, as in the NPV of profits for this scenario could potentially be increased by 59%.

The top 5% of the NPV range that resulted across all examined scalar combinations was fairly narrow, ranging from US$24.79 to 26.98 billion, arising from 13 different fishery group effort conditions (Table 11). A table with the full results is available in the supplementary material as an excel spreadsheet. The effort combination that produced the maximum NPV was obtained by decreasing effort within the tropical and southern longline fisheries and the associated purse-seine fishery by 50%, with the unassociated purse-seine fishery remaining at the 2012 effort level. However, the effort regimes listed in Table 11 all give reasonable returns over the next 20 years and some of them would be possibly more plausible to introduce than others.

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[8] although a 3% discount rate appears reasonable, and while the value has little impact when considering results in relative terms, there could be justification to use an alternative value if results were to be viewed in absolute terms.

The indicative revenue for the different species under the effort regime of maximum NPV was compared to revenue that would be produced if the current effort (BAU scenario) continued over the next 20 years. All revenue scenarios fall relative to the effort regime in 2012 (revenues for all domestic and pole-and-line fisheries are not included at this stage) (Figure 6). However, the conditions under the maximum NPV imply lower costs – the idea behind the optimum effort regime is that it is expected that for most fisheries the decrease in catch would be offset by an increase in CPUE. For WCPO fisheries, the CPUE would be higher overall under the maximum NPV effort regime than with business as usual. The tropical and southern longline CPUE would increase on average by 67% and 29% respectively and the purse-seine associated fishery would increase by about 16% and the unassociated fishery by 19%.

The NPV is depicted in Figure 7 for the tropical and southern longline fisheries and both purse-seine set-type fisheries. Under BAU, the southern and tropical longline fishery will have negative NPV. The purse-seine fisheries will continue to have substantial NPV and resulting profits. However, if the effort regime that produces maximum NPV over the next 20 years was in place, the tropical longline fishery would start to make considerable profits, but the southern longline fishery will continue to make a loss (albeit small and lower than current estimated losses). For the southern longline fishery to make a profit, effort cuts may have to be higher than the 50% maximum decrease examined here. For the purse-seine fishery, the unassociated fishery will increase its NPV, whereas the associated fishery with an effort cut of 50% will decrease their NPV by 32% relative to the BAU scenario.

Reference points for the four tuna species are based on the latest spawning biomass relative to the average spawning biomass without fishing over the last 10 years, excluding the terminal assessment year. Under the BAU scenario the spawning biomass of all tuna stocks considered here, will decrease from 2012 levels. When fishing under effort levels of maximum NPV, the spawning biomass shows an increase over the 20 years for all species (Figure 8); from 0.14 to 0.2 (the limit reference point) for bigeye, from 0.35 to 0.39 for yellowfin, from 0.59 to 0.74 for albacore and from 0.54 to 0.56 for skipjack tuna. It should be noted that these results are based only on the selected reference-case assessments for each species.

This model can be used to evaluate the consequences of trade-offs within fishing fleets, for example the impacts of a shift of effort from FAD fishing to fishing on free schools within the purse seine fishery. Based on the current results, for example, a shift of 25% of the effort from FADs to free-schools would increase the NPV of all tropical tunas over 20 years by 7.4%. Further, to illustrate the individual potential effect on NPV, NPV's were plotted against the effort scalars for each of the four effort groups, by keeping the other three constant (Figure 9). With the exception of the free-school fishery, for all other effort groups the preliminary results suggest that the optimum effort seems to be lower than the maximum 50% reduction that was used here, because NPV has not reached a maximum. Changes in the unassociated purse seine effort did not contribute to large changes in the overall NPV profits, but a small decrease in the FAD and tropical longline fishery showed large increases in the NPV.

4. Discussion

While this paper has been produced for illustrative purposes and was therefore mostly focused on the maximisation of the NPV of fishery profits, the species-integrated bioeconomic model presented has the potential to be used as a management simulation tool to examine the economic impact of different management scenarios across different fleets and fisheries and to supplement the biological information provided by the stock assessment models.

A potential area for further development of this model is the incorporation of additional economic strata so that the model reflects not just the fishing fleets but other economic units such as coastal state on-shore economic developments.

As this multi-species, multi-fishery model is currently under development this paper should serve as a general introduction to the overall approach and methods. The results are illustrative and the absolute quantities in particular should not be used at this stage for policy advice. However, the relative responses of NPV and average profits to changes in effort may be more useful at this stage.

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Table 1: Stock assessment results for the four main tuna species in the WCPO. Management quantities are given with a range of estimated uncertainty from each model grid. The results for bigeye, yellowfin and skipjack are from the 2014 assessments, whereas the results for albacore are from the 2012 assessment.

Species	**Spawning biomass latest in (mt)**	**Catch (mt) (2013)**	**Spawning biomass at MSY (mt)**	**$F_{current}/F_{MSY}$**	**$SB_{latest}/SB_{F=0}$**
Skipjack	3,052,995 (3,052,419-9,798,792)	1,664,309	1,683,000 (1,336,750-3,170,000)	0.62 (0.17-0.82)	0.48 (0.46-0.73)
Yellowfin	773,429 (385,949-1,223,085)	655,668	607,024 (309,150-859,990)	0.76 (0.51-1.09)	0.38 (0.29-0.52)
Bigeye	265,599 (194,090-296,027)	161,679	345,400 (231,240-444,490)	1.57 (1.22-2.14)	0.16 (0.12-0.19)
Albacore	241,700 (127,259-621,281)	131,872	108,100 (45,739-2690,625)	0.21 (0.04-1.08)	0.58 (0.31-0.77)

Table 2: Fisheries numbers for the four tuna species assigned to the pre-specified economic strata. The numbers in this table coincide with the fishery numbers that are listed in the tables in Appendix 1 for each species.

Economic Strata	YFT	BET	SKJ	ALB
LL1&2	1,2,3	1,2,3	3	
LL3	4,5,8	4,5,8	7,11	
LL4	9,10	9,10	15	
LL5	11,12,28,30	11,12,28,30		1,2,3,4,5,6,7,15, 16,17,18,19,20
LL6	13	13		8,9,10,11,12, 13,14,21,22,23,24
LL7	6,7	6,7	23	
PS1	20	20	2	
PSA3	14,26	14,26	5,9	
PSU3	15,27	15,27	6,10	
PSA4	16	16	13	
PSU4	17	17	14	
PSA7	25,31	25,31	18,20	
PSU7	32,33	32,33	21	
P&L	21,22,23,29	21,22,23,29	1,4,8,12,19	
Domestic			16,17,22	
Miscellaneous	18,19,24	18,19,24		

Table 3: Average proportion of catches taken by the longline fleet in the economic strata. The 'otuna' represents other tuna like teleosts and other refers to all other species.

Eco strata	**albacore**	**bigeye**	**Yellowfin**	**otuna**	**billfish**	**shark**	**Other**
LL1&2	0.34	0.15	0.07	0.02	0.17	0.25	0.02
LL3	0.07	0.40	0.35	0.00	0.11	0.05	0.01
LL4	0.07	0.50	0.25	0.00	0.11	0.05	0.02
LL5	0.41	0.07	0.26	0.06	0.12	0.04	0.04
LL6	0.63	0.06	0.10	0.01	0.07	0.05	0.08
LL7	0.02	0.12	0.32	0.00	0.14	0.36	0.05

Table 4: Regression coefficients, significance statistics (R^2(adj) and p-value) and the expected proportion of catch in the total catch for all economic strata. These are used to estimate other tuna, billfish, shark and other species from the albacore catches in that area. The 'otuna' represents other tuna-like teleosts and 'other' refers to all other species.

			LL1&2				
	OTUNA		**BILLFISH**		**SHARK**		**OTH**
Intercept	9.06	**Intercept**	3.45	**Intercept**	19.1	**Intercept**	7.75
ln(yft_mt)	-0.30	**ln(yft_mt)**	0.70	**ln(yft_mt)**	-1.2	**ln(yft_mt)**	-0.10
R-squared	*-0.04*	**R-squared**	0.45	**R-squared**	*0.04*	**R-squared**	*-0.04*
p-value	*0.66*	**p-value**	0.00	**p-value**	*0.18*	**p-value**	*0.79*
prop in catch	*0.02*	**prop in catch**	0.17	**prop in catch**	0.25	**prop in catch**	*0.02*
			LL3				
	OTUNA		**BILLFISH**		**SHARK**		**OTH**
Intercept	11.49	**Intercept**	4.99	**Intercept**	14.51	**Intercept**	27.14
ln(yft_mt)	-0.83	**ln(bet_mt)**	0.37	**ln(yft_mt)**	-0.72	**ln(yft_mt)**	-2.13
R-squared	*0.02*	**R-squared**	*0.01*	**R-squared**	*-0.02*	**R-squared**	0.15
p-value	*0.22*	**p-value**	*0.26*	**p-value**	*0.44*	**p-value**	0.03
prop in catch	*0.00*	**prop in catch**	0.11	**prop in catch**	0.05	**prop in catch**	*0.01*
			LL4				
	OTUNA		**BILLFISH**		**SHARK**		**OTH**
Intercept	-19.96	**Intercept**	-0.24	**Intercept**	-22.07	**Intercept**	-21.03
ln(bet_mt)	2.40	**ln(bet_mt)**	0.87	**ln(bet_mt)**	2.87	**ln(bet_mt)**	2.71
R-squared	0.30	**R-squared**	0.56	**R-squared**	0.37	**R-squared**	0.44
p-value	0.00	**p-value**	0.00	**p-value**	0.00	**p-value**	0.00
prop in catch	*0.00*	**prop in catch**	0.11	**prop in catch**	0.05	**prop in catch**	*0.02*
			LL5				
	OTUNA		**BILLFISH**		**SHARK**		**OTH**
Intercept	17.82	**Intercept**	4.91	**Intercept**	-8.33	**Intercept**	-9.15
ln(bet_mt)	-1.49	**ln(bet_mt)**	0.42	**ln(alb_mt)**	1.62	**ln(alb_mt)**	1.71
R-squared	*-0.05*	**R-squared**	-0.03	**R-squared**	0.48	**R-squared**	0.43
p-value	*0.17*	**p-value**	0.00	**p-value**	0.00	**p-value**	0.00
prop in catch	0.06	**prop in catch**	0.12	**prop in catch**	0.04	**prop in catch**	0.04
			LL6				
	OTUNA		**BILLFISH**		**SHARK**		**OTH**
Intercept	-1.08	**Intercept**	-5.07	**Intercept**	-16.85	**Intercept**	-9.92
ln(alb_mt)	0.70	**ln(alb_mt)**	1.27	**ln(alb_mt)**	2.39	**ln(alb_mt)**	1.76
R-squared	0.17	**R-squared**	0.77	**R-squared**	0.74	**R-squared**	0.71
p-value	0.03	**p-value**	0.00	**p-value**	0.00	**p-value**	0.00
prop in catch	0.01	**prop in catch**	0.07	**prop in catch**	0.05	**prop in catch**	0.08
			LL7				
	OTUNA		**BILLFISH**		**SHARK**		**OTH**
Intercept	7.12	**Intercept**	-12.37	**Intercept**	-25.72	**Intercept**	75.85
ln(yft_mt)	-0.26	**ln(yft_mt)**	2.10	**ln(yft_mt)**	3.44	**ln(yft_mt)**	-6.76
R-squared	*-0.04*	**R-squared**	0.49	**R-squared**	0.43	**R-squared**	0.83
p-value	*0.72*	**p-value**	0.00	**p-value**	0.00	**p-value**	0.00
prop in catch	*0.00*	**prop in catch**	0.14	**prop in catch**	0.36	**prop in catch**	0.05

The p-values in italics are not significant at the 0.05 level. The grey shaded values indicate important bycatch species where no realistic relationship could be found.

Table 5: Prices for different products from the longline fishery. The 'otuna' represents other tuna like teleosts and 'other' refers to all other species.

	BET	YFT	ALB	OTUNA	BILLFISH	SHARK	OTHER
AU	7804	5313	2464	2464	5313	3000	2464
CN	7804	5313	2464	2464	5313	3000	2464
FJ	7804	5313	2464	2464	5313	3000	2464
ID	7804	5313	2464	2464	5313	3000	2464
JP	8237	5790	2597	2597	5790	3000	2597
KR	7804	5313	2464	2464	5313	3000	2464
NC	7804	5313	2464	2464	5313	3000	2464
TW	7804	5313	2464	2464	5313	3000	2464
US	7804	5313	2464	2464	5313	3000	2464
VN	7804	5313	2464	2464	5313	3000	2464
VU	7804	5313	2464	2464	5313	3000	2464
oth	7804	5313	2464	2464	5313	3000	2464

Table 6: Prices for the different weight bins destined for canning for the for WCPO tuna species

Weight categories	Bigeye	Skipjack	Yellowfin
(0-1.4kg)	1595	1595	1595
(1.4-1.8kg)	1795	1795	1795
(1.8-3.4kg)	1945	1945	1945
(3.4-9.1kg)	1995	2300	1995
(>9.1kg)	1995	2400	1995

Table 7: Values indicate the percent change in price for a 1% change in supply (i.e., inverse of price elasticity of demand (ε)).

	Bertignac et al. 2000 from Campbell (1998)	Reid et al. (2003)	Pan and Pooley (2004)	Reid et al. (2006)	Kompas (2010)	This study
BET		0.1	0.08		0.1	0.1
YFT		0.1	0.08		0.15	0.1
SKJ		0.52	0.15		0.53	0.52
Alb		0.15	0.07	0.15		0.15
Purse-seine	0.65			0.53		0.53
Longline	0.40			0.10		0.1

Table 8: The overall effort in 2012 in the economic strata for both longline fishing and purse-seine fishing, in hundreds of hook and fishing days.

Longline Economic strata	**Hundred hooks**	**Purse-seine Economic strata**	**Fishing Days**
LL1&2	1624033	**PS1**	8192
LL3	1244541	**PSU3**	14993
LL4	2220598	**PSU4**	19021
LL5	2733906	**PSU7**	7049
LL6	3147778	**PSA3**	10644
LL7	4734496	**PSA4**	16149
		PSA7	36

Table 9: Cost per hook of the individual longline fleets in the economic strata.

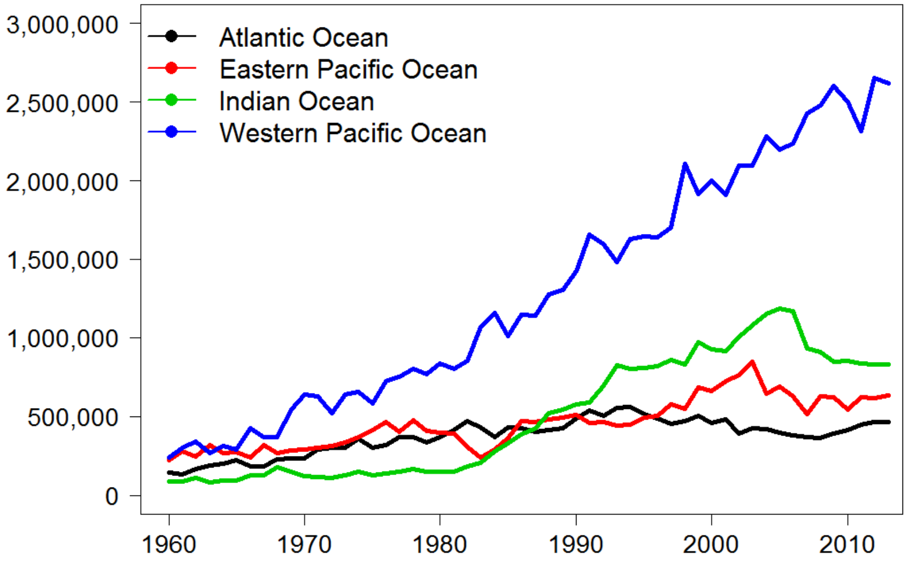
	LL1&2	**LL3**	**LL4**	**LL5**	**LL6**	**LL7**
AU	1.31	1.31	1.31	1.31	1.31	1.31
CN	1.04	1.04	1.04	1.04	1.04	1.04
FJ	1.04	1.04	1.04	1.04	1.04	1.04
ID	1.31	1.31	1.31	1.31	1.31	1.31
JP	1.92	1.92	1.92	1.92	1.92	1.92
KR	1.78	1.78	1.78	1.78	1.78	1.78
NC	1.31	1.31	1.31	1.31	1.31	1.31
TW	1.04	1.04	1.04	1.04	1.04	1.04
US	1.31	1.31	1.31	1.31	1.31	1.31
VN	1.31	1.31	1.31	1.31	1.31	1.31
VU	1.04	1.04	1.04	1.04	1.04	1.04
oth	1.31	1.31	1.31	1.31	1.31	1.31

Table 10: Cost per vessel day for the individual purse-seine fleets in the economic strata.

	PS1	PSA3	PSU3	PSA4	PSU4	PSA7	PSU7
CN	19036	19036	19036	19036	19036	19036	19036
ID	22652	22652	22652	22652	22652	22652	22652
JP	24561	24561	24561	24561	24561	24561	24561
KI	24642	24642	24642	24642	24642	24642	24642
KR	27240	27240	27240	27240	27240	27240	27240
MH	24796	24796	24796	24796	24796	24796	24796
PG	18983	18983	18983	18983	18983	18983	18983
PH	16259	16259	16259	16259	16259	16259	16259
SB	15228	15228	15228	15228	15228	15228	15228
TW	22222	22222	22222	22222	22222	22222	22222
US	24566	24566	24566	24566	24566	24566	24566
VN	22652	22652	22652	22652	22652	22652	22652
VU	26651	26651	26651	26651	26651	26651	26651
oth	27642	27642	27642	27642	27642	27642	27642

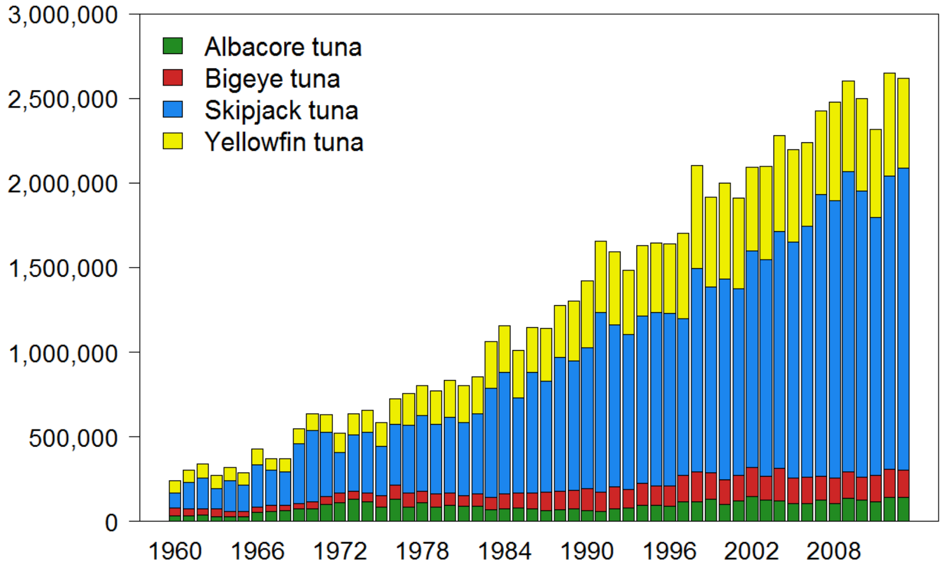
Table 11: The scenarios (i.e., percent change from the BAU scenario) that produced the top 5% of Net Present Value over a 20 year period.

Tropical longline	Southern longline	FAD	Free-school	NPV profit in billion USD	Average profit per year in billion USD
-50%	-50%	-50%	0%	26.98	1.82
-50%	-50%	-50%	25%	26.93	1.81
-50%	-50%	-50%	-25%	26.33	1.78
-50%	-25%	-50%	0%	25.81	1.74
-50%	-50%	-25%	0%	25.75	1.73
-50%	-25%	-50%	25%	25.74	1.73
-50%	-50%	-25%	-25%	25.63	1.72
-25%	-50%	-50%	0%	25.60	1.72
-25%	-50%	-50%	25%	25.40	1.71
-50%	-50%	-25%	25%	25.27	1.69
-50%	-25%	-50%	-25%	25.20	1.70
-25%	-50%	-50%	-25%	25.14	1.70
-50%	-50%	-50%	-50%	24.79	1.68



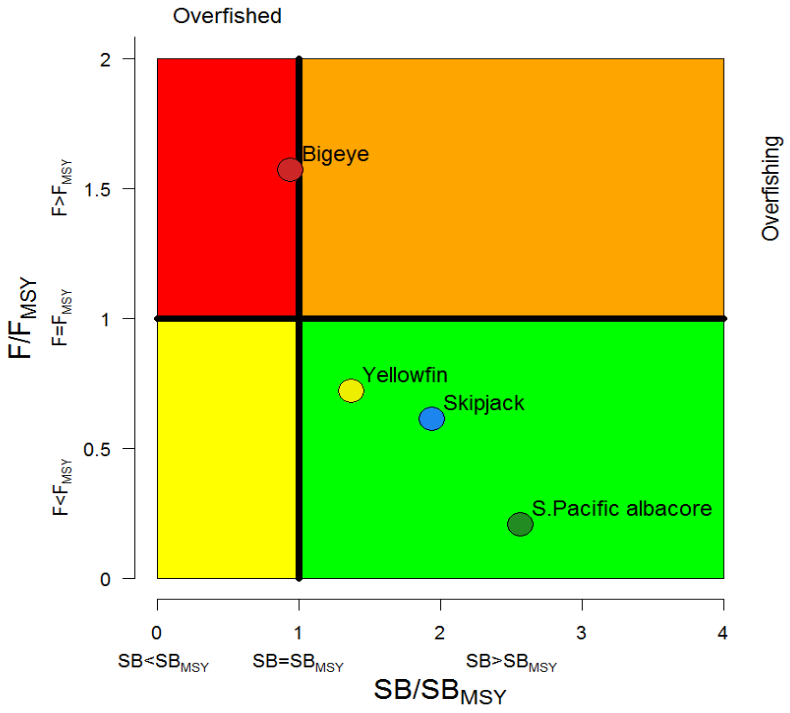
Data source: SPC CES Database

Figure 1: Catches of tuna (mt) taken in the Atlantic, Eastern Pacific, Indian and Western Pacific Ocean.



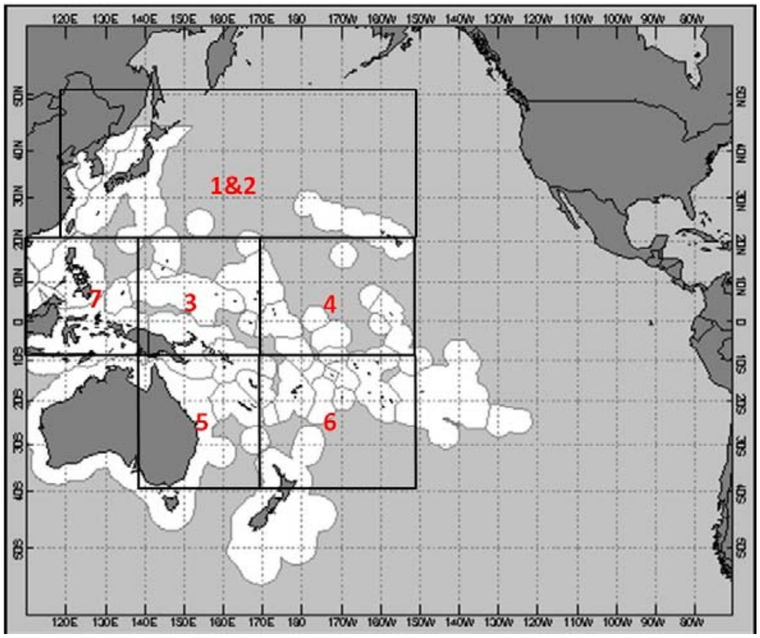
Data source: SPC CES Database

Figure 2: Total tuna catch (mt) in the Western and Central Pacific Ocean (1960-2013).



Data source: SPC Stock assessments

Figure 3: Kobe-plot for the four tuna species within the WCPO area.



Area 1&2: 50^{0}N-20^{0}N, 120^{0}E-150^{0}W

Area 3: 20^{0}N-10^{0}S, 140^{0}E-170^{0}E

Area 4: 20^{0}N-10^{0}S, 170^{0}E-150^{0}W

Area 5: 10^{0}S-40^{0}S, 140^{0}E-170^{0}E

Area 6: 10^{0}S-40^{0}S, 170^{0}E-150^{0}W

Area 7: 20^{0}N-10^{0}S, 110^{0}E-140^{0}E

Figure 4: Regions chosen for the bioeconomic model. Every longline and purse-seine fishery for the four species had to fit into one of these regions. Pole-and-line, domestic fisheries and all other fishing gears are given a separate economic strata (Table 2).

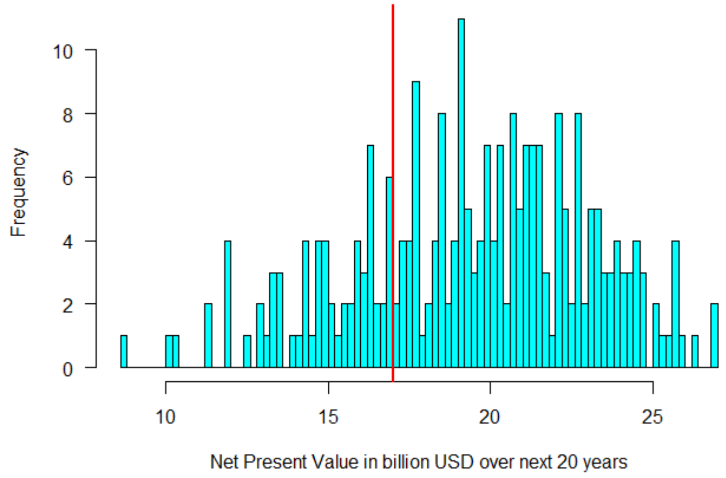


Figure 5: Frequency distribution of Net Present Values over different combinations of effort between tropical and southern longline fishing and associated and unassociated purse-seine fishing. The red vertical line indicates the NPV for the BAU model.

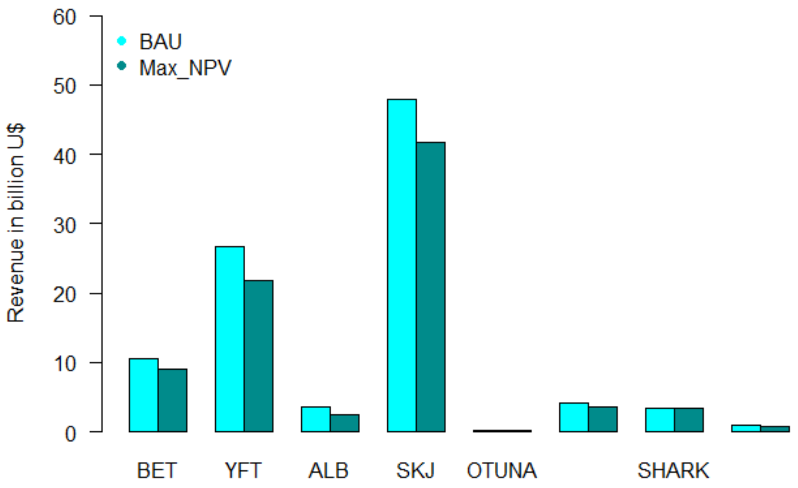


Figure 6: Expected revenue by species in billions USD over the next 20 years for the maximum net present value scenario and for the BAU scenario (BAU). Note that all domestic fisheries and pole-and-line revenues are excluded. The otuna represents other tuna like teleosts and other refers to all other species.

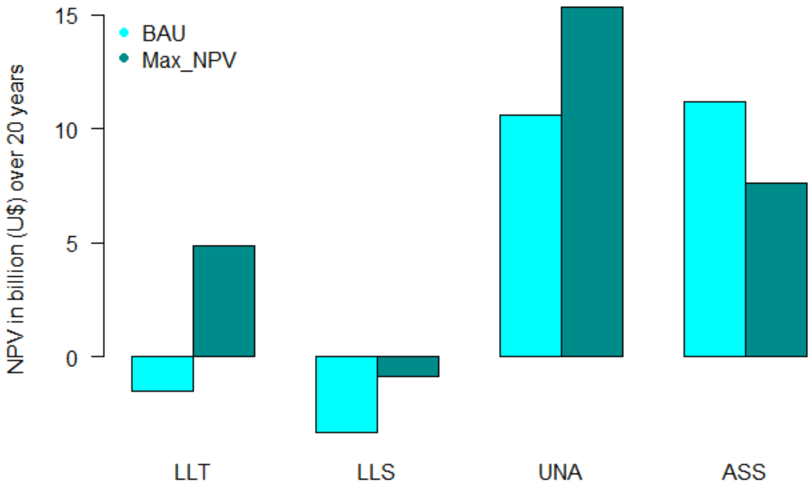


Figure 7: Net present value in billions USD over the next 20 years for the four different effort groups under the BAU scenario and maximum NPV.

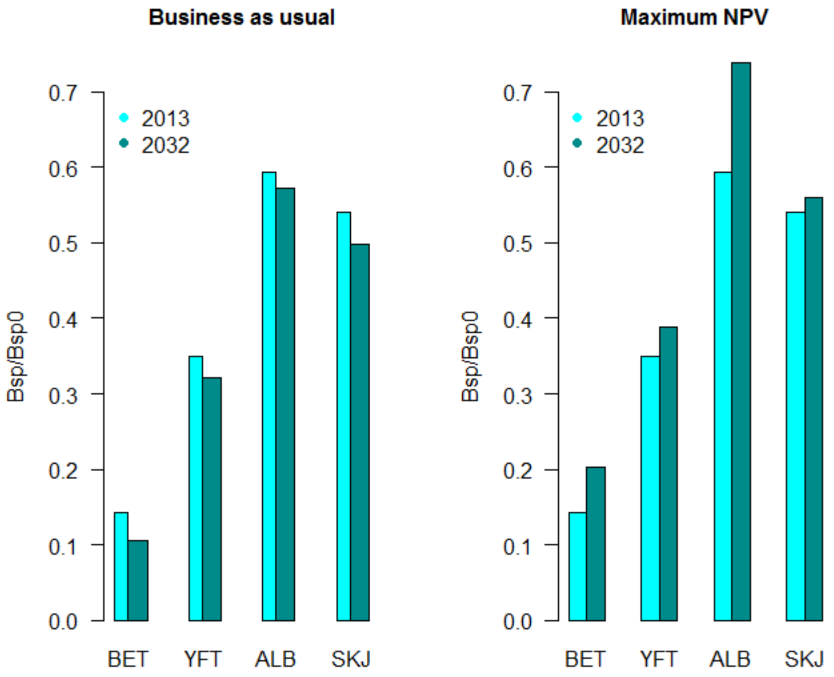


Figure 8: Comparing the status of the resource (SB/SBF=0) for 2013 and 2032 under the “BAU” and maximum NPV effort scenarios.

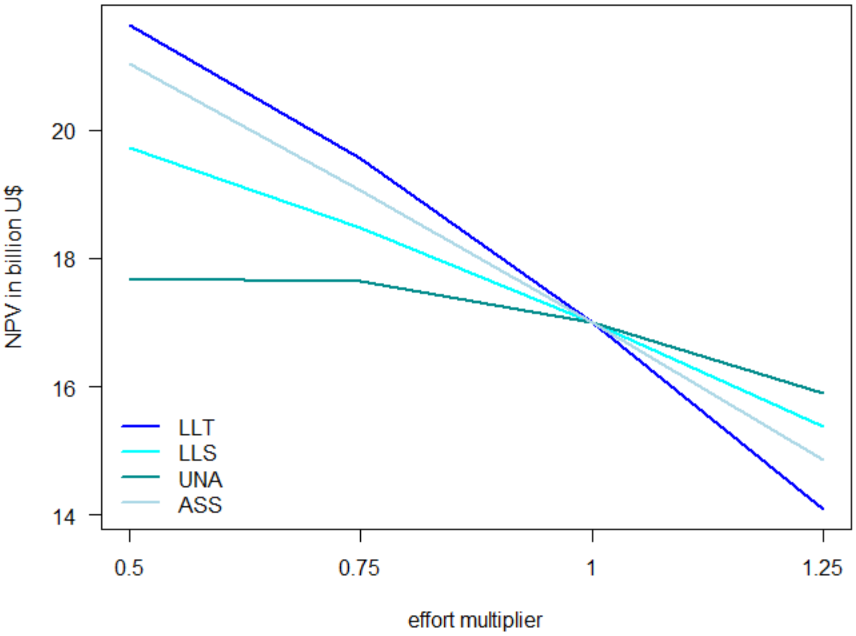


Figure 9: NPV in USD dollars (billions) over the next 20 years for each individual fishery (tropical longlining (LLT), southern longlining (LLS), purse seine FAD (ASS) and free school (UNA) fishing, while effort in the other three effort groups remained at the 2012 level.

6. Appendices

6.1 Appendix 1

Table A1.1: Coordinates of the different assessment areas for the four main tuna species in the WCPO.

Species	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
Albacore	25S-0 140E-180E	25S-0 180E-110W	50S-25S 140E-180E	50S-25S 180E-110W	25S-0 110W-70W	50S-25S 110W-70W			
Skipjack	20N-40N 120E-150W	0-20N 140E-170E & 5S-0 155E-170E & 5S-20S 160E-170E	20S-20N 170E-150W	20N-10S 110E-140E	5S-20S 140E-160E & 5S-0 140E-155E				
Yellowfin	20N-50N 120E-170E	20N-50N 170E-150W	0-20N 140E-170E & 5S- 0 155E-170E & 5S-10S 160E-170E	10S-20N 170E-150W	10S-40S 140E-170E	10S-40S 170E-150W	20N-10S 110E-140E	5S-10S 140E-160E & 5S-0 140E-155E	15S-20S 140E-150E
Bigeye	20N-50N 120E-170E	20N-50N 170E-150W	0-20N 140E-170E & 5S- 0 155E-170E & 5S-10S 160E-170E	10S-20N 170E-150W	10S-40S 140E-170E	10S-40S 170E-150W	20N-10S 110E-140E	5S-10S 140E-160E & 5S-0 140E-155E	15S-20S 140E-150E

Table A1.2. Definition of fisheries for the nine-region MULTIFAN-CL analysis of yellowfin and bigeye tuna.

Fishery	Nationality	Gear	Region
1. LL ALL 1	Japan, Korea, Chinese Taipei	Longline	1
2. LL ALL 2	Japan, Korea, Chinese Taipei	Longline	2
3. LL HW 2	United States (Hawaii)	Longline	2
4. LL ALL 3	All, except CT-Offshore, CN, FSM, MH, PH, ID, and PW	Longline	3
5. LL TW-CH 3	Eastern LL region 3: CT-Offshore, CN, FSM, MH, PH, PW, and ID	Longline	3
6. LL TW-CH 7	Western LL region 7: CT-Offshore, CN, FSM, MH, PH, PW, VN, and ID	Longline	7
7. LL ALL 7	All, except CT-Offshore, CN, FSM, MH, PH, ID, and PW	Longline	7
8. LL ALL 8	Japan, Korea, Chinese Taipei, Papua New Guinea	Longline	8
9. LL ALL 4	All, includes CT-Offshore, CN, FSM, MH, PH, ID, and PICTs; excludes United States	Longline	4
10. LL HW 4	United States (Hawaii)	Longline	4
11. LL AU 5	Australia	Longline	5
12. LL ALL 5	All excl. Australia	Longline	5
13. LL ALL 6	All, includes CT-Offshore, CN, FSM, MH, PH, ID, PICTs, and US	Longline	6
14. PS ASS 3	All	Purse seine, log/FAD sets	3
15. PS UNS 3	All	Purse seine, school sets	3
16. PS ASS 4	All	Purse seine, log/FAD sets	4
17. PS UNS 4	All	Purse seine, school sets	4
18. PH MISC 7	Philippines	Miscellaneous (small fish), including purse seine within PH archipelagic waters.	7
19. PH HL 7	Philippines, Indonesia	Handline (large fish)	7
20. PS JP 1	Japan	Purse seine, all sets	1
21. PL JP 1	Japan	Pole-and-line	1
22. PL ALL 3	All, except Indonesia	Pole-and-line	3
23. PL ALL 8	All	Pole-and-line	8
24. ID MISC 7	Indonesia	Miscellaneous (small fish), including purse seine within ID archipelagic waters.	7
25. PS PHID 7	Philippines and Indonesia	Offshore purse seine in waters east of about 125°E (and outside of PH and ID archipelagic waters).	7
26. PS ASS 8	All	Purse seine, log/FAD sets	8
27. PS UNS 8	All	Purse seine, school sets	8
28. LL AU 9	Australia	Longline	9
29. PL ALL 7	All	Pole-and-line	7
30. L ALL 9	All	Longline	9
31. PS ASS 7	All (excludes IDPH domestic)	Purse seine, log/FAD sets	7
32. PS UNS 7	All (excludes IDPH domestic)	Purse seine, school sets	7
33. PS	VN		7

Table A1.3: Definition of fisheries for the five-region MULTIFAN-CL analysis of skipjack tuna

Fishery	Nationality	Gear	Region
1. PL JP 1	JP	Pole and Line	1
2. PS ALL	ALL	Purse seine	1
3. LL JP 1	JP	Longline	1
4. PL JP 2	JP	Pole and Line	2
5. PS ASSOC 2	AU,CN,EP,EC,SV,FM,FR,IDDW,JO, JPDW,JOOS,JP,KI,KR,MH,MX,NZ,PG,PHDW, SU,SB,ES,TWOS,TW,TV,USHW,US,VU,VN	Purse seine	2
6. PS UNASSOC 2	AU,CN,EP,EC,SV,FM,FR,IDDW,JO,JPDW, JOOS,JP,KI,KR,MH,MX,NZ,PG,PHDW,SU, SB,ES,TWOS,TW,TV,USHW,US,VU,VN	Purse seine	2
7. LL JP 2	JP	Longline	2
8. PL ALL 5	ALL	Pole and Line	5
9. PS ASSOC 5	ALL	Purse seine	5
10. PS UNASSOC 5	ALL	Purse seine	5
11. LL JP 5	JP	Longline	5
12. PL 3	ALL	Pole and Line	3
13. PS ASSOC 3	AU,CN,EP,EC,SV,FM,FR,IDDW,JO, JPDW,JOOS,JP,KI,KR,MH,MX,NZ,PG,PHDW, SU,SB,ES,TWOS,TW,TV,USHW,US,VU,VN	Purse seine	3
14. PS UNASSOC 3	AU,CN,EP,EC,SV,FM,FR,IDDW,JO,JPDW, JOOS,JP,KI,KR,MH,MX,NZ,PG,PHDW,SU, SB,ES,TWOS,TW,TV,USHW,US,VU,VN	Purse seine	3
15. LL JP 3	JP	Longline	3
16. Dom PH 4	PH	Domestic	4
17. Dom ID 4	ID	Domestic	4
18. IDID, PHPH	ID,PH	Purse seine	4
19. PL 4	ALL	Pole and Line	4
20. PS ASSOC 4 !(PHPH, IDID, VN)	PH, ID, VN	Purse seine	4
21. PS UNASSOC 4 !(PHPH, IDID, VN)	PH, ID, VN	Purse seine	4
22. DOM VN	VN	Domestic (!L)	4
23. LL JP 4	JP	Longline	4

Table A1.4: Definition of fisheries for the six-region MULTIFAN-CL analysis of albacore tuna

Fishery	Nationality	**Gear**	**Region**
1. JP LL 1	Japan	Longline	1
2. KR LL 1	Korea	Longline	1
3. TW LL 1	Chinese Taipei	Longline	1
4. AU LL 1	Australia	Longline	1
5. NC LL 1	New Caledonia	Longline	1
6. FJ LL 1	Fiji	Longline	1
7. OTHER LL 1	Other	Longline	1
8. JP LL 2	Japan	Longline	2
9. KR LL 2	Korea	Longline	2
10. TW LL 2	Chinese Taipei	Longline	2
11. AS,WS LL 2	American Samoa, Samoa	Longline	2
12. TO LL 2	Tonga	Longline	2
13. PF LL 2	French Polynesia	Longline	2
14. OTHER LL 2	Other	Longline	2
15. JP LL 3	Japan	Longline	3
16. KR LL 3	Korea	Longline	3
17. TW LL 3	Chinese Taipei	Longline	3
18. AU LL 3	Australia	Longline	3
19. NZ LL 3	New Zealand	Longline	3
20. OTHER LL 3	Other	Longline	3
21. JP LL 4	Japan	Longline	4
22. KR LL 4	Korea	Longline	4
23. TW LL 4	Chinese Taipei	Longline	4
24. OTHER LL 4	Other	Longline	4
25. TROLL 3	New Zealand, United States	Troll	3
26. TROLL 4	New Zealand, United States	Troll	4
27. DN 3	Japan, Chinese Taipei	Drift net	3
28. DN 4	Japan, Chinese Taipei	Drift net	4
29. OTHER LL 5	Other	Longline	5
30. OTHER LL 6	Other	Longline	6

6.2 Appendix 2

Table A2.1: Proportion of different species caught by individual longline fleets in the economic strata.

	Area1&2	Area 3	Area 4	Area 5	Area 6	Area 7
			Bigeye tuna			
AU				0.04		
CN		0.21	0.29	0.29	0.29	
FJ				0.1	0.21	
ID						
JP	0.75	0.31	0.05	0.1		
KR		0.13	0.14			
NC				0.1		
TW	0.1	0.1	0.09	0.26	0.15	0.12
US	0.01		0.06		0.08	
VU			0.16	0.06	0.12	
oth	0.14	0.25	0.21	0.04	0.16	0.88
			Yellowfin tuna			
AU				0.2		
CN		0.15	0.19	0.16	0.19	
FJ				0.04	0.13	
ID						0.52
JP	0.66	0.22	0.07	0.19		
KR		0.33	0.41			
NC				0.03		
TW	0.03	0.15	0.15	0.31	0.32	0.08
US	0.28		0.06		0.03	
VN						0.27
VU			0.02	0.04	0.09	
oth	0.04	0.14	0.08	0.02	0.18	0.13
			Albacore tuna			
AU				0.14		
CN		0.06	0.13	0.08	0.14	
FJ				0.06	0.28	
ID						0.57
JP	0.63	0.31	0.09	0.2		
KR		0.28	0.45			
NC				0.06		
TW	0.3	0.2	0.13	0.3	0.29	0.1
US	0.06		0.04		0.06	
VN						0.32
VU			0.05	0.04	0.08	
oth	0.02	0.14	0.1	0.11	0.1	0.03
			Other tuna			
FJ					0.23	
JP	0.33	0.02				
KR	0	0.24	0.2			
TW	0.46	0.22	0.09	0.99	0.02	0.98
US	0.21		0.32		0.31	
VU			0.16		0.13	
oth	0.01	0.51	0.24		0.29	0.02
Billfish						
AU				0.4		
CN		0.12	0.2	0.09	0.14	
FJ				0.03	0.1	
ID						0.86
JP	0.63	0.22	0.07	0.16		

KR	0	0.22	0.33			
NC				0.05		
TW	0.23	0.32	0.24	0.21	0.11	0.06
US	0.13		0.06		0.04	
VN						0.06
VU			0.04	0.02	0.06	
oth		0.12	0.08	0.03	0.52	0.03
Sharks						
AU				0.15		
CN		0.04	0.05	0.07	0.04	
FJ				0.01	0.08	
ID						0.62
JP	0.54	0.04	0.02	0.15		
KR		0.45	0.59			
NC				0.01		
TW	0.4	0.44	0.19	0.54	0.19	0.01
US	0.06		0.13		0.05	
VN						0.36
VU			0.01	0.02	0.01	
oth		0.02		0.02	0.61	
Other species						
AU				0.1		
CN		0.07	0.1	0.08		
FJ				0.05	0.23	
ID						
JP						
KR		0.11	0.18			
NC				0.11		
TW	0.52	0.63	0.3	0.55	0.02	1
US	0.44		0.25		0.31	
VU			0.06	0.05	0.13	
oth	0.03	0.19	0.11	0.05	0.29	

Table A2.2: Proportion of different species caught by individual purse seine fleets in the economic strata.

	Area 1&2	**Area 3 (Ass)**	**Area 3 (Una)**	**Area 4 (Ass)**	**Area 4 (Una)**	**Area 7 (Ass)**	**Area 7 (Una)**
				Bigeye tuna			
CN		0.05	0.06				
ID						0.51	0.36
JP	1.00	0.04	0.06		0.03		
KI					0.23		
KR		0.09	0.22	0.10	0.46		
MH		0.12					
PG		0.11	0.15	0.30	0.15		
PH		0.03	0.12			0.28	0.50
SB				0.06			
TW		0.18	0.14	0.07			
US		0.18	0.11	0.17	0.04		
VN						0.20	0.13
VU				0.13			
oth		0.20	0.13	0.18	0.09	0.01	0.01
				Yellowfin tuna			
CN		0.06	0.03				
ID						0.48	0.43
JP	1.00	0.10	0.18		0.06		
KI					0.12		
KR		0.11	0.21	0.10	0.36		
MH		0.08					
PG		0.12	0.15	0.24	0.22		
PH		0.04	0.05			0.36	0.42
SB				0.11			
TW		0.15	0.13	0.04			
US		0.18	0.14	0.17	0.09		
VN						0.14	0.14
VU				0.20			
oth		0.16	0.11	0.14	0.15	0.02	0.01
				Skipjack tuna			
CN		0.07	0.02				
ID						0.55	0.49
JP	1.00	0.03	0.12		0.10		
KI					0.10		
KR		0.09	0.26	0.08	0.49		
MH		0.06					
PG		0.18	0.18	0.26	0.16		
PH		0.07	0.14			0.33	0.40
SB				0.25			
TW		0.16	0.11	0.05			
US		0.15	0.07	0.12	0.03		
VN						0.11	0.11
VU				0.12			
oth	0.01	0.19	0.09	0.12	0.12	0.01	0.00

Table A2.3: Proportion of effort by individual longline fleets in the economic strata.

	LL1&2	**LL3**	**LL4**	**LL5**	**LL6**	**LL7**
AU				0.07		
CN		0.16	0.23	0.27	0.28	
FJ				0.1	0.25	
ID						0.55
JP	0.48	0.18	0.06	0.11		
KR		0.23	0.33			
NC				0.05		
TW	0.35	0.28	0.16	0.27	0.14	0.14
US	0.13		0.07		0.07	
VN						0.27
VU			0.05	0.07	0.11	
oth	0.05	0.16	0.1	0.05	0.15	0.04

Table A2.4: Proportion of effort by individual purse-seine fleets in the economic strata.

	PS1	**PSA3**	**PSU3**	**PSA4**	**PSU4**	**PSA7**	**PSU7**
CN		0.07	0.05				
ID						0.45	0.40
JP	1.00	0.07	0.14		0.07		
KI					0.10		
KR		0.08	0.15	0.12	0.43		
MH		0.06					
PG		0.17	0.17	0.17	0.17		
PH		0.06	0.10			0.31	0.36
SB				0.17			
TW		0.14	0.16	0.05			
US		0.16	0.12	0.17	0.08		
VN						0.24	0.24
VU				0.13			
oth		0.17	0.11	0.19	0.15	0.00	0.00