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Biological and economic consequences of alternative trajectories to achieve a candidate south Pacific albacore target reference point

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Rarotonga, Cook Islands
9 – 17 August 2017

BIOLOGICAL AND ECONOMIC CONSEQUENCES OF ALTERNATIVE TRAJECTORIES TO ACHIEVE A CANDIDATE SOUTH PACIFIC ALBACORE TARGET REFERENCE POINT

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Summary

Following biological and economic objectives for the south Pacific albacore fishery proposed at the WCPFC 2nd MOW, and associated analyses presented to SC11 and the 2015 WCPFC Harvest Strategy Workshop meeting, a delegation paper was submitted to WCPFC12 proposing an interim Target Reference Point (TRP) for the south Pacific albacore stock of 45% $SB_{F=0,\ 2003\text{-}2012}$. That proposal was based upon the positive consequences that increases in stock biomass would have for catch rates, a primary driver of profitability and economic viability in the fishery.

The recovery/rebuilding of a stock to a specified level (be it a target or limit reference point) within a given timeframe can be achieved through many different trajectories that have very different implications for the fisheries exploiting the stock. To support further discussions of candidate TRPs for the south Pacific albacore stock and southern longline fishery, paper SC12-MI-WP-01:

1. Examined the potential consequences of continued fishing at recent levels for the south Pacific albacore stock, to provide baseline scenarios;
2. Examined the biological and economic consequences of alternative trajectories to achieving the candidate TRP by 2033 (a 20 year recovery period).

SC12 recommended a revised version of the paper be forwarded to WCPFC13. Here we concentrate on the findings and discussion. The approach for biological and economic modelling, and alternative input values used, is described in detail in Appendix 1, and summarised as: using deterministic projections, biological and economic consequences of status quo (2013) effort and catch scenarios were examined for the south Pacific albacore stock and longline fishery. Three alternative management interventions recovering the stock to a candidate TRP of 45% $_{SBF=0}$ over 20 years were also examined:

1. 'Take the reduction early': an immediate one-off effort cut;
2. 'Delay the reduction': making a one-off effort cut in 2024;
3. 'Spread the reduction': reduce effort every year by a fixed annual percentage.

To provide context, across the nine stock assessment models used, average 2013 stock status (the last year of the assessment) was 41%$SB_{F=0}$. Status quo conditions led to both stock and CPUE declines, and significantly reduced profits over the next 20 years:

- The stock was reduced to 32% $SB_{F=0}$ with <u>effort</u> at 2013 levels, implying a 20% risk of the stock falling below the limit reference point (LRP), while longline CPUE was estimated to decline by 14% from 2013 levels over the projection period. Fishery profits declined under base case economic conditions, while losses were predicted under pessimistic economic conditions;
- The stock was reduced to 23%$SB_{F=0}$ with <u>catch</u> at 2013 levels. The decline was greater than under the status quo <u>effort</u> scenario; where effort is constant, catch declines as stock size declines. Achieving constant catch from a declining stock biomass required over a doubling of fishing effort by 2033, led to a reduction in CPUE by 32%, economic losses under all economic conditions, a 41% risk of falling below the limit reference point, and a risk of stock collapse.

Economic performance was much improved under the effort reduction scenarios that achieved the TRP by 2033. While final year profits when the TRP had been achieved were similar under all scenarios,

profits earned in each year of the transition period varied considerably. In turn, there remained some risk of economic losses under pessimistic economic conditions when the stock was at the TRP:

1. 'take the reduction early': the stock achieved the TRP within 5 years after an immediate cut in effort to 53% of 2013 levels, then remained at equilibrium around the TRP level. This scenario minimised short-term reductions in stock size. The total net present value of profits over the projection period was the highest of the scenarios examined, under base case and pessimistic economic conditions. Under base case economic conditions annual profit in the first projection year (2014) was only marginally lower than under all the other scenarios, despite the 47% cut in effort and assumed 47% reduction in vessel numbers, then profits were the highest from the 2nd projection year (2015) onwards. The positive CPUE response associated with cutting effort early results in increased individual vessel profits that offset much of the reduction in total fishery profit due to reduced vessel numbers. Annual fishery and vessel profits and CPUE under the other scenarios continue to decline rapidly until at least the 4th projection year (2017) whereas under the reduce effort early scenario, profits decline marginally between the 1st and 2nd projection years (2014 and 2015) before increasing slowly thereafter, along with CPUE.
2. 'delay the reduction': a slightly larger cut in effort in 2024, to 49% of 2013 levels was required following initial stock declines. The TRP was then achieved within 10 years. Economically, this was the worst performing scenario as the maintenance of current effort levels in the fishery until 2024 drives CPUE and fishery profits down.
3. 'spread the reduction': an annual 3% effort cut was required to achieve the TRP in 2033 exactly. Effort was reduced to 43% of 2013 effort levels over the 20 year period. This scenario's economic performance was in between the other two, although it was out-performed by both other scenarios in later years. Nevertheless, the gradual but steady reductions in effort supported improvements in fishery profitability year on year, and overall a higher discounted Net Present Value (NPV) compared to the 'delay the reduction' scenario.

Following these results, we also note that:

- Displacement costs to vessels exiting the fishery were not included, but will influence results.
- Fleets are assumed to decline proportionately with any decline in effort, implying cost per hook remains constant after any effort cuts. However, if vessel reductions are not proportional to those in effort (e.g. individual vessels just use fewer hooks), this would increase the cost per hook.
  - The three economic conditions examined provide some sensitivity around prices and costs, but remain fixed over the 20 years. Economic indicator analyses of the fishery (WCPFC-SC12-2016/ST-WP-04) suggest the likelihood of optimistic conditions occurring is decreasing over time. Managers should consider the likelihood of good and bad economic conditions, and resulting tradeoffs and risks, when selecting a robust management strategy.
- Performance of an implemented scenario should be monitored, to allow adjustment in the face of future recruitment levels, unforeseen shifts in fishing strategies, implementation issues, and changes in catch levels, prices and operating conditions that affect economics.
- Economic performance is affected by the assumed level of key bycatch species. In the real world, this will also mean that economic performance is affected by other WCPFC fisheries.

This study demonstrates that the choice of management scenario to achieve a stock TRP must consider its economic and social implications across the specified time horizon, including the value operators place on their investment. While a 20 year recovery timescale was used here, ultimately managers must decide over what period, and how, effort is to be managed to achieve fishery objectives.

Table 1 Average stock and fishery status under i) status quo conditions, and ii) using alternative approaches to achieve the candidate TRP by 2033, from deterministic projections. Minimum, median and maximum annual fishery profit and cumulative NPV discounted at 5% under the three economic scenarios (across the 20 year period) are also presented.

	LL effort scalar (2013)	Median $SB_{2033}/SB_{F=0}$	Median longline VB_{2033}/VB_{2013}	Median albacore catch ($Catch_{2033}/Catch_{2013}$)	NPV base case (US$ mils)	Fishery profit base case		Fishery profit optimistic	Fishery profit pessimistic
Status quo effort	1	0.32	0.86	0.72	185.6	Min	2.3	115.6	-111.0
						Med	4.1	117.8	-109.5
						Max	71.8	199.1	-55.4
Status quo catch	-	0.23	0.68	1	-2562.8	Min	-323.1	-134.7	-512.4
						Med	-283.5	-96.4	-470.6
						Max	71.8	199.1	-55.4
Cut effort in 2014	0.53	0.45	1.17	0.59	734.7	Min	41.8	110.0	-55.4
						Med	52.9	123.2	-18.0
						Max	71.8	199.1	-15.5
Status quo effort to 2023, cut effort in 2024	0.49	0.45	1.17	0.55	384.2	Min	2.3	79.6	-111.0
						Med	32.7	117.4	-55.4
						Max	71.8	199.1	-11.3
Cut effort by 3% per annum, starting 2015	0.43 in 2033	0.45	1.17	0.50	465.1	Min	8.8	110.3	-99.1
						Med	34.9	117.0	-55.4
						Max	71.8	199.1	-7.4

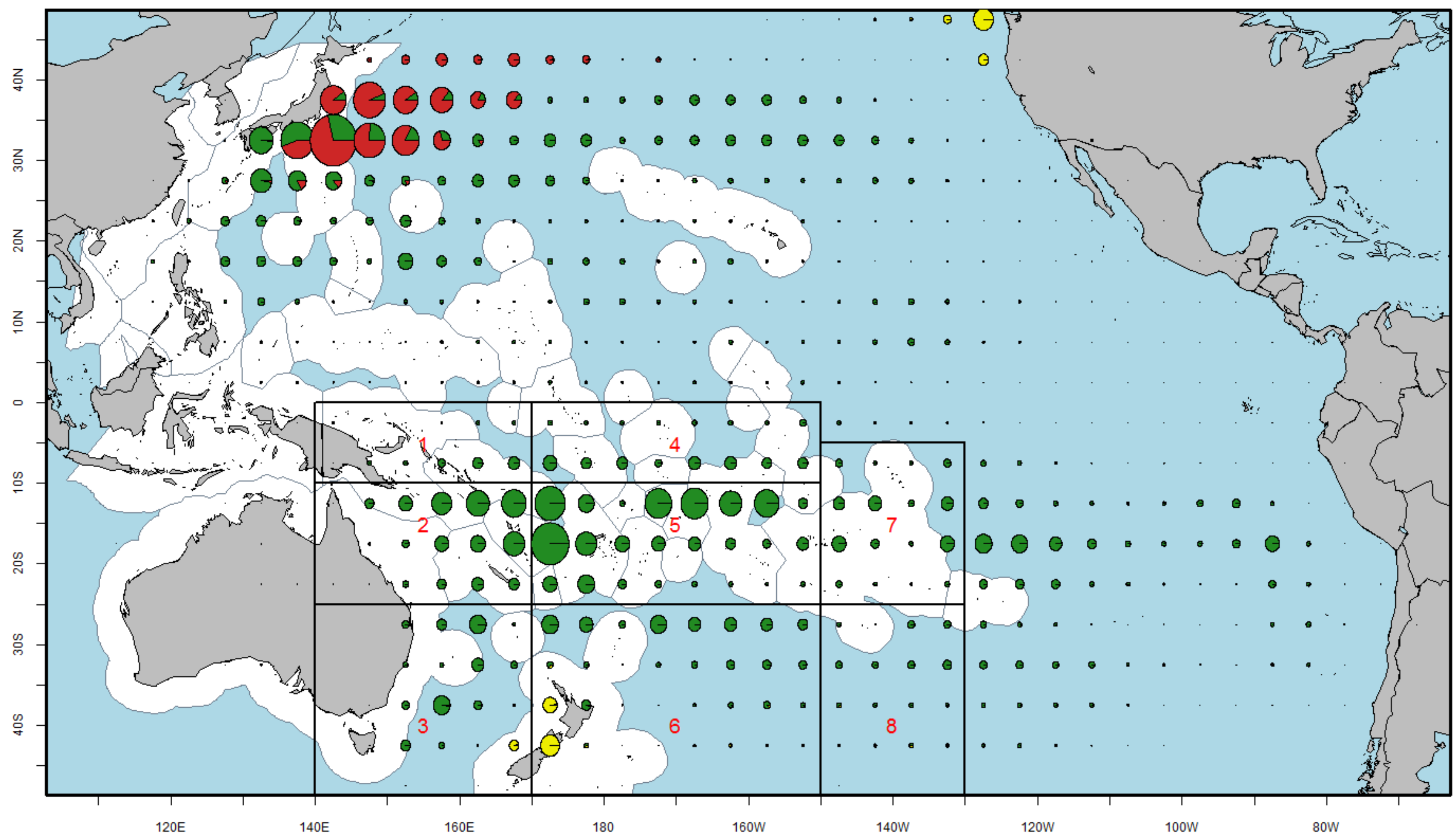

Figure 1. Regions of the albacore stock assessment overlaying catch distribution (2004-2013). Catch distribution is by 5° square and fishing method: longline (green), pole-and-line (red), and other (yellow) for the entire Pacific Ocean.

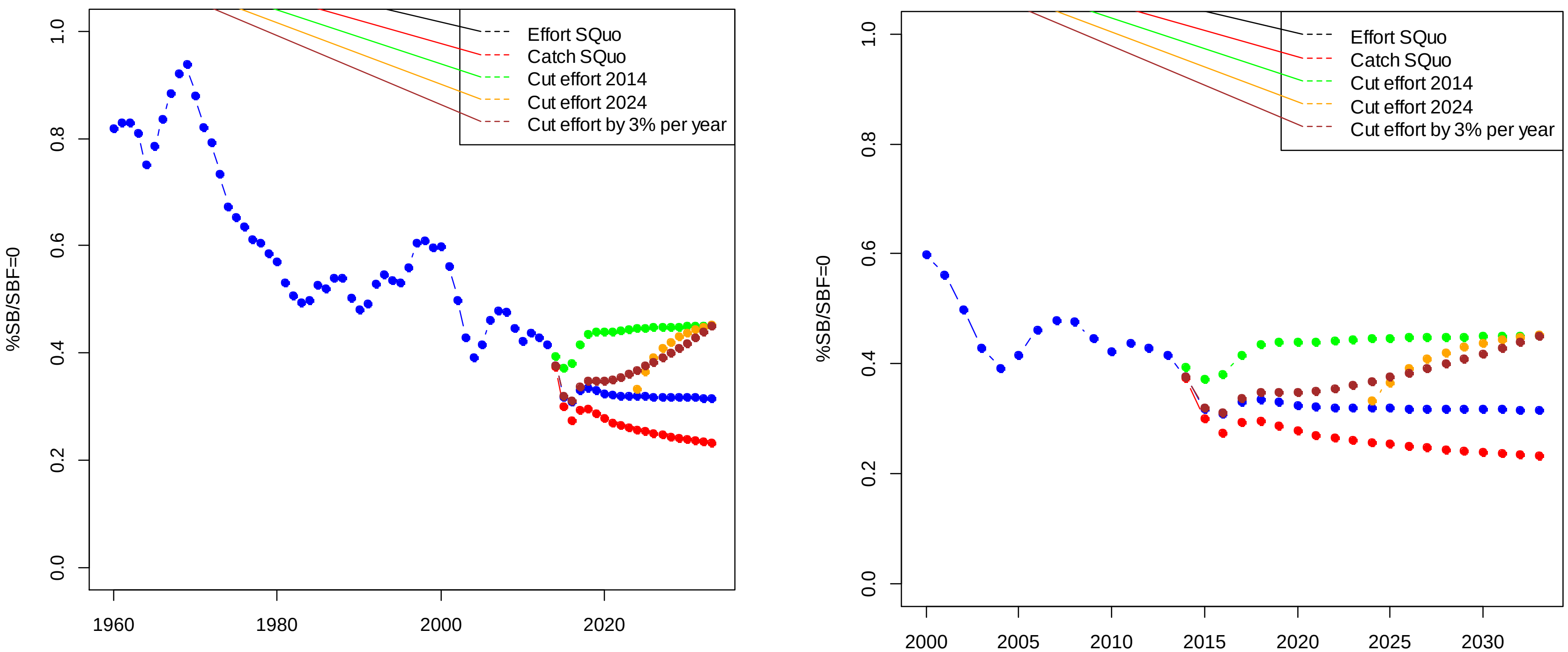

Figure 2. Deterministic stock status trajectories under alternative management scenarios; left: full time series; right: shortened time series.

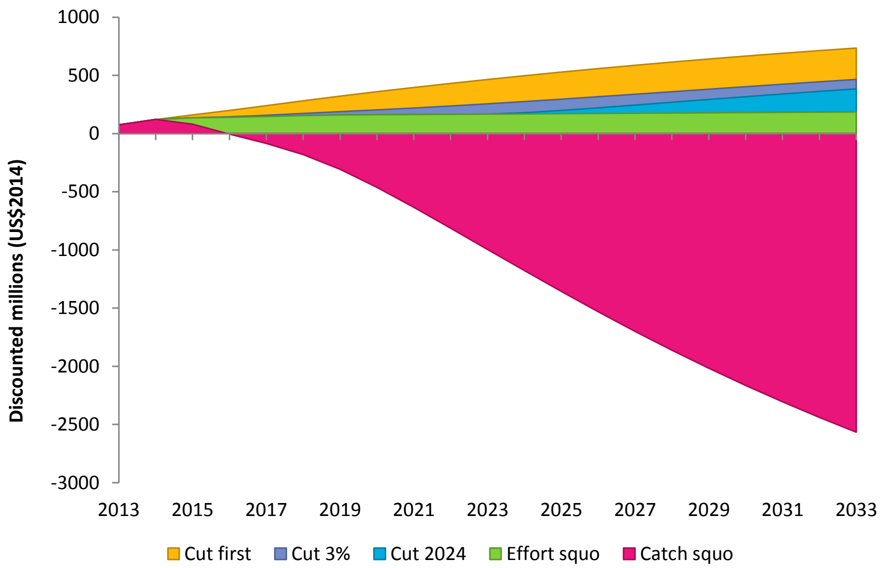

Figure 3. Discounted cumulative net present value of profits for the southern longline fishery under the 5 scenarios, using 'base case' cost and prices. Real discount rate is set at 5% to reflect opportunity cost of capital investment.

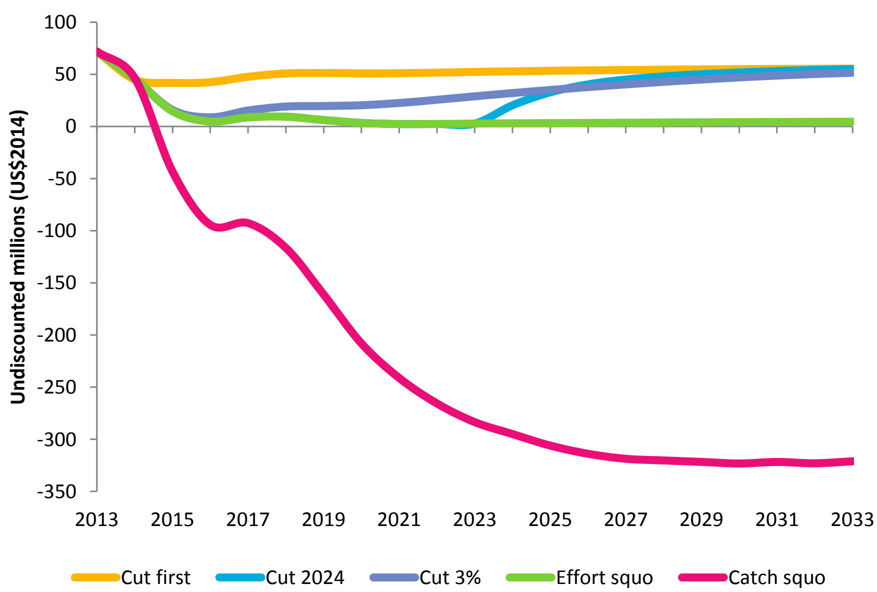

Figure 4. Undiscounted annual profits for the southern longline fishery under the 5 scenarios, in USD millions, using 'base case' cost and prices.

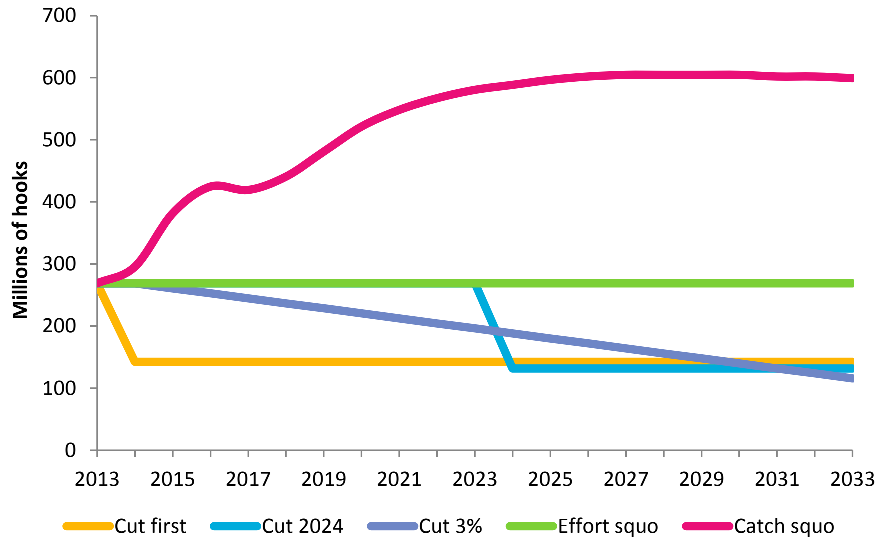

Figure 5. Effort required in the southern longline fishery under the 5 scenarios, in millions of hooks.

Appendix 1: Summary of analysis approach

The analysis was undertaken in two phases. In the first, deterministic stock projections were performed under different southern longline fishery scenarios to identify stock trajectories that achieved the candidate TRP by 2033. In the second, catch estimates developed from those projections were used to assess the consequences of the different interventions for the profitability of southern longline fleets.

South Pacific albacore stock projections

All projections were performed based upon the 2015 assessment for south Pacific albacore. Deterministic 20 year projections were run for five scenarios. Given the iterative nature of the approach required to identify appropriate levels of effort reduction that recover the stock to the TRP within 20 years, and the need to incorporate economic analyses, it was not practical to use stochastic projections here. Deterministic projections are felt to provide an indication of the 'average' future outcome from each model. The first two scenarios examined the consequences of status quo conditions, assuming effort or catch would remain unchanged into the future:

1. No change in effort levels (2013 longline effort kept constant into the future), regardless of the likelihood that at least some effort would become unprofitable;
2. No change in catch levels (2013 longline catch kept constant into the future; this scenario assumes effort will increase if the stock declines, in order for the same annual catch to be taken). This scenario also assumes that additional effort would be possible in spite of the deteriorating profitability that would occur with such stock declines.

The final three scenarios recovered the south Pacific albacore stock to the candidate TRP over a 20 year timescale by manipulating longline effort. Although there are many different scenarios through which the stock could be managed to achieve the candidate TRP over that time period, the following three scenarios attempt to bracket the possibilities:

3. 'Take the reduction early': Achieve the TRP in 2033 through an immediate one-off cut in fishing effort;
4. 'Delay the reduction': Achieve the TRP in 2033 by maintaining status quo effort until 2023 (10 years), then making a one-off cut in fishing effort in 2024 sufficient to recover the stock to the TRP over the final 10 years;
5. 'Spread the reduction': Achieve the TRP in 2033 by reducing effort every year from 2015 to 2033 by a fixed annual percentage (a step-by-step reduction). This approach aims to minimize shocks to the system; given the potential implications for markets, industry etc. of a sudden reduction in effort, this may represent a more practical management intervention.

In each scenario, an iterative approach was taken to identify the exact amount of effort that needed to be removed from the southern longline fishery to achieve the candidate TRP by 2033 under each scenario.

Uncertainty within deterministic projections

Stock projections were deterministic, with future recruitment assumed to represent the average level defined by the stock recruitment relationship for a given underlying adult biomass. Projections were run across the subset of assessment runs selected by SC11 to capture existing uncertainty in our knowledge of south Pacific albacore. Results were weighted according to the decisions of SC11. The main assumptions made within the projections were:

- Nine alternative assessment runs from the 2015 south Pacific albacore stock assessment uncertainty grid were used to capture uncertainty in 'current' stock status and biological characteristics. These runs covered alternative stock recruitment relationship steepness assumptions and assumed values of the natural mortality rate (see Table below);
- Future recruitment at a given adult biomass level was defined by the stock-recruitment relationship;
- Catchability (which can have a trend in the historical component of the model) was assumed to remain constant in the projection period at the level estimated in the terminal year of the assessment model;
- Projections were run for twenty years from 2013;
- Levels of effort in the troll fishery were kept constant at 2013 levels.

When examining results, those from each of the nine models were weighted as in the table below, consistent with the approach taken at SC10; the run SC considered most biologically plausible was given the most weight, and results from runs considered less biologically plausible were 'down-weighted'.

Table A1. Nine stock assessment model runs from the 2015 assessment selected to capture uncertainty in current conditions and knowledge of south Pacific albacore biology, and weighting values assigned to each run for analysis of results.

Run #	Settings	Weighting
500	M = 0.30, Steepness 0.80 (ref case)	1
504	M = 0.25, Steepness 0.80	0.8
508	M = 0.40, Steepness 0.80	0.8
512	M = 0.30, Steepness 0.65	0.8
513	M = 0.30, Steepness 0.95	0.8
520	M = 0.25, Steepness 0.65	0.64
521	M = 0.25, Steepness 0.95	0.64
528	M = 0.40, Steepness 0.65	0.64
529	M = 0.40, Steepness 0.95	0.64

The unfished biomass level ($SB_{F=0}$, calculated as the average of the spawning biomass over the period 2003-12 that would have occurred in the absence of fishing) was calculated within each of the nine assessment model runs to ensure consistency with the underlying biological assumptions. The agreed Limit Reference Point was 20% of that unfished level.

From each of the scenarios, the annual south Pacific albacore catch taken in the southern longline fishery was estimated, here defined as the longline fishery operating south of 10°S and excluding the overlap area (attempting to minimise the impact of longline activity frequently focussed on other species on the high seas), i.e. within regions 2, 3, 5 and 6 of the assessment model (see Figure 1). Key fishery parameters (albacore catch and vulnerable biomass (a CPUE proxy)) were also evaluated in this study.

Estimating bycatch levels

For the economic analysis, the amount of key bycatch was estimated to support the calculation of fishery profits. In previous analyses, a regression approach has been used to estimate the catch of non-target species. This approach was maintained for the estimation of equivalent billfish, shark and other species catches. For yellowfin and bigeye, an approach consistent with the regional bioeconomic model was used.

Yellowfin and bigeye

The yellowfin and bigeye stock assessments (Davies et al., 2014 and Harley et al., 2014) were used to underpin the modelling of future southern longline fishery catches of these species.

As the last year in the bigeye and yellowfin assessments was 2012, all fisheries were projected through to 2013 using the reference case stock assessment, with the relevant catch or effort multiplier to ensure the stocks were being projected from the same starting year as that for albacore. From the updated 2013 status, scalars were applied to the effort in fisheries equivalent to the southern longline fishery (specifically fisheries 11, 12, 13, 28 and 30) consistent with each scenario examined for south Pacific albacore. The annual species catches within those fisheries under the different scenarios was then estimated.

One feature of the tropical tuna assessments in the southern region is that they include significant catches from longline fleets targeting tropical tunas. As a result, at the regional scale they do not directly represent the southern longline fleet targeting albacore. Inflated tropical tuna catch levels result. Therefore, the bigeye and yellowfin stock assessments were used to capture stock dynamics resulting from the southern longline fishery management interventions identified, and estimate the resulting 20 year time series of catches of these species. To ensure results were consistent with the catch levels from the albacore targeting fleet, the relative annual change in each of yellowfin and bigeye catch levels from 2013 was calculated for the 20 year projection period. Those relative changes were then applied to the regression-based estimate of yellowfin and bigeye catch in 2013 derived from the south Pacific albacore catch level (as for the other species, below). The resulting time series of bigeye and yellowfin catches were used within the economic calculations.

Other species
Annual albacore catch levels from logsheet information over the period 1990–2012 by longline fleet were related to annual catches of combined billfish, sharks, and a combined 'other species' category, through linear regression. These regressions were used to calculate annual bycatch levels of each species based upon the annual south Pacific albacore catch by fleet estimated within the deterministic stock projections. Linear regressions were fitted to the natural logarithms of the catch data using the *lm*() function in R. Where diagnostics indicated that there was no clear relationship between the level of albacore catch taken by a fleet and the corresponding bycatch species level, a constant catch of that species or group was assumed, being the average over the time period. Oceanic whitetip and silky sharks were excluded from the shark catch data to mimic the future impact of recent non-retention CMMs.

The stock dynamics of key economic bycatch species (bigeye and yellowfin) have therefore been incorporated as realistically as possible through the use of the regional bioeconomic modelling approach. This meant they were no longer directly related to changes in albacore catch rates. The change in approach to estimating bigeye and yellowfin catch levels influenced the performance of fleet profitability under the status quo effort scenario. In particular, it resulted in lower declines in valuable yellowfin catches compared to previous analyses. The use of the regional bioeconomic model for tropical tuna catch estimation does require assumptions on future levels of tropical purse seine and longline fishing, which are important drivers of overall bigeye and yellowfin stock sizes. While a status quo assumption was made in the current analysis, changes in tropical fishing levels will have influences on southern longline fishery profitability.

Obtaining realistic bigeye and yellowfin catch estimates for 'albacore targeting' longliners from the regional bioeconomic model approach proved challenging. Catch estimates were strongly influenced by fleets operating at those latitudes targeting other species. This positively biased profitability to levels that industry feedback suggested were highly unlikely. As the 2015 albacore stock assessment modelled an amalgamated longline fleet for each region, it was not possible to segregate catches effectively. Therefore a pragmatic approach was used taking the regional bioeconomic model estimated trends in yellowfin and bigeye catches under each management scenario, and applying to the catch levels estimated for 2013 through the original regression approach. While this is a step forward from previous analyses, the considerable contribution to revenue from bigeye and yellowfin catches remains an area of uncertainty.

Economic outcomes

Economic outcomes were evaluated based on two measures of performance: undiscounted annual real profits earned in the southern longline fishery, and discounted cumulative Net Present Value (NPV) of these profits over the 20 year projection period. Annual real profits illustrate the economic implications for the fishery *along* the path of each scenario, and were not discounted to assist comparison across scenarios at a particular point in time. In contrast, NPV of these profits were discounted and cumulated to show the accrued profit or loss up to that point in time, taking into account the opportunity cost of capital. More specifically, NPV demonstrates the relative overall costs of transition under each scenario, with the discount rate giving more weight to profits/losses made earlier in the projection period, and less weight to those earned later on. In other words, a dollar of profit next year is valued more highly than a dollar made in twenty years' time.

As noted above, while the biological stock projections look at the biological consequences for the whole of the albacore stock assessment area (Figure 1), the economic analysis concentrated only on the outputs for the southern longline fishery (assessment regions 2, 3, 5 and 6, excluding the overlap area with IATTC). Catches of albacore and bycatch species were therefore estimated for those regions only and used to estimate revenue based upon the average ex-vessel price for each species. Economic costs, not including payments for access fees, were estimated based upon annual effort in number of hooks defined by the different scenarios, and a specified cost per hook.

The general steps taken in this analysis were:

- Obtain 20 year deterministic projections for south Pacific albacore catch and key bycatch species under the 5 scenarios by assessment area;
- Calculate real annual fishery revenue by multiplying long-term average price for each species (US$/mt) with the corresponding catch (mt). Also calculate alternative real annual fishery revenue under different price conditions (±20% of base prices);
- Estimate real cost of fishing using 3 different costs per hook ($0.90, $1.10 and $1.30) for effort (annual number of hooks used) associated with each of the 5 scenarios; and
- Calculate annual economic profits (fishery rent) over the projection period. Compute the cumulative NPV under discount rates of 3%, 5% and 7% per annum, across the 5 stock trajectories and 3 different economic scenarios.

The ‘base case’ economic scenario is estimated using the long-term real price and a cost per hook of US$1.10. However there is considerable uncertainty and fleet-specific variability in prices received and costs incurred, including the effects of subsidies within specific fleets and economic conditions beyond the control of governments or management. Therefore results for two alternative economic scenarios (‘optimistic’ and ‘pessimistic’) were also estimated to provide an analysis of the sensitivity of results to these uncertainties. The optimistic case uses prices that are 20% higher than the long-term real price for species and a lower cost per hook of US$0.90, while the pessimistic case is calculated based on prices that are 20% lower and a cost per hook of $1.30. Fish prices used reflect ex-vessel prices to key markets, and represent ‘real term’ 2014 USD prices. For details on the methodology and values used.

Three price structures were used (low, base, and high prices) to capture recent market fluctuations. The ‘base’ price reflects the long term average price at key regional markets, while the low and high levels were calculated ±20% from that level. Revenues were based on an average price received for an average metric ton of fish caught by species category. Market prices are assumed to be constant (in real terms) throughout the projection period, invariant to the landing location and total catch, and do not take into account any size-based market differences. The lower and higher price structures were designed to examine uncertainties around these assumptions. These prices were applied to the estimated annual catch of albacore from the deterministic projection under each of the 5 effort scenarios, and corresponding catches of other species estimated as defined above.

Although sensitivity is built around prices and costs, prices and costs are not assumed to vary within each economic scenario.

The use of constant price (in real terms) is justified by the fact that, despite some short-term fluctuations, the long-term real price trend for albacore imports into Thailand since 1997 has been relatively flat. Furthermore, a statistical analysis using price, catch and other macroeconomic data from 2000 to 2014 was conducted to examine the short and long run relationship between the volume and price for albacore tuna landed in the WCPO. The results showed that there is insufficient evidence to suggest any co-integrated/sustainable long run price dependence on albacore catch (i.e. no statistically significant price elasticity was detected). Therefore, it is assumed in this analysis that real long-term price is constant and invariant to changes in effort.

Table A2. Real prices and cost used in the economic analysis

Scenario	**Optimistic**	**Base case**	**Pessimistic**
Real costs	**Low**	**Med**	**High**
Per hook (US$2014)	0.9	1.1	1.3
Real prices in US$2014/mt	**20% higher**	**Base**	**20% lower**
Albacore	3480	2900	2320
Yellowfin	11760	9800	7840
Bigeye	13620	11350	9080
Billfish	5400	4500	3600
Shark	1860	1550	1240
Others	2957	2464	1971

Using a constant cost per hook relies on a less realistic assumption that the fleet declines proportionately to declines in effort. Depending on which vessels exit the fishery (e.g. inefficient vessels or efficient but unsubsidized vessels) to exit the fishery, the cost per hook would vary. For example, if the fleet reduces by proportionally less than the number of hooks (efficient but unsubsidized vessels exit), then cost per hook will be higher as each remaining vessel is implied to be deploying less hooks (i.e. relatively more fixed capital costs will need to be included per hook). On the other hand, if less efficient vessels exit the fishery and each remaining vessel is able to deploy more hooks, then the cost per hook should decline.

This issue is also closely linked with the exclusion of wider economic costs such as costs to displaced vessels. For more efficient vessels that are forced to exit the fishery, the cost is likely to be greater compared to inefficient vessels. This is likely to distort the economic outcomes under the 5 effort scenarios, especially under different discount rates. Therefore, further work is planned to look at this two part cost assumption: displacement cost to vessels that exit and cost implications regarding to the change in fleet size compared with changes in effort.

It is also important to note that the economic profits calculated reflect those earned by the harvest sector alone. Costs therefore cover only those incurred in the operation of the vessel (i.e. vessel operating costs, other cash costs and fixed capital costs of remaining vessels), and the opportunity cost of capital. Displacement cost for vessels that exit the fishery and other wider economic benefits to national economics from the fishery, such as employment, on-shore processing and government taxes received etc. are not considered. It is intended in future work to examine this two part cost effect on industry: the displacement cost of vessels that exit, and the cost implications on the vessels which remain in the fishery resulting from disproportionate reductions in vessels numbers to reductions in effort.

The economic analysis is focused only on the profitability of the harvesting sector. Economic losses incurred by those vessels that are forced to exit the industry and from the reduction in other wider economic benefits, such as employment, on-shore processing and government taxes received etc. are not considered. However, if fishing is to continue at the current levels of effort or catch, declines in fleet profits may reduce wider economic benefits regardless. In addition, the analysis assumes that effort reductions will result in proportional reductions to the size of the fleet which may affect the results presented. Nonetheless, while the analysis can be improved by addressing these issues, it clearly illustrates that the different transition paths to achieving the same TRP will result in significantly different economic outcomes.

We also note that this evaluation does not consider whether vessels leaving the fishery move, for example, into the tropical longline fishery rather than being decommissioned. The potential wider effects of management interventions on other fisheries and hence fish stocks, would need to be considered within a framework such as the regional bio-economic model.

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Detailed table of results for effort scenarios under alternative economic conditions and discounting

Table A3. Real annual economic profit of the southern longline fishery under the 5 effort scenarios, not discounted for opportunity cost of capital. Prices and costs for each economic scenario are as in Table A2. All values are expressed in real millions US$2014.

	Base case					Optimistic case					Pessimistic case				
Year	Effort squo	Catch squo	Cut first	Cut 2024	Cut 3%	Effort squo	Catch squo	Cut first	Cut 2024	Cut 3%	Effort squo	Catch squo	Cut first	Cut 2024	Cut 3%
2013	71.8	71.8	71.8	71.8	71.8	199.1	199.1	199.1	199.1	199.1	-55.4	-55.4	-55.4	-55.4	-55.4
2014	45.6	46.4	44.8	45.6	45.6	167.6	179.9	113.6	167.6	167.6	-76.4	-87.0	-23.9	-76.4	-76.4
2015	14.6	-43.1	41.8	14.6	15.8	130.4	108.5	110.0	130.4	128.5	-101.2	-194.8	-26.4	-101.2	-96.8
2016	4.8	-94.3	42.4	4.8	8.8	118.6	65.1	110.7	118.6	116.6	-109.0	-253.8	-25.9	-109.0	-99.1
2017	8.8	-92.7	47.6	8.8	15.3	123.4	64.8	116.9	123.4	121.1	-105.9	-250.2	-21.7	-105.9	-90.5
2018	9.3	-116.4	50.8	9.3	19.1	124.1	45.4	120.8	124.1	122.2	-105.4	-278.2	-19.2	-105.4	-84.1
2019	6.2	-161.1	51.2	6.2	19.6	120.3	8.7	121.3	120.3	119.4	-107.9	-330.9	-18.8	-107.9	-80.3
2020	3.4	-208.0	50.9	3.4	20.3	116.9	-30.6	120.9	116.9	117.0	-110.1	-385.3	-19.1	-110.1	-76.3
2021	2.3	-241.2	51.0	2.3	22.5	115.6	-59.2	121.1	115.6	116.1	-111.0	-423.2	-19.0	-111.0	-71.2
2022	2.4	-265.6	51.6	2.4	25.6	115.7	-80.6	121.7	115.7	116.5	-111.0	-450.6	-18.5	-111.0	-65.3
2023	2.7	-283.5	52.3	2.7	28.9	116.1	-96.4	122.5	116.1	117.0	-110.7	-470.6	-18.0	-110.7	-59.3
2024	3.0	-294.9	52.9	20.3	32.0	116.5	-106.8	123.2	79.6	117.4	-110.4	-483.1	-17.5	-39.1	-53.4
2025	3.2	-306.0	53.3	32.7	34.9	116.7	-116.7	123.8	94.5	117.5	-110.3	-495.3	-17.1	-29.1	-47.7
2026	3.4	-313.8	53.8	40.3	37.7	116.9	-123.8	124.3	103.7	117.5	-110.2	-503.9	-16.8	-23.0	-42.1
2027	3.6	-318.7	54.1	45.0	40.3	117.2	-128.5	124.7	109.3	117.2	-110.0	-508.9	-16.5	-19.3	-36.6
2028	3.8	-320.2	54.4	48.0	42.8	117.4	-130.4	125.1	112.8	116.8	-109.8	-510.1	-16.3	-16.9	-31.3
2029	4.0	-321.6	54.7	50.1	45.0	117.6	-132.0	125.5	115.4	116.1	-109.7	-511.2	-16.0	-15.2	-26.1
2030	4.1	-323.1	54.9	51.8	47.0	117.8	-133.8	125.7	117.4	115.1	-109.5	-512.4	-15.9	-13.9	-21.1
2031	4.3	-321.7	55.1	53.1	48.8	118.0	-133.2	126.0	119.0	113.8	-109.4	-510.2	-15.7	-12.8	-16.3
2032	4.4	-323.0	55.3	54.2	50.2	118.2	-134.7	126.2	120.3	112.2	-109.3	-511.2	-15.6	-12.0	-11.7
2033	4.5	-321.1	55.4	55.0	51.5	118.3	-133.6	126.3	121.3	110.3	-109.2	-508.5	-15.5	-11.3	-7.4

Table A4. Discounted cumulative net present value of the southern longline fishery under the 5 effort scenarios. Prices and costs for each economic scenario are as in Table A2. All values are expressed in real millions US$2014. All values are expressed in real millions US$2014.

	Base case					Optimistic case					Pessimistic case				
Year	Effort squo	Catch squo	Cut first	Cut 2024	Cut 3%	Effort squo	Catch squo	Cut first	Cut 2024	Cut 3%	Effort squo	Catch squo	Cut first	Cut 2024	Cut 3%
2013	75.4	75.4	75.4	75.4	75.4	209.0	209.0	209.0	209.0	209.0	-58.2	-58.2	-58.2	-58.2	-58.2
2014	121.0	121.9	120.3	121.0	121.0	376.6	388.9	322.6	376.6	376.6	-134.5	-145.2	-82.1	-134.5	-134.5
2015	134.9	80.8	160.1	134.9	136.1	500.8	492.2	427.4	500.8	498.9	-230.9	-330.7	-107.2	-230.9	-226.7
2016	139.3	-4.8	198.6	139.3	144.0	608.3	551.3	527.8	608.3	604.7	-329.8	-560.8	-130.7	-329.8	-316.6
2017	146.8	-84.9	239.7	146.8	157.3	714.9	607.3	628.8	714.9	709.3	-421.2	-777.0	-149.5	-421.2	-394.7
2018	154.5	-180.6	281.5	154.5	172.9	817.0	644.6	728.2	817.0	809.8	-507.9	-1005.8	-165.2	-507.9	-463.9
2019	159.4	-306.8	321.6	159.4	188.3	911.2	651.4	823.2	911.2	903.3	-592.5	-1265.1	-180.0	-592.5	-526.8
2020	161.9	-462.0	359.6	161.9	203.5	998.4	628.6	913.4	998.4	990.6	-674.7	-1552.6	-194.2	-674.7	-583.7
2021	163.5	-633.4	395.9	163.5	219.4	1080.6	586.5	999.4	1080.6	1073.1	-753.6	-1853.4	-207.7	-753.6	-634.3
2022	165.1	-813.2	430.8	165.1	236.7	1158.9	531.9	1081.8	1158.9	1152.0	-828.7	-2158.4	-220.3	-828.7	-678.5
2023	166.9	-995.9	464.5	166.9	255.3	1233.8	469.8	1160.8	1233.8	1227.4	-900.0	-2461.7	-231.9	-900.0	-716.7
2024	168.7	-1177.0	496.9	179.3	275.0	1305.3	404.3	1236.5	1282.6	1299.5	-967.8	-2758.3	-242.7	-924.0	-749.5
2025	170.6	-1355.9	528.1	198.4	295.4	1373.5	336.0	1308.9	1337.9	1368.2	-1032.3	-3047.9	-252.7	-941.0	-777.4
2026	172.5	-1530.7	558.0	220.9	316.4	1438.6	267.1	1378.1	1395.7	1433.6	-1093.6	-3328.5	-262.0	-953.9	-800.8
2027	174.4	-1699.7	586.7	244.7	337.8	1500.7	199.0	1444.2	1453.6	1495.8	-1152.0	-3598.3	-270.8	-964.1	-820.2
2028	176.3	-1861.4	614.2	269.0	359.4	1560.0	133.1	1507.4	1510.6	1554.8	-1207.4	-3856.0	-279.0	-972.7	-836.0
2029	178.2	-2016.1	640.5	293.0	381.0	1616.6	69.6	1567.8	1566.1	1610.6	-1260.2	-4101.9	-286.7	-980.0	-848.5
2030	180.1	-2164.2	665.7	316.8	402.6	1670.6	8.3	1625.4	1619.9	1663.3	-1310.4	-4336.6	-294.0	-986.4	-858.2
2031	182.0	-2304.5	689.7	339.9	423.9	1722.1	-49.8	1680.3	1671.8	1713.0	-1358.1	-4559.2	-300.9	-991.9	-865.3
2032	183.8	-2438.7	712.7	362.5	444.7	1771.2	-105.8	1732.8	1721.8	1759.6	-1403.5	-4771.6	-307.3	-996.9	-870.1
2033	185.6	-2565.8	734.7	384.2	465.1	1818.0	-158.7	1782.8	1769.8	1803.2	-1446.8	-4972.8	-313.5	-1001.4	-873.1

Table A5. Sensitivity analysis of cumulative net present value for the southern longline fishery under the 5 effort scenarios, assuming base case economic conditions (Table A2). All values are expressed in real millions US$2014.

Year	5% discount rate					3% discount rate					7% discount rate				
	Effort squo	Catch squo	Cut first	Cut 2024	Cut 3%	Effort squo	Catch squo	Cut first	Cut 2024	Cut 3%	Effort squo	Catch squo	Cut first	Cut 2024	Cut 3%
2013	75.4	75.4	75.4	75.4	75.4	74.0	74.0	74.0	74.0	74.0	76.9	76.9	76.9	76.9	76.9
2014	121.0	121.9	120.3	121.0	121.0	119.6	120.4	118.8	119.6	119.6	122.5	123.3	121.7	122.5	122.5
2015	134.9	80.8	160.1	134.9	136.1	133.8	78.5	159.4	133.8	135.0	136.1	83.0	160.8	136.1	137.3
2016	139.3	-4.8	198.6	139.3	144.0	138.3	-10.4	199.4	138.3	143.2	140.3	0.6	197.8	140.3	144.9
2017	146.8	-84.9	239.7	146.8	157.3	146.3	-95.2	243.0	146.3	157.2	147.4	-75.1	236.7	147.4	157.4
2018	154.5	-180.6	281.5	154.5	172.9	154.6	-198.6	288.1	154.6	174.2	154.6	-163.9	275.4	154.6	171.9
2019	159.4	-306.8	321.6	159.4	188.3	159.9	-337.6	332.3	159.9	191.0	159.0	-278.7	311.9	159.0	185.9
2020	161.9	-462.0	359.6	161.9	203.5	162.7	-511.8	374.9	162.7	208.1	161.2	-417.3	345.9	161.2	199.4
2021	163.5	-633.4	395.9	163.5	219.4	164.6	-707.9	416.4	164.6	226.3	162.6	-567.5	377.7	162.6	213.4
2022	165.1	-813.2	430.8	165.1	236.7	166.5	-917.5	457.1	166.5	246.5	164.0	-722.1	407.7	164.0	228.3
2023	166.9	-995.9	464.5	166.9	255.3	168.6	-1134.8	497.2	168.6	268.7	165.5	-876.3	436.1	165.5	244.0
2024	168.7	-1177.0	496.9	179.3	275.0	170.8	-1354.3	536.5	183.6	292.5	167.0	-1026.2	463.0	175.8	260.3
2025	170.6	-1355.9	528.1	198.4	295.4	173.1	-1575.3	575.0	207.3	317.7	168.6	-1171.6	488.3	191.3	276.9
2026	172.5	-1530.7	558.0	220.9	316.4	175.5	-1795.4	612.7	235.6	344.2	170.1	-1311.0	512.2	209.3	293.6
2027	174.4	-1699.7	586.7	244.7	337.8	178.0	-2012.4	649.6	266.2	371.6	171.6	-1443.2	534.6	227.9	310.4
2028	176.3	-1861.4	614.2	269.0	359.4	180.5	-2224.1	685.6	297.9	399.9	173.0	-1567.4	555.7	246.5	327.0
2029	178.2	-2016.1	640.5	293.0	381.0	183.0	-2430.6	720.7	330.0	428.8	174.5	-1683.9	575.6	264.7	343.3
2030	180.1	-2164.2	665.7	316.8	402.6	185.6	-2632.0	754.9	362.3	458.1	175.9	-1793.4	594.2	282.2	359.2
2031	182.0	-2304.5	689.7	339.9	423.9	188.2	-2826.6	788.3	394.4	487.6	177.2	-1895.2	611.6	299.0	374.6
2032	183.8	-2438.7	712.7	362.5	444.7	190.8	-3016.3	820.8	426.3	517.1	178.5	-1990.8	628.0	315.0	389.5
2033	185.6	-2565.8	734.7	384.2	465.1	193.4	-3199.4	852.4	457.6	546.4	179.8	-2079.6	643.3	330.3	403.7

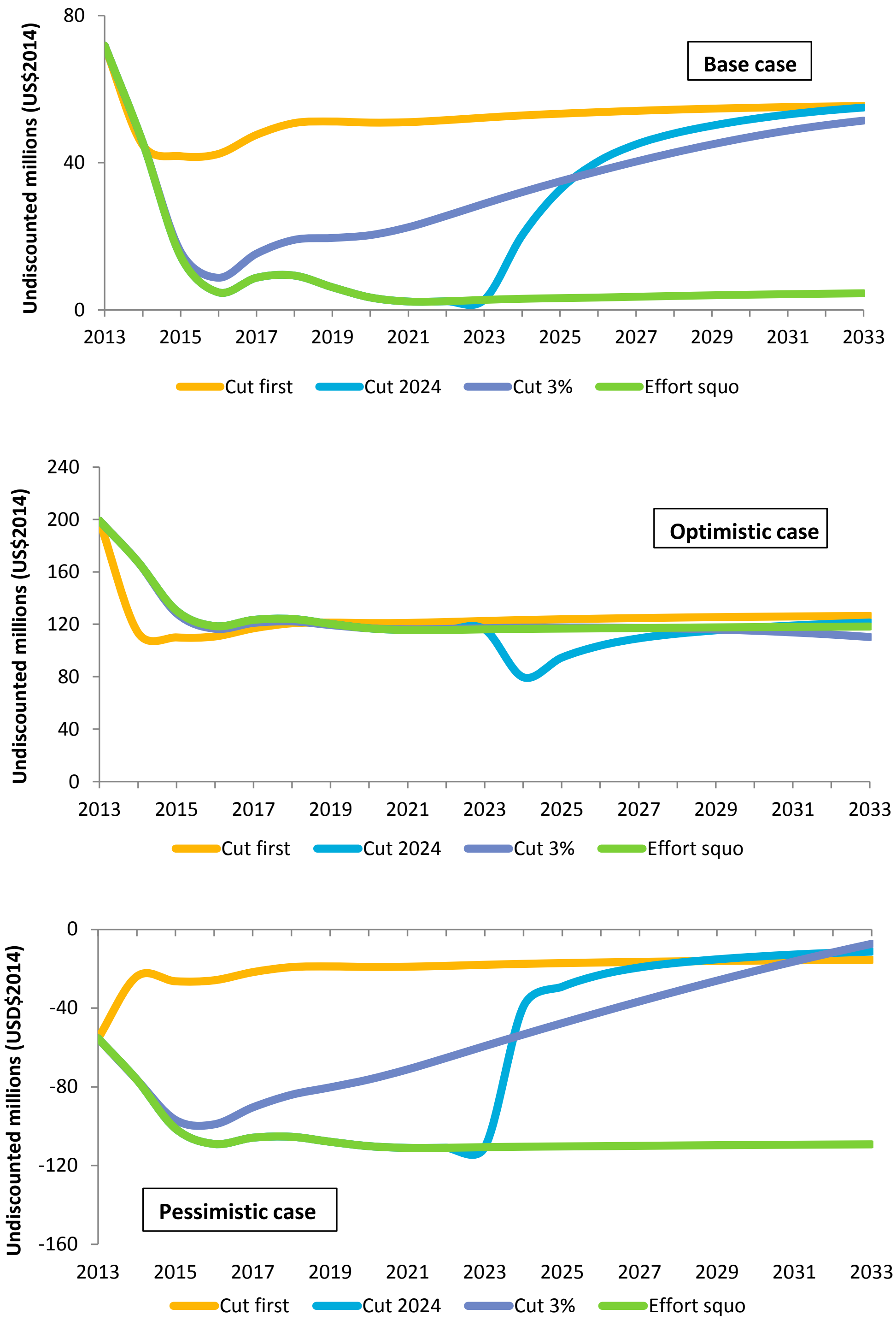

Figure A1. A comparison of undiscounted real annual profit in the southern longline fishery under different economic conditions (see Table A2).

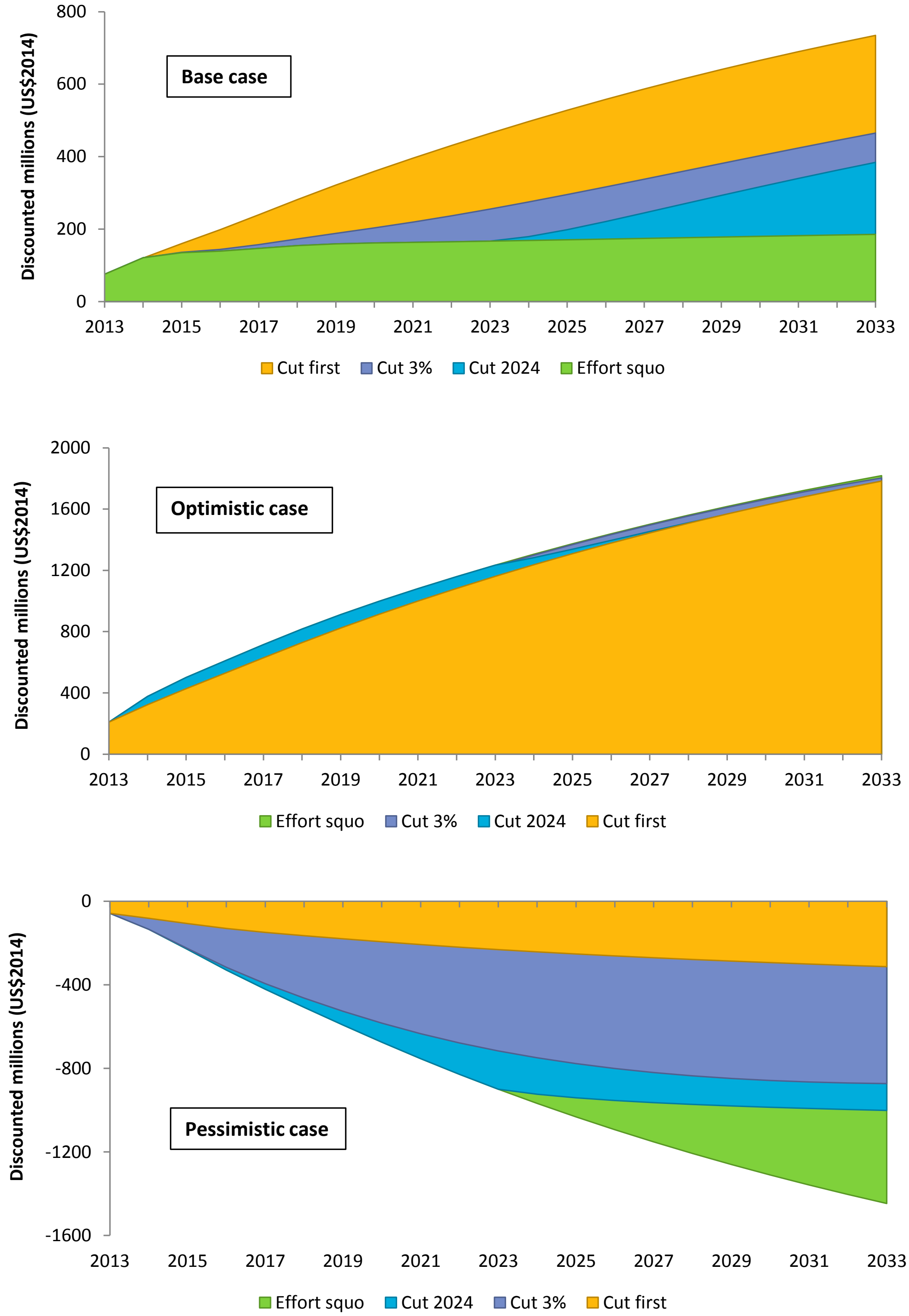

Figure A2. A comparison of net present values for the southern longline fishery under different economic conditions using a discount rate of 5% (see Table A2).