Refining target catch levels for the hoki fishery

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Background

The hoki fishery has an established management target for the eastern and western stocks of 35-50% of the equilibrium, unexploited spawning biomass (SB_0). This target was originally adopted by the Hoki Stock Assessment Working Group in 2008 (?) and subsequently evaluated in 2009 (Langley 2009 and 2011). The evaluation confirmed the appropriateness of the target biomass level (35-50% SB_0).

The lower boundary of the target biomass is set at a level considerably higher than the empirically derived estimate of B_{MSY} (X% for the eastern and western stocks). The target biomass level was established to provide a sufficient buffer to maintain the spawning biomass above the Harvest Strategy Standard (HSS) "soft limit" of 20% SB_0. For the western stock, in particular, there is a considerable lag in the determination of the strength of individual year classes recruiting to the fishery. The target biomass is set at a level that enables the monitoring of a period of poor recruitment and the subsequent introduction of appropriate management measures to minimise the probability of the stock declining below the "soft limit".

Implicit in the establishment of a target biomass level is the determination of a level or levels of catch that is commensurate with the target biomass level. The average level of catch will be primarily determined by the underlying productivity of the stock. The catch levels may be explicitly stated, as would be specified under a formal Management Procedure, or be established in a more implicit manner. There is also an associated management response when the biomass is outside of the target biomass range, specifically the extent that the catch is decreased or increased from the target catch level when the stock biomass is below or above the target biomass range.

This study evaluates a range of alternative catch scenarios for the hoki fishery. The performance of the individual scenarios was evaluated based on a range of indicators relating to the sustainability of the hoki stocks and the operational requirements of the fishery.

Fishery structure and performance indicators

The range of catch scenarios evaluated reflects the current configuration of the hoki fishery. For simplicity, the hoki fishery is divided into four separate spatial and seasonal components: the Chatham Rise (current catch 42 kt), the Sub Antarctic Plateau (15 kt), the west coast South Island (55 kt), and Cook Strait (18 kt). The current fleet configuration and onshore processing capacity limits the catch from the Cook Strait fishery to a maximum of about 18,000 t.

The fishery on the Chatham Rise is primarily operated by a fleet of X fillet vessels. These vessels tend to operate continuously on the Chatham Rise from December to June. Each vessel requires a certain tonnage to operate efficiently and profitably during that period. Thus, a fixed tonnage of catch on the Chatham Rise is required to support a corresponding fleet of X vessels. Lower or higher catch levels would likely result in a change in the number of vessels in the fleet.

The vessels operating on the Chatham Rise also require a certain catch rate of hoki to operate profitably. The fishery is also dependent on maintaining catches of fish above a specific size for efficient processing. These criteria represent key performance measures for the evaluation of alternative target catch levels for the Chatham Rise fishery and the hoki fishery overall.

The Sub Antarctic fishery targets non spawning hoki primarily during XX. However, the magnitude of the catch from the fishery is limited by the number of vessels operating in the fleet (essentially the same fleet that operates in the Chatham Rise fishery) and the spatial (and seasonal) extent of the area of the fishery that supports commercial catch rates of hoki. It is considered that there is limited scope to increase catches substantially from the current level of 15,000 t.

The west coast South Island fishery operates on spawning aggregations of hoki during June-September. Catches from the fishery can be expected to vary in response to recent levels of recruitment to the western stock. During periods of higher abundance, additional fishing capacity (vessels and/or days fished) may be deployed to increase the total catch from the fishery.

Thus, an overall management strategy for the hoki fishery can be formulated that has fixed levels of catch allocated to the Chatham Rise, Sub Antarctic and Cook Strait fisheries and catches from the west coast South Island that fluctuate about a target catch level. The extent of the variation in the catch level for the west coast South Island fishery is a compromise between achieving higher average catches (larger, more frequent changes in the catch level) and maintaining a degree of stability in the catch.

Given these constraints and the specified performance indicators, related to the sustainability of the stocks and the operation of the commercial fishery, a range of catch scenarios were formulated. These scenarios were configured with different levels of catch specified for the Chatham Rise fishery and different levels of target catch specified for the west coast South Island. Catches from the west coast South Island fishery vary from the target level relative to recent biomass levels (for the western stock).

A meeting of key hoki quota owners (19 August 2009, need to reiterate that these are still appropriate) agreed on a range of performance indicators for evaluating alternative management strategies for the hoki fishery. The specific performance indicators are as follow.

i. The maintenance of the hoki stock(s) above a level that would ensure the long-term sustainability of the fishery.
ii. Maximising the overall level of catch from the fishery within the current operating constraints of the fishery.
iii. Stability in the TACC and area catch limits; i.e., relatively infrequent changes in the TACC and relatively small changes in the TACC between years.
iv. The maintenance of catch rates from the main fisheries at or above current (2008/09) levels.
v. The maintenance of the average size of fish in the catch at or above current (2008/09) levels.

These fishery performance indicators were used as the principal criteria for evaluating the range of catch scenarios considered in the analysis. For comparative purposes, a range of metrics were defined that quantified the elements of the individual performance indicators.

Approach

The analysis was based on the primary 2012 hoki assessment model (Run 1.3, “kill em”) (reference). The analysis projected the stock forward for the period 2013 to 2040 from the current (2012) population age structure. Future recruitments were sampled from the estimated annual recruitments from the stock assessment model for the period 1995-2009. For the western and eastern stocks, average recruitment during this period was lower (72% and 88%, respectively) than the long-term average level of recruitment (1972-2009) (Figure 1 and Figure 2).

A range of alternative catch scenarios were defined for the fishery during the projection period. Annual catches for the Cook Strait and Sub Antarctic fisheries were held constant at (approximately) current levels (18,000 t and 15,000 t, respectively). The annual catch from the Chatham Rise fishery was fixed at four alternative levels (32,000 t, 42,000 t, 52,000 t and 62,000 t). Four levels of **target** catch were defined for the WCSI fishery (45,000 t, 55,000 t, 65,000 t and 75,000 t). All combinations of Chatham Rise catches and WCSI target catches were evaluated (4x4=16 options) (Table 1).

During the simulation period the stock was "monitored" by simulated trawl surveys of the Sub Antarctic (western stock) and Chatham Rise (5++ years adult component = eastern stock). The simulated Chatham Rise trawl surveys also provided an estimate of the recent recruitment levels (age 2+ fish) for both stocks combined. All three surveys were assumed to have a moderate level of precision (lognormal error with a coefficient of variation of 30%) that is somewhat lower than the inferred precision from the current stock assessment. The moderate level of precision may allow for a higher degree of variability in the catchability of the individual trawl surveys (of particular relevance to the Sub Antarctic trawl survey).

For each stock, a reference biomass was computed that was compatible to the adult trawl survey biomass estimates. The reference trawl survey biomass (TB_0) was defined as the equilibrium, unexploited biomass generated from the average level of recruitment from the recent period (1995-2010) mediated by the respective trawl survey selectivity in the Sub Antarctic (western stock) or Chatham Rise (eastern stock) area. For the Chatham Rise, the survey biomass excluded the younger age classes (< 5+ years) as these age classes represented a combination of hoki from the western and eastern stocks.

During the projection period, the ratio of the trawl survey biomass to the reference biomass level was used as an indicator of the stock status for the western and eastern stocks. A 3-year moving average of the trawl survey biomass estimates was used to derive the estimate of the current trawl survey biomass ($TB_{current}$). This smoothing approach attempts to mimic the mediation of the trawl survey biomass estimates in the full stock assessment model thus moderating the variability of the individual trawl survey biomass estimates. A range of smoothing approaches were examined with the 3-year MA approach appearing to best replicate the fit of the trawl survey biomass estimates in the stock assessment model.

The actual measure of annual stock status was derived from the ratio of the projected spawning biomass ($SB_{current}$) to the unexploited, equilibrium spawning biomass (SB_0).

Constant catch levels were assumed for the two eastern fisheries (Chatham Rise and Cook Strait). Therefore, the range of candidate scenarios did not utilise the adult biomass estimates from the Chatham Rise trawl survey; however, alternative management scenarios could be formulated to vary the catches in response to changes in the monitored biomass.

For the WCSI fishery, annual catches were set annually (or biennially) in response to the recent trawl survey results ($TB_{current}/TB_0$). This approach represented a proxy for the current assessment and management of the hoki fishery. When the western hoki biomass was "assessed" to be within the defined target biomass level (35-50% B_0), the WCSI catch for the following year was set equal to the target WCSI catch level for the individual scenario. If the western biomass was assessed to be below the target biomass level, the WCSI catch for the following year was reduced. Conversely, if the western biomass was assessed to be above the target biomass level, the WCSI catch for the following year was increased above the target catch level.

The changes (increases or decreases) in WCSI catch are made in 10,000 t increments relative to the target catch level. The magnitude of the change varied depending on the assessed difference between the assessed biomass level and the target biomass level (Figure 4). For an example with a target catch of 42,000 t and a target biomass of 0.425 (the mid-point between the target of 0.35-0.50), if the biomass level was assessed to be 0.10 below the target (0.325 B0) the catch level would be set at the target catch level minus 0.10 * 10,000 * 10 = 32,000 t. The same mechanism for setting the catch limit was applied to increase the biomass when above the target biomass level.

The WCSI catch level was further moderated by the estimate of annual recruitment strength from the Chatham Rise survey. The surveyed 2+ age class is comprised of fish from the western and eastern stock. Thus, the surveys are only immediately informative about the likelihood of weak year classes in both stocks; a relatively low recruitment index indicates that neither the eastern or western year classes are strong, whereas a moderate index could be the culmination of a weak and a strong year class from either stock.

It was considered likely that a weak year class could recruit to the western stock if the annual recruitment index was less than 75% of the average (1995-2009) recruitment level. This assumption is supported by an examination of the recruitment estimates from the stock assessment model. [In fact, the relative annual recruitments for the eastern and western stocks are actually quite strongly correlated over the long term, but less so over the recent period 1995-2009]. When a weak year class was detected, the subsequent annual catch for the WCSI was set at the target catch level regardless of whether the western stock status was assessed to be above the target biomass level. If the biomass level was assessed to be below the lower target biomass (< 35% B_0) and recruitment was below 75% of the average level then the assessed level of annual catch (above) was reduced by 10,000 t. To some extent, this procedure mimics the short-term stock projections that are undertaken during the annual hoki assessment.

In addition, if the western biomass was assessed to have fallen below 20% B0 (Harvest Strategy Standard soft limit) the catch was reduced to the minimum catch level of 20,000 t to allow for rebuilding of the stock. If the western biomass was assessed to have fallen below 10% B0 (Harvest Strategy Standard hard limit) the WCSI catch was set to zero in line with the HSS (i.e. the spawning fishery was closed, although the catch of 15,000 t from the Sub Antarctic was maintained).

These mechanisms can result in some catch limit changes for the WCSI that exceed +/- 10,000 t per year. Other scenarios could be examined that limit any TACC change to a maximum level (say +/10,000) and or only change the TACC every 2 or 3 years.

For each scenario, 100 simulations were conducted. Each simulation represented an individual sample from the set of McMCs from the 2012 stock assessment model. Each sample also had an associated set of projected recruitments (2012-2040) for the western and eastern stocks. The projected recruitments were sampled (with replacement) from the estimated recruitments (numbers of 1+ fish) from the 1995-2010 period. The sequences of projected recruitments for the eastern and western stocks were sampled independently.

A key element of the assessment of the western stock is the sustained period of low recruitment during 1997-2003. The low levels of recruitment in this period are largely responsible for the lower level of average recruitment during the 1995-2010 and hence are influential in determining the overall productivity of the stock during the projection period. Further, the target biomass level and the associated catch levels need to be robust to the likelihood of similar sustained periods of low recruitment occurring in the future. The simulated recruitments for the western stock were examined to identify the set that included a similar sustained period of low recruitment in the earlier period of the projection. Of the set of 100 replicates, 22% of the replicates included a sustained period (>= 5 years) of low recruitment in the western stock during the first 20 years of the projection (Figure 5). The performance of the subset of replicates was examined in detail to evaluate the effectiveness of the WCSI catch setting procedure in response to poor recruitment (particularly the mediation of the catch level via the recruitment index).

A range of performance measures were defined to enable the comparison of the range of scenarios evaluated.

Metric	Description
Pr(SB < x% SB_0)	The percentage of the individual simulations that result in the mid-season spawning biomass

	declining below x% (10%, 20%, 25%, 30%) of the unexploited, equilibrium spawning biomass more than 10% of the years in the projection period.
Years below x% SB_0	The average number of years below 10% or 20% of SB_0 for simulations that are below 10% or 20% SB_0 of unexploited west coast South Island biomass in at least one year of the projection period.
Catch_avg	Average of the average catch from individual simulations by fishery (west coast South Island, Cook Strait, Sub Antarctic, and Chatham Rise).
Catch_sd	Average of the standard deviation of catch from individual simulations by fishery (west coast South Island, Cook Strait, Sub Antarctic, and Chatham Rise).
Catch_delta	Proportion of years when there is a change in the catch limit (increases and decreases) for each fishery.
VBio_median	Median (and 25% & 75% quantiles) fishery specific vulnerable biomass (across years and simulations) relative to the level of vulnerable biomass in the 2009 reference year.
WT_median	Median (and 25% & 75% quantiles) fishery-specific average weight of fish (in kg) in the catch (across years and simulations).
Fish_age_avg	Average fishery-specific average age of fish (in years) in the catch (across years and simulations).

Two sets of simulations were undertaken. The primary set of simulations incorporated an annual survey of the Sub Antarctic area and, accordingly, reset the WCSI catch level on an annual basis. The second set of simulations conducted the trawl survey biennially and reset the WCSI catch for a two year period. The second set of simulations is more consistent with the current Deepwater Research Plan which schedules Sub Antarctic trawl surveys biennially for the next 10 years.

Results

The analysis determines that the current (2012) level of biomass for the western stock is greater than the upper bound of the target biomass range (Figure 6). This is a more optimistic measure of stock status than the formal stock assessment of hoki which estimates current stock status as XXX% SB_0. The difference between the two analyses is due to the recruitment period included in the computation of the reference biomass level (SB_0). The definition of SB_0 in the current analysis is based on the lower level of average recruitment from 1995-2009, resulting in a lower SB_0 and a higher current biomass ratio (SB_{2012}/SB_0).

For all scenarios, the western stock biomass is projected to increase from 2101 to 2014 and then decline over the subsequent 8-10 year period (Figure 6). Over the longer term, the biomass levels stabilise within the target biomass range (Figure 7). Candidate scenarios with a higher level of target catch for the WCSI fishery and/or a higher level of Chatham Rise catch tend to result in lower levels of western stock biomass, while candidate scenarios with a lower level of target catch for the WCSI fishery and/or a lower level of Chatham Rise catch tend to result in higher biomass levels of western stock (Figure 7).

However, there is considerable variation in the performance of individual replicates as indicated by the range of the western biomass levels (relative to SB_0) in any year of the projection period (Figure 6). In general, the biomass is maintained within the target biomass range approximately 50% of the time. Nonetheless, most of the candidate scenarios maintain the lower bound (10% quantile) of the western biomass above the “soft limit” reference level throughout the projection period (Figure 8). The replicates that generate biomass trajectories at the lower range are primarily derived from McMC draws with a lower overall level of recruitment (and vice versa).

For the eastern stock, biomass trajectories only vary with the different levels of Chatham Rise catch [Cook Strait catches are equivalent in all scenarios and there is no feedback from the western stock] (Figure 9). Projected biomass levels tend to be inversely proportional to the level of catch specified for the Chatham Rise (32, 42, 52, 62 kt). The two lower catch levels tend to maintain the eastern stock above the target biomass level, while the two higher catch levels reduce the eastern biomass to be within the target biomass range. There is a relatively broad confidence interval associated with each set of replicates for a specific candidate level of catch. For the highest Chatham Rise catch scenario, the lower bound of the projected biomass tends to stabilise at a level between the "soft limit" (20% SB_0) and the lower bound of the target biomass level (35% SB_0) (Figure 10).

The initial decline in the projected western biomass (over the 10 year period), is primarily due to the WCSI harvest rules increasing annual catches over the short term to capitalise on the current higher stock abundance (Figure 11). The harvest rules then tend to reduce the WCSI catch slightly (on average) over the following 10 years resulting in the stabilisation of the western biomass for the remainder of the projection period (Figure 7).

A key performance indicator for the hoki fishery is the maintenance of current commercial catch rates in the Chatham Rise fishery. For scenarios with a Chatham Rise catch equivalent to the current (2012) level of catch (42 kt), the commercial biomass of hoki is projected to stabilise at a level that is approximately 85% of the current (2012) level of commercial biomass (Figure 12). Commercial catch rates could be expected to decline to a similar level. The average (whole) weight of fish in the Chatham Rise catch is projected to remain relatively constant at current catch levels (Figure 13).

A comparison of the main performance indicators for the range of catch scenarios is presented in Table 2 and Figure 14. The main observations are as follow.

- For western stock, the risk of breaching the "soft limit" increases with higher WCSI target catch levels. For the current level of Chatham Rise catch (42 kt), a WCSI **target** catch level of 55 kt has a low associated probability of breaching the "soft limit" and zero risk of breaching the "hard limit".
- For eastern stock, there is a negligible risk of breaching the "soft limit" at levels of Chatham Rise catch up to 52 kt. There is a low level of risk of breaching the "soft limit" for a catch level of 62 kt.
- For the western stock, the risk of breaching "soft limit" increases with higher Chatham Rise catches. This is because Chatham Rise catches include catches of juvenile hoki from the western stock.
- Average annual WCSI catches are lower than the corresponding WCSI target catch levels (45, 55, 65, 75 kt). The range of the realised average annual catches is considerably narrower than the range of the target catch levels (15 kt compared to 30 kt).
- Higher average annual WCSI catches are achieved from scenarios with a higher target catch level. However, variability in annual WCSI catch is higher for scenarios with a target catch level greater than 55 kt.
- All WCSI target catch options require variation in the WCSI catch level (TACC) every 2-3 years to maintain the biomass at a level approximating the target biomass (35-50% SB_0).
- Individual WCSI TACC changes are generally within +/- 15 kt regardless of scenario.
- Catch rates from the Chatham Rise fishery are predicted to decline by about 10% at current catch levels (42 kt). Higher catch levels from the Chatham Rise fishery will result in considerably lower average catch rates; for example a Chatham Rise catch of 62 kt is predicted to reduce catch rates by about 30% (relative to the 2012 level).
- At current catch levels, the abundance of fish in the WCSI fishery is predicted to decline by about 25% from current (2012) levels. This reflects the reduction in biomass from the current level (i.e. above the target biomass level). Higher WCSI target catch levels are predicted to result in lower WCSI biomass levels. Trends in the abundance of hoki in the Sub Antarctic fishery will closely follow the WCSI fishery.
- The abundance of hoki in the WCSI fishery is predicted to be considerably more variable than the Chatham Rise.
- The average weight of fish in the catch from the Chatham Rise fishery does not vary substantially over the range of scenarios. Similarly, the weight of fish caught from the WCSI fishery is predicted to be similar for the range of scenarios.

Overall, catch levels approximating the current fishery specific catches are likely to satisfy the main performance criteria for the western and eastern stocks. Exploitation rates for the eastern stock are lower than the western stock and there is potential to increase the overall level of catch from the eastern stock; however, any increase in the catch from the Chatham Rise will also need to be moderated by a decrease in the catch from the western stock (due to the shared nursery ground for both stocks) to achieve an equivalent level of risk (Figure 15). Further, an increase in the catch from the Chatham Rise above current levels would result in a decline in the abundance of commercial size fish in the area and a corresponding decline in the catch rates achieved by the fleet (Figure 14).

Total catches from the hoki fishery could be directly increased by increasing the catch from the Cook Strait fishery (eastern stock), although current operational constraints (onshore processing, vessel length restrictions) limit the opportunity to increase catches from this fishery.

A comparison between the indicators for annual and biennial survey options reveals that the performance of the alternative monitoring strategies is very similar at current levels of catch (Table 2 and Table 3). However, for higher catch levels, particularly higher levels of Chatham Rise catch (52 and 62 kt) there is an increase in the probability that the western stock biomass would decline below the "soft limit" when the Sub Antarctic survey is conducted biennially. Comparatively, the realised WCSI catches are also slightly lower for the candidate scenarios with the higher level of catch from the Chatham Rise fishery, while the variation in WCSI annual catches is predicted to be higher despite the less frequent changes to the TACC.

Discussion

The veracity of the results of the study is dependent on three key assumptions.

1. The current (2012) base-case hoki stock assessment model is a reasonable approximation of the key dynamics of the hoki stocks (growth, natural mortality, recruitment, movement, etc), the monitoring regime (trawl survey selectivity and catchability), and the current commercial fishery (primarily fishery selectivity).
2. Future recruitments will be comparable to the recruitments estimated during 1995-2009 in respect to the average level of recruitment and the variability in recruitments between successive years.
3. The "real life" management of hoki catch levels (TACC) would be similar to the mechanism applied to vary the WCSI catch levels in the simulations.

Future catch levels are very dependent on the assumptions regarding future recruitment. The study assumed that future recruitments would be consistent with the recruitment level during the recent 15 year period (1995-2009). For the western stock, recent recruitment was considerably lower than during the preceding period (72% of long-term average), while recent recruitment was also lower for the eastern stock (88% long-term average). These recent levels of recruitment are consistent with the recent levels of hoki stock abundance and catch. The lower levels of average recruitment are attributable to a sustained period of very low recruitment from 1997-2003. More recent recruitments (2004-2011) were estimated to be comparable to the longer term average level, with the exception of the very low recruitment estimated for the final year (2012).

The factors that contributed to the probability of the western stock declining below the "soft limit" were examined. Beyond the key explanatory factors of the WCSI target catch level and the level of Chatham Rise catch, the main factor was the absolute level of average recruitment (1995-2009) for the western stock from the respective McMC sample. Not surprisingly, a McMC sample with a lower level of recruitment had a higher probability of breaching the "soft limit" for a given WCSI target catch and absolute level of Chatham Rise catch.

The performance of the management procedure was relatively insensitive to the variability in recruitment during the projected period. There was only a marginal increase in the probability of the western stock declining below the "soft limit" for those scenarios that included a sustained period of low recruitment; i.e. at least 6 years of recruitment below 75% of the average level.

For individual simulations, failure to maintain biomass above the "soft limit" also relates to accuracy of the preceding Sub Antarctic trawl surveys. There is a relatively low precision (c.v. 30%) assumed for the trawl survey biomass estimates. Simulations that generate successive trawl survey biomass indices that were considerably higher than the actual low levels of stock biomass will maintain the WCSI catch at a higher level and, thereby, increase the risk of the western stock decreasing below the "soft limit". The level of risk is more pronounced when Sub Antarctic trawl surveys are conducted biennially (rather than annually). Nonetheless, the analysis indicates the risk is low given the current catch levels and the target biomass level. However, the risk may be higher if there is a strong temporal trend in the catchability of the Sub Antarctic trawl surveys (as has been suggested).

Conclusions

Future catch levels are very dependent on assumptions regarding future recruitment. The study assumed that future recruitments would be consistent with the recruitment level during the last 15 years (1995-2009). Hoki recruitment dynamics remain poorly understood. Therefore, it is prudent to assume that future recruitments (at least in the short-term) will be consistent with the recruitment level from the 15 year period (1995-2009). This assumption essentially determines the overall level of catch available to the fishery.

The study evaluated a range of alternative catch scenarios for the various fisheries. The key conclusions of the study are as follow.

1. Future annual catches (averaging 125 kt; WCSI 50 kt, Chatham Rise 42 kt, Cook Strait 18 kt and Sub Antarctic 15 kt) are consistent with the current TACC (130 kt) (assuming recent recruitment levels and the current distribution of catch among fisheries).
2. Some variation in WCSI catches can be expected following short periods of lower or higher recruitment. Recruitment fluctuations will result in variation in the WCSI catch from 35 to 65 kt and variation in the total annual catch (125 kt, range 110-140 kt).
3. These catch levels will maintain the stocks at sustainable levels, maintain average catch rates at about the current (2012) level, minimise changes in the TACC and maintain the current size of fish in the catch.
4. The current distribution of catch results in a lower level of exploitation for the eastern stock compared to the western stock. There is potential for higher yields from the eastern stock; however, catches from the Chatham Rise fishery are comprised of fish from the eastern and western hoki stocks and increasing catches on the Chatham Rise will reduce the available catch from the WCSI fishery.
5. A small increase in the total average catch (from 125 k to 130 kt) could be achieved by increasing the catch from Chatham Rise fishery from 42,000 t to 52,000 t and decreasing the WCSI catch (from 50 kt to 45 kt). However, increasing the Chatham Rise catch by 10 kt would result in considerably lower catch rates (75% of current level) from the Chatham Rise fishery.
6. Increasing catches from the Cook Strait fishery would increase utilization of the eastern stock directly. There is potential to increase the total HOK 1 catch (from 125 kt to 135 kt) by increasing the Cook Strait catch from 18 kt to 28 kt without an appreciable change in the performance of the other fisheries.
7. Higher levels of total catch would be available if future recruitments were considerably higher than recent recruitment levels. However, the proportional distribution of catch among fisheries is unlikely to change substantially.
8. Further study is required to improve the understanding of the recruitment process for hoki. This could include an evaluation of the current hoki stock hypotheses, an understanding of the environmental factors influencing hoki recruitment, increased understanding of the relationship between spawning biomass and recruitment and a reevaluation of the possible fishery effects on recruitment (juvenile mortality).

Table 1. The catch scenarios evaluated in the analysis. The WCSI values (in bold) represent target catches rather than realised catch. Scenario 6 approximates the current (2012) catch distribution.

Scenario	Cook Strait	Chatham Rise	WCSI	Sub Antarctic	Total
1	18,000	32,000	**45,000**	15,000	110,000
2	18,000	42,000	**45,000**	15,000	120,000
3	18,000	52,000	**45,000**	15,000	130,000
4	18,000	62,000	**45,000**	15,000	140,000
5	18,000	32,000	**55,000**	15,000	120,000
6	18,000	42,000	**55,000**	15,000	130,000
7	18,000	52,000	**55,000**	15,000	140,000
8	18,000	62,000	**55,000**	15,000	150,000
9	18,000	32,000	**65,000**	15,000	130,000
10	18,000	42,000	**65,000**	15,000	140,000
11	18,000	52,000	**65,000**	15,000	150,000
12	18,000	62,000	**65,000**	15,000	160,000
13	18,000	32,000	**75,000**	15,000	140,000
14	18,000	42,000	**75,000**	15,000	150,000
15	18,000	52,000	**75,000**	15,000	160,000
16	18,000	62,000	**75,000**	15,000	170,000

Table 2. Summary of the results for the individual catch scenarios for the model option with an **annual** Sub Antarctic trawl survey. The biomass metric is the proportion of the individual simulations that are below the stated biomass level (x) at least 10% of the years in the projection period. The mean annual realised catch from the WCSI fishery and the associated standard deviation are presented. N represents the number of simulated TACC changes during the projection period. The reference option is highlighted in grey.

Scenario	Pr(*SB* < x% SB_0) W stock				Pr(*SB* < x% SB_0) E stock				WCSI catch		
	10%	**20%**	**25%**	**30%**	**10%**	**20%**	**25%**	**30%**	**Mean**	**s.dev**	**N**
1	0.00	0.05	0.09	0.19	0.00	0.01	0.01	0.01	44,765	13,070	12.6
2	0.00	0.08	0.19	0.41	0.00	0.01	0.01	0.01	49,908	14,736	11.4
3	0.00	0.10	0.28	0.53	0.00	0.01	0.01	0.01	54,537	19,207	12.5
4	0.00	0.16	0.44	0.66	0.00	0.01	0.01	0.01	58,194	23,933	11.0
5	0.00	0.04	0.11	0.27	0.00	0.01	0.02	0.05	43,775	13,056	12.7
6	0.00	0.08	0.21	0.46	0.00	0.01	0.02	0.05	48,798	14,846	11.7
7	0.00	0.11	0.36	0.57	0.00	0.01	0.02	0.05	52,792	18,889	11.6
8	0.01	0.26	0.49	0.76	0.00	0.01	0.02	0.05	56,656	24,264	11.0
9	0.00	0.06	0.13	0.36	0.01	0.02	0.07	0.16	41,973	13,217	12.1
10	0.00	0.09	0.27	0.50	0.01	0.02	0.07	0.16	47,390	15,389	11.3
11	0.01	0.20	0.40	0.62	0.01	0.02	0.07	0.16	51,515	19,416	11.6
12	0.02	0.29	0.52	0.77	0.01	0.02	0.07	0.16	54,600	25,376	10.8
13	0.00	0.06	0.19	0.42	0.01	0.05	0.17	0.36	40,521	13,079	11.9
14	0.00	0.10	0.35	0.56	0.01	0.05	0.17	0.36	45,733	15,774	11.0
15	0.02	0.23	0.50	0.71	0.01	0.05	0.17	0.36	49,310	20,113	11.2
16	0.02	0.30	0.62	0.83	0.01	0.05	0.17	0.36	51,885	26,385	10.3

Table 3. Summary of the results for the individual catch scenarios for the model option with a **biennial** Sub Antarctic trawl survey. The biomass metric is the proportion of the individual simulations that are below the stated biomass level (x) at least 10% of the years in the projection period. The mean annual realised catch from the WCSI fishery and the associated standard deviation are presented. N represents the number of simulated TACC changes during the projection period. The reference option is highlighted in grey. NA = not available.

Scenario	**Pr(*SB* < x% *SB*$_0$) W stock**				**Pr(*SB* < x% *SB*$_0$) E stock**				**WCSI catch**		
	10%	**20%**	**25%**	**30%**	**10%**	**20%**	**25%**	**30%**	**Mean**	**s.dev**	**N**
1	0.00	0.04	0.08	0.25	0.00	0.01	0.01	0.01	44,548	13,846	11.7
2	0.00	0.07	0.18	0.40	0.00	0.01	0.01	0.01	50,512	15,748	10.4
3	0.01	0.15	0.30	0.51	0.00	0.01	0.01	0.01	54,537	19,123	10.9
4	0.02	0.25	0.43	0.67	0.00	0.01	0.01	0.01	57,888	24,927	10.0
5	0.00	0.04	0.11	0.32	0.00	0.01	0.02	0.05	43,092	13,556	10.8
6	0.01	0.08	0.25	0.45	0.00	0.01	0.02	0.05	48,546	16,045	10.7
7	0.01	0.18	0.41	0.59	0.00	0.01	0.02	0.05	52,879	19,536	10.5
8	0.00	0.40	0.54	0.77	0.00	0.00	0.01	0.06	53,569	24,622	7.2
9	NA	0.07	0.18	0.42	0.01	0.02	0.07	0.16	41,887	14,696	8.0
10	NA	0.17	0.32	0.56	0.01	0.02	0.08	0.17	46,554	16,947	6.9
11	NA	0.25	0.50	0.72	0.00	0.01	0.06	0.14	49,938	21,172	7.7
12	NA	0.45	0.65	0.80	0.00	0.01	0.06	0.15	51,113	25,136	6.7
13	NA	0.08	0.21	0.46	0.01	0.05	0.16	0.34	40,262	13,667	7.8
14	NA	0.14	0.44	0.65	0.00	0.05	0.16	0.34	45,348	17,441	6.9
15	NA	0.38	0.55	0.72	0.00	0.07	0.15	0.32	47,581	21,312	7.2
16	NA	0.50	0.68	0.87	0.00	0.03	0.12	0.23	48,315	26,180	6.5

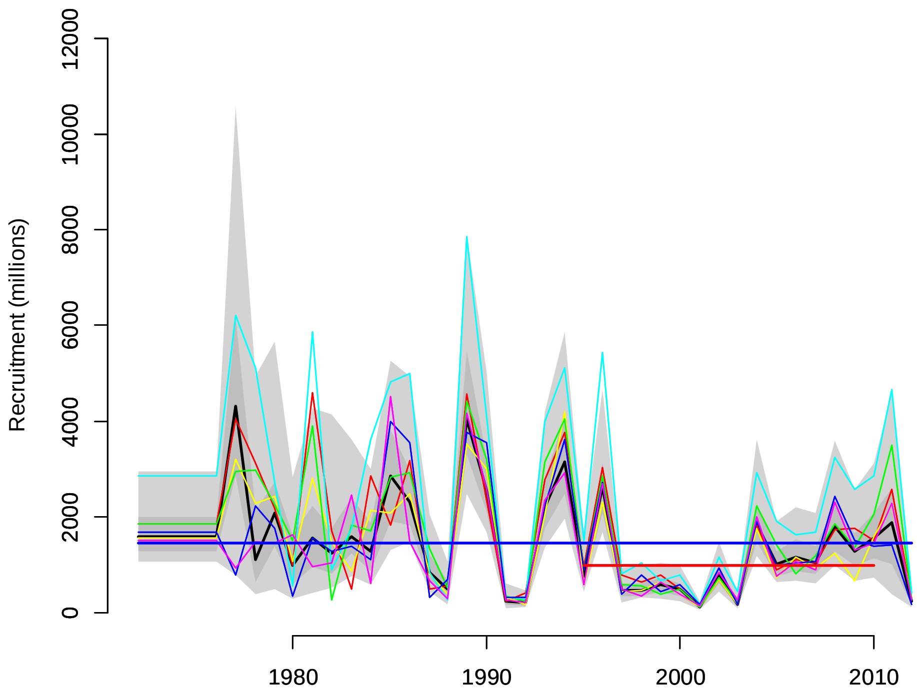

Figure 1. Estimates of annual recruitment (numbers of fish) for the western stock from the 2012 base-case hoki stock assessment model (Run 1.3). The black line represents the median of the McMC estimates, the light grey area encompasses the 5–95% quantile range and the dark grey area encompasses the 25–75% quantile range of spawning biomass. The solid blue line represents the average of the entire time-series and the solid red line represents the average recruitment for 1995-2009. The coloured lines are examples of individual biomass trajectories from the set of simulations.

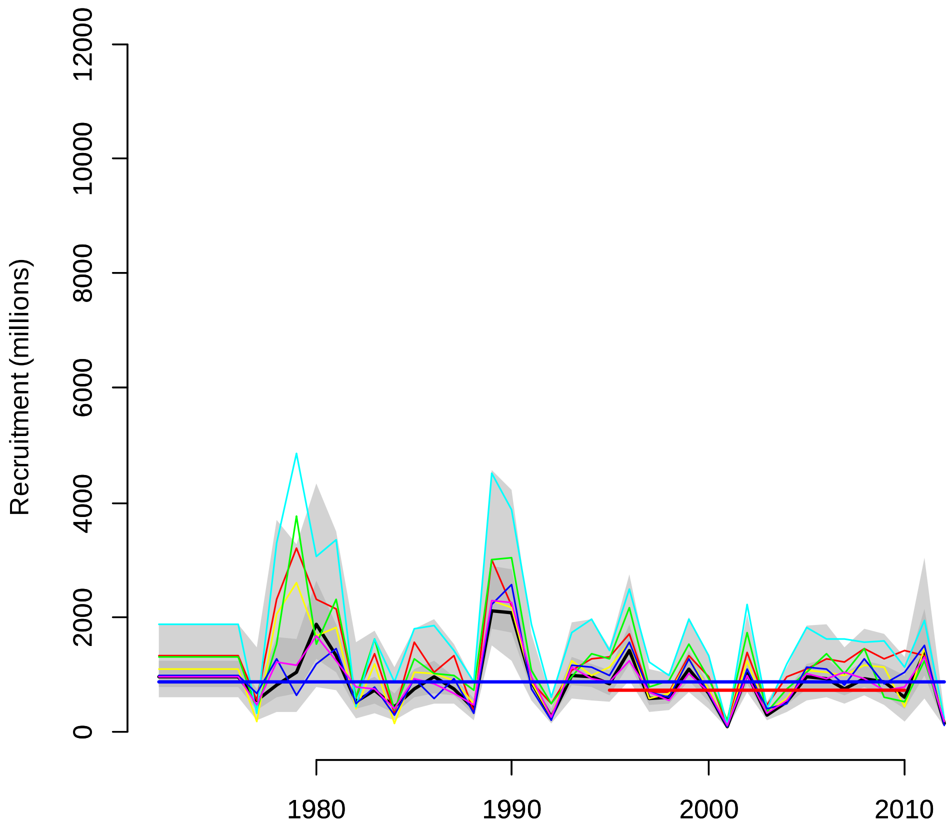

Figure 2. Estimates of annual recruitment (numbers of fish) for the eastern stock from the 2012 base-case hoki stock assessment model (Run 1.3). The black line represents the median of the McMC estimates, the light grey area encompasses the 5–95% quantile range and the dark grey area encompasses the 25–75% quantile range of spawning biomass. The solid blue line represents the average of the entire time-series and the solid red line represents the average recruitment for 1995-2009. The coloured lines are examples of individual biomass trajectories from the set of simulations.

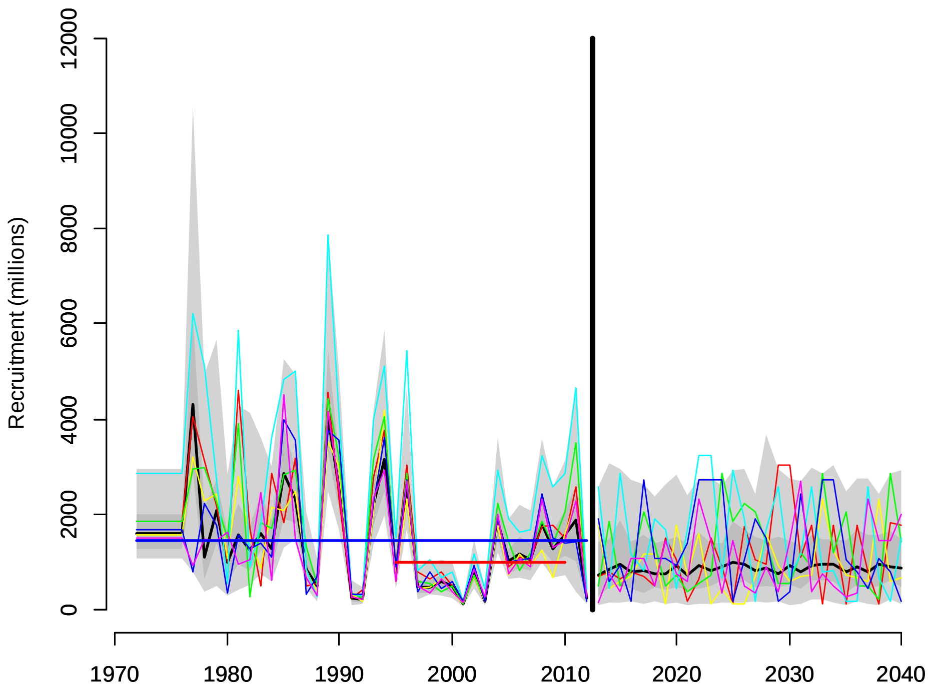

Figure 3. Estimates of annual recruitment (numbers of fish) for the western stock from the 2012 base-case hoki stock assessment model (Run 1.3) and simulated future recruitments (2013-2040). The black line represents the median of the McMC estimates, the light grey area encompasses the 5–95% quantile range and the dark grey area encompasses the 25–75% quantile range of spawning biomass. The solid blue line represents the average of the entire time-series and the solid red line represents the average recruitment for 1995-2009. The coloured lines are examples of individual biomass trajectories from the set of simulations.

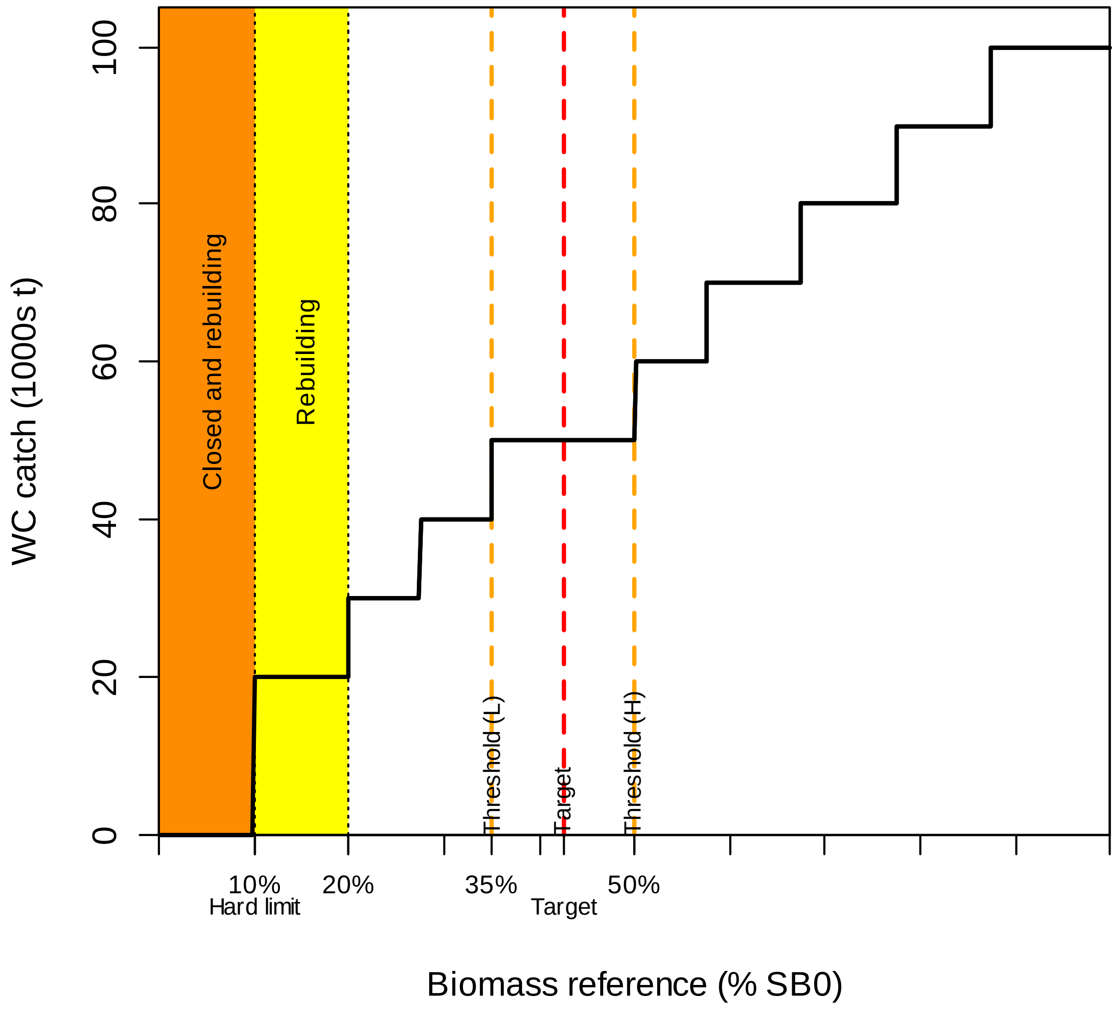

Figure 4. An example of the harvest strategy control rule for the WCSI catch with a target catch level of **50,000** t. The catch in the following year is varied in accordance with the level of reference biomass. The dashed red vertical line represents the target biomass level and the dashed orange lines represent the lower and upper threshold biomass levels.

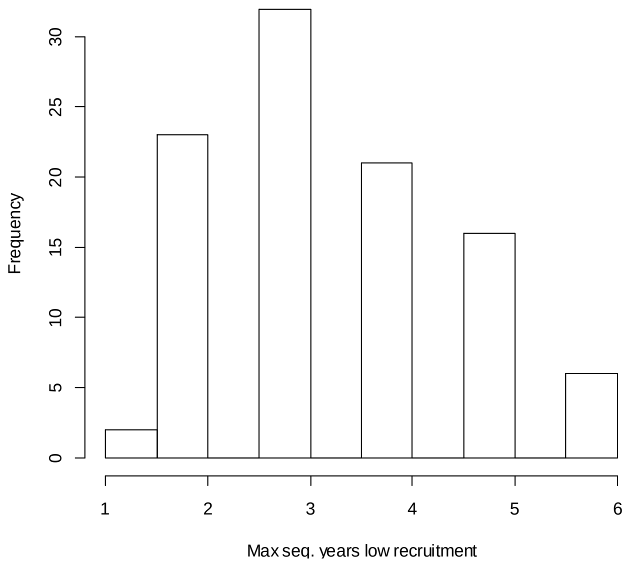

Figure 5. Frequency distribution of the maximum number of sequential years with low recruitment (less than 75% of the average level) during the first 20 years of the simulated recruitment period (2013-2032)for the western stock. Each observation represents a single each simulated recruitment sequence used in the projection.

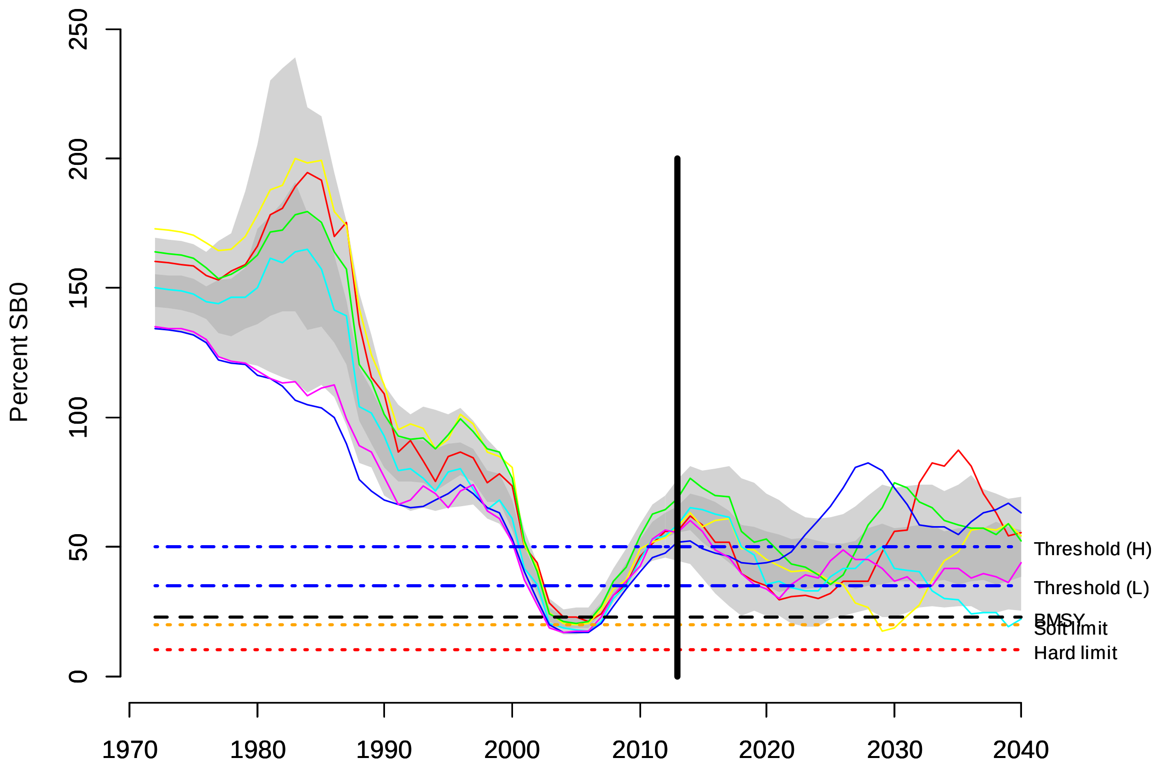

Figure 6. Annual spawning biomass relative to unexploited, equilibrium spawning biomass for the western stock from the 2012 base-case hoki stock assessment model (Run 1.3) and projected (2013-2040) under catch scenario 6. The light grey area encompasses the 5–95% quantile range and the dark grey area encompasses the 25–75% quantile range of spawning biomass. The coloured lines are examples of individual biomass trajectories from the set of simulations. The reference biomass levels are presented as dashed lines. Unexploited, equilibrium spawning biomass is computed based on the average recruitment level from the 1995-2009.

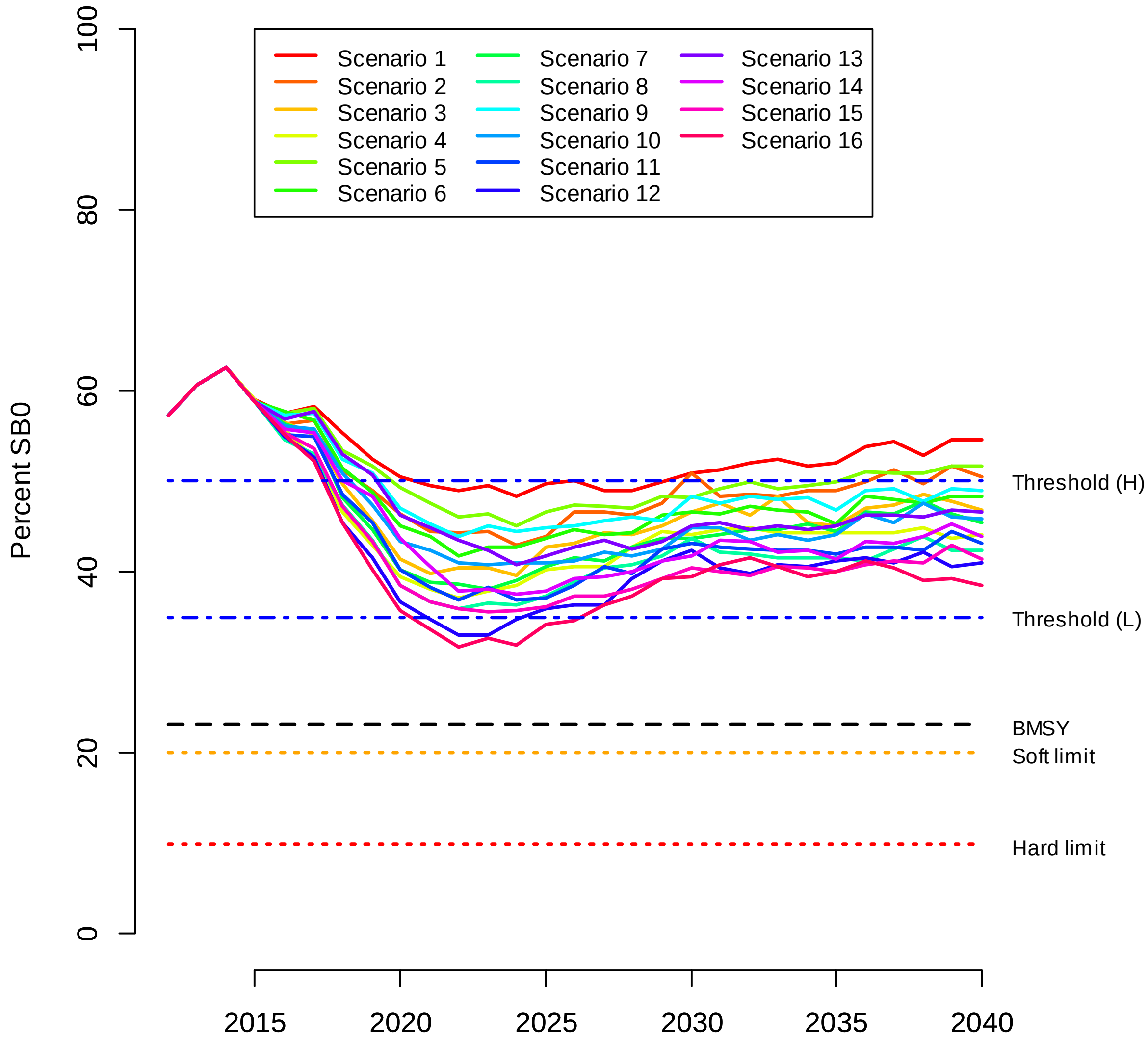

Figure 7. A comparison of the median biomass of the projections of western spawning biomass for each of the candidate scenarios. For each scenario, the annual median biomass level of the individual replicates is plotted.

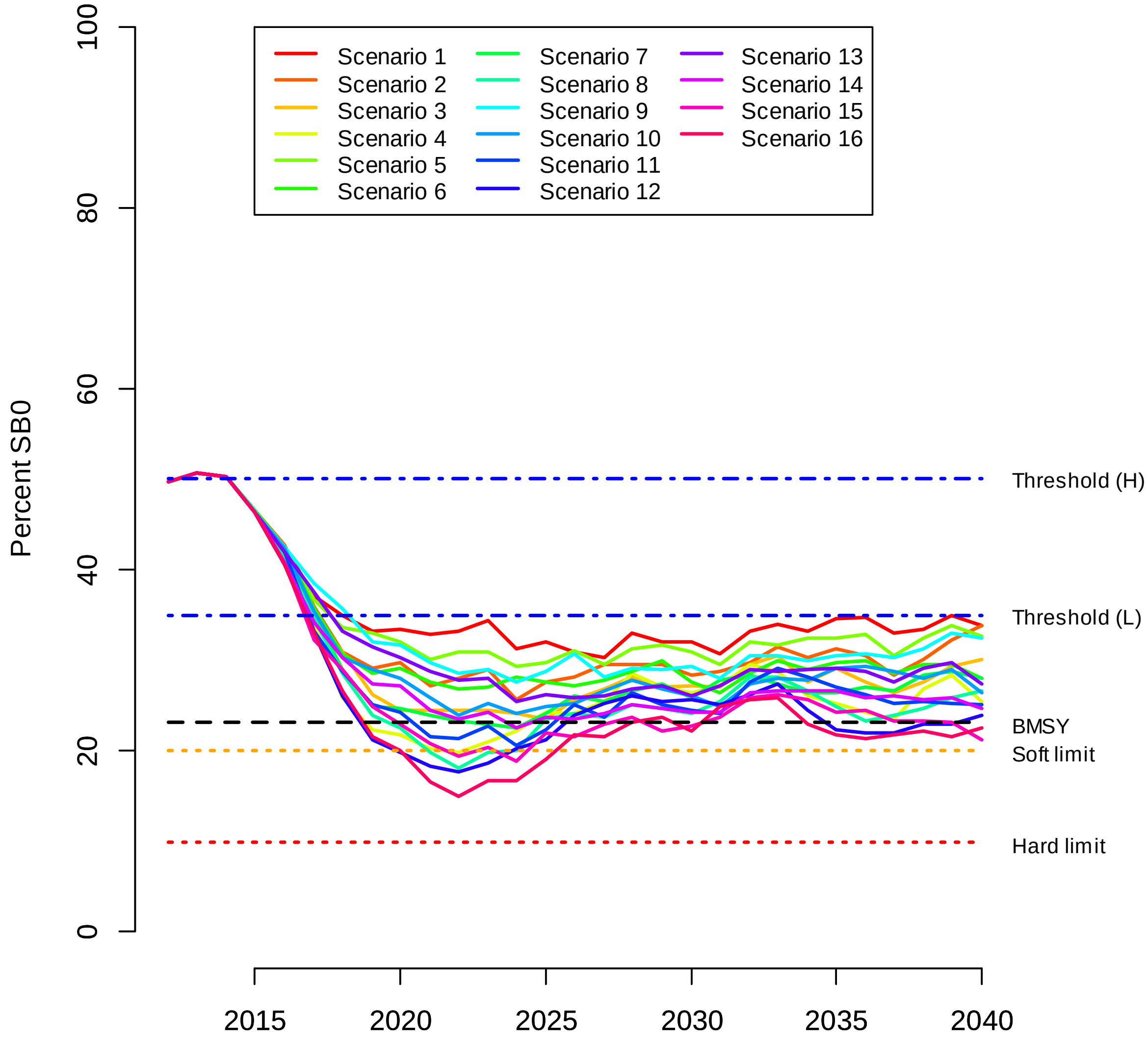

Figure 8. A comparison of the lower bound of the projections of western spawning biomass for each of the candidate scenarios. For each scenario, the 10% quantile of the annual biomass level of the individual replicates is plotted.

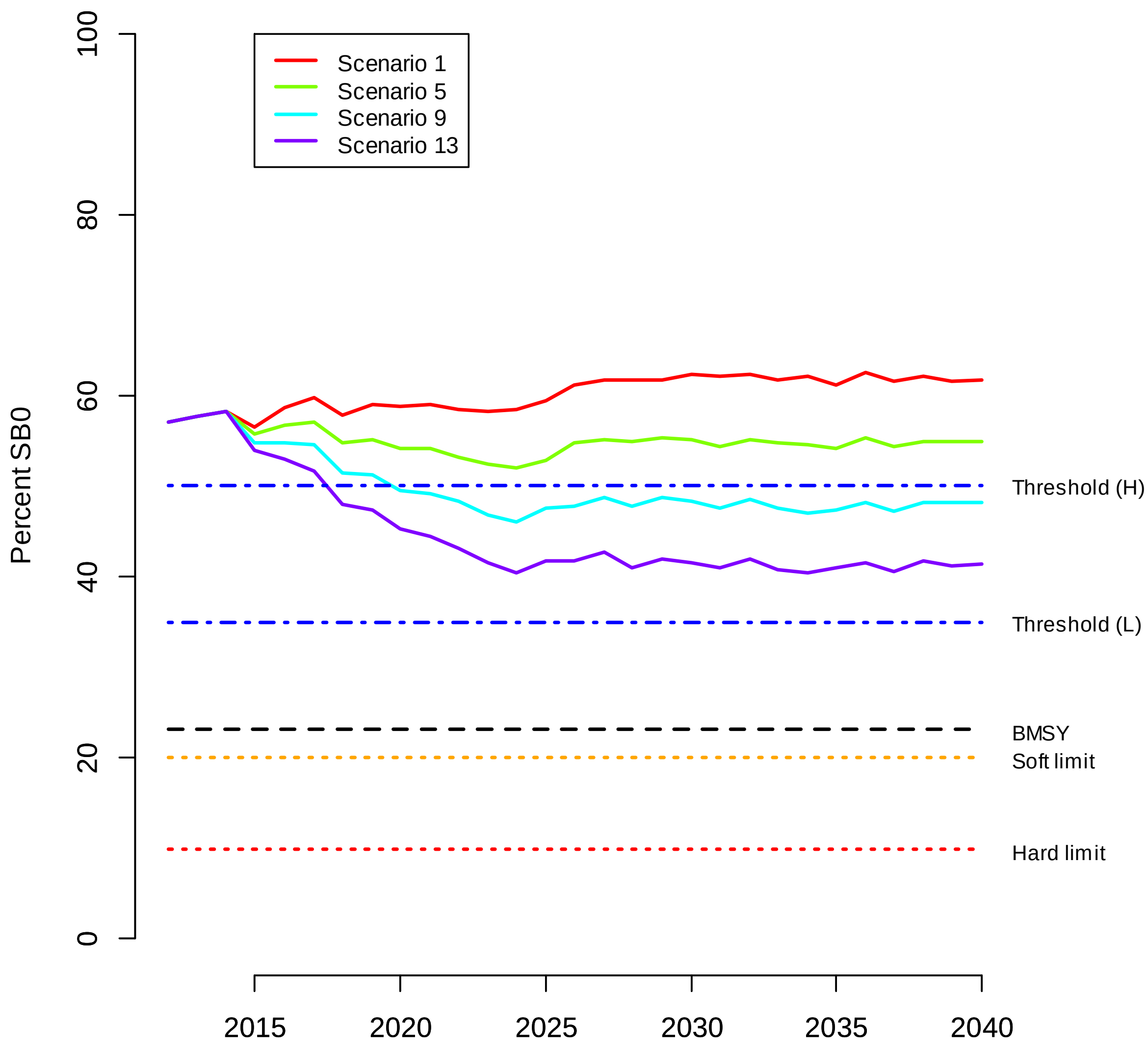

Figure 9. A comparison of the projections of eastern spawning biomass for four candidate scenarios with different levels of Chatham Rise catch. For each scenario, the annual median biomass level of the individual replicates is plotted.

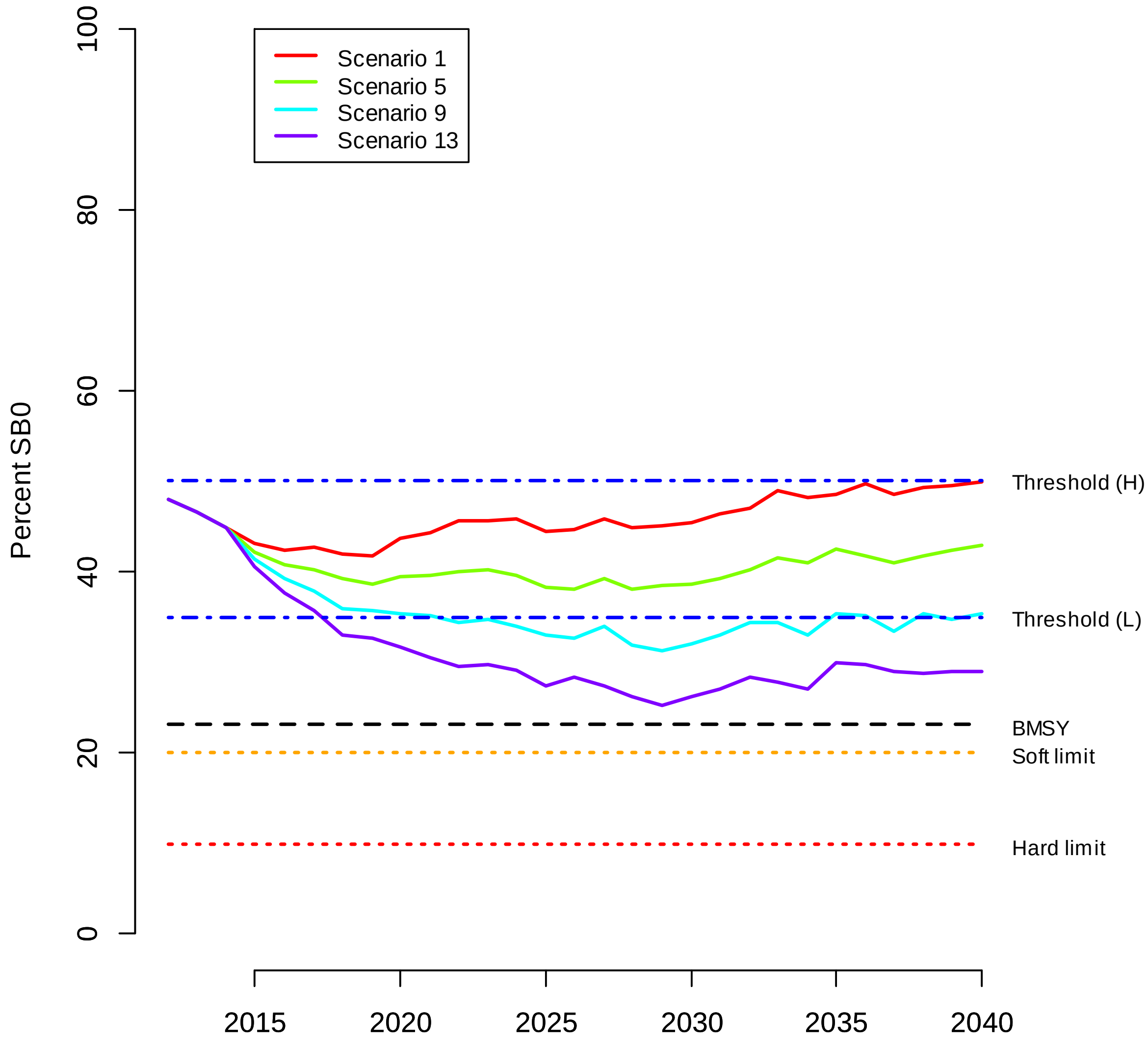

Figure 10. A comparison of the lower bound of the projections of eastern spawning biomass for four candidate scenarios with different levels of Chatham Rise catch. For each scenario, the 10% quantile of the annual biomass level of the individual replicates is plotted.

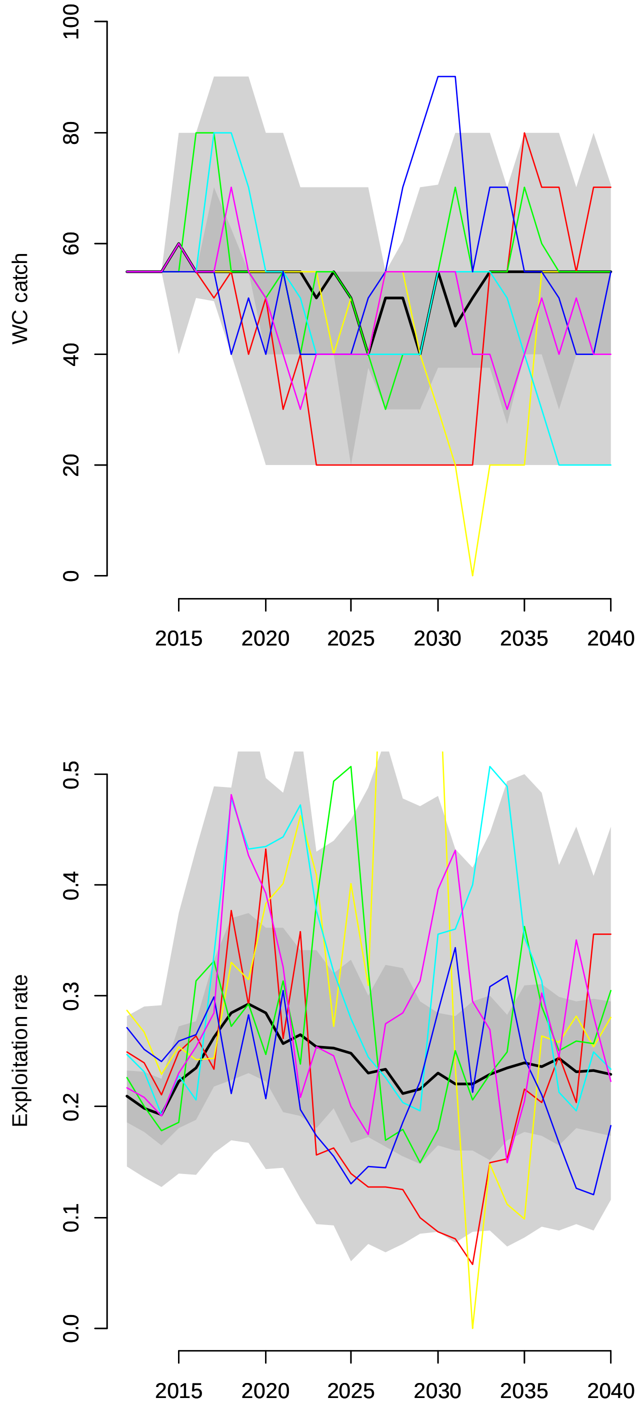

Figure 11. Annual WCSI projected catches (2013-2040) and the WCSI exploitation rate under catch scenario 6. The light grey area encompasses the 5–95% quantile range and the dark grey area encompasses the 25–75% quantile range of spawning biomass. The coloured lines are examples of individual projections from the set of simulations.

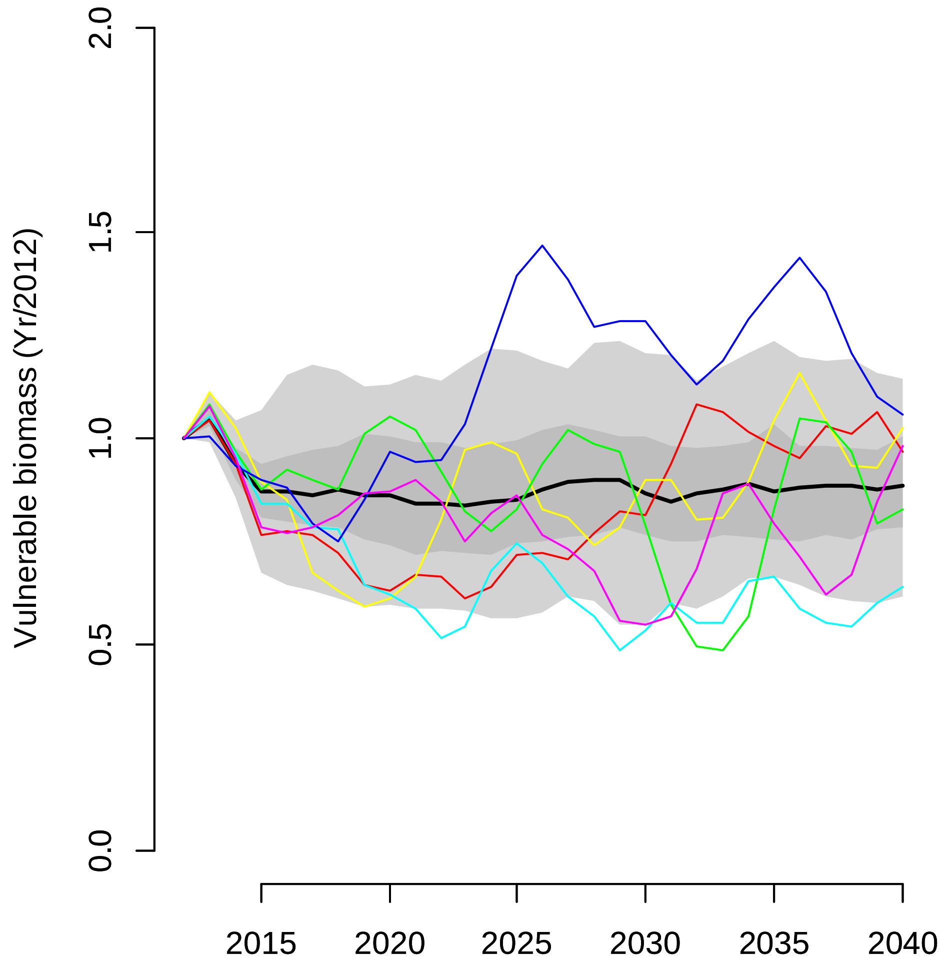

Figure 12. Projected annual commercial (vulnerable) biomass in the Chatham Rise fishery (2013-2040) under catch scenario 6. The light grey area encompasses the 5–95% quantile range and the dark grey area encompasses the 25–75% quantile range of spawning biomass. The coloured lines are examples of individual projections from the set of simulations.

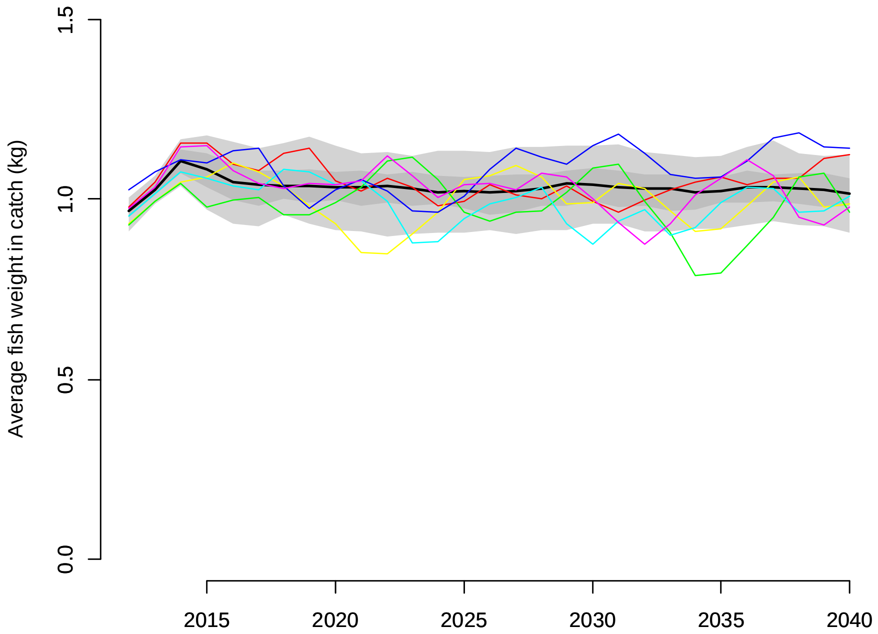

Figure 13. Projected annual average fish weight (kilogrammes) in the catch from the Chatham Rise fishery (2013-2040) under catch scenario 6. The light grey area encompasses the 5–95% quantile range and the dark grey area encompasses the 25–75% quantile range of spawning biomass. The coloured lines are examples of individual projections from the set of simulations.

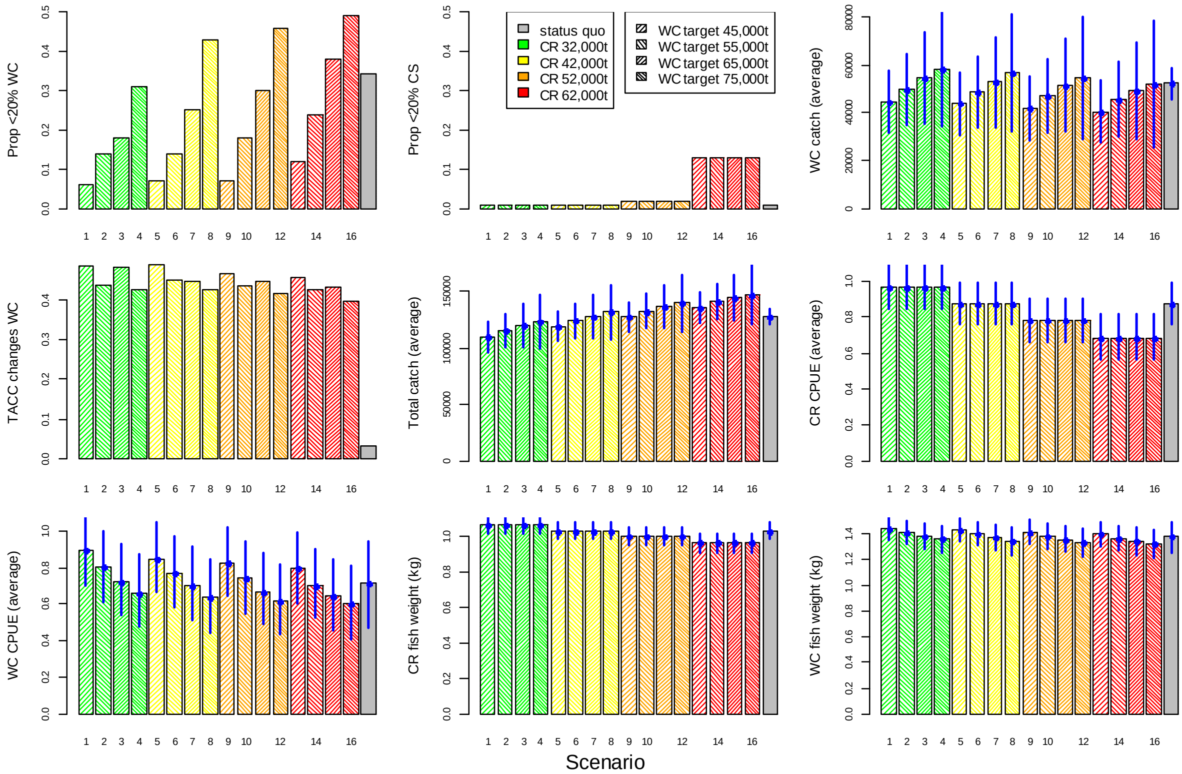

Figure 14. Summary of the key performance indicators for the range of catch scenarios (for the model options with annual Sub Antarctic trawl surveys). **Note the definition of risk differ slightly from Table 2. These values are for a single year below the threshold whereas Table 2 reports the simulations that are below 20% for at least 10% of the time – need to tidy up for consistency.**

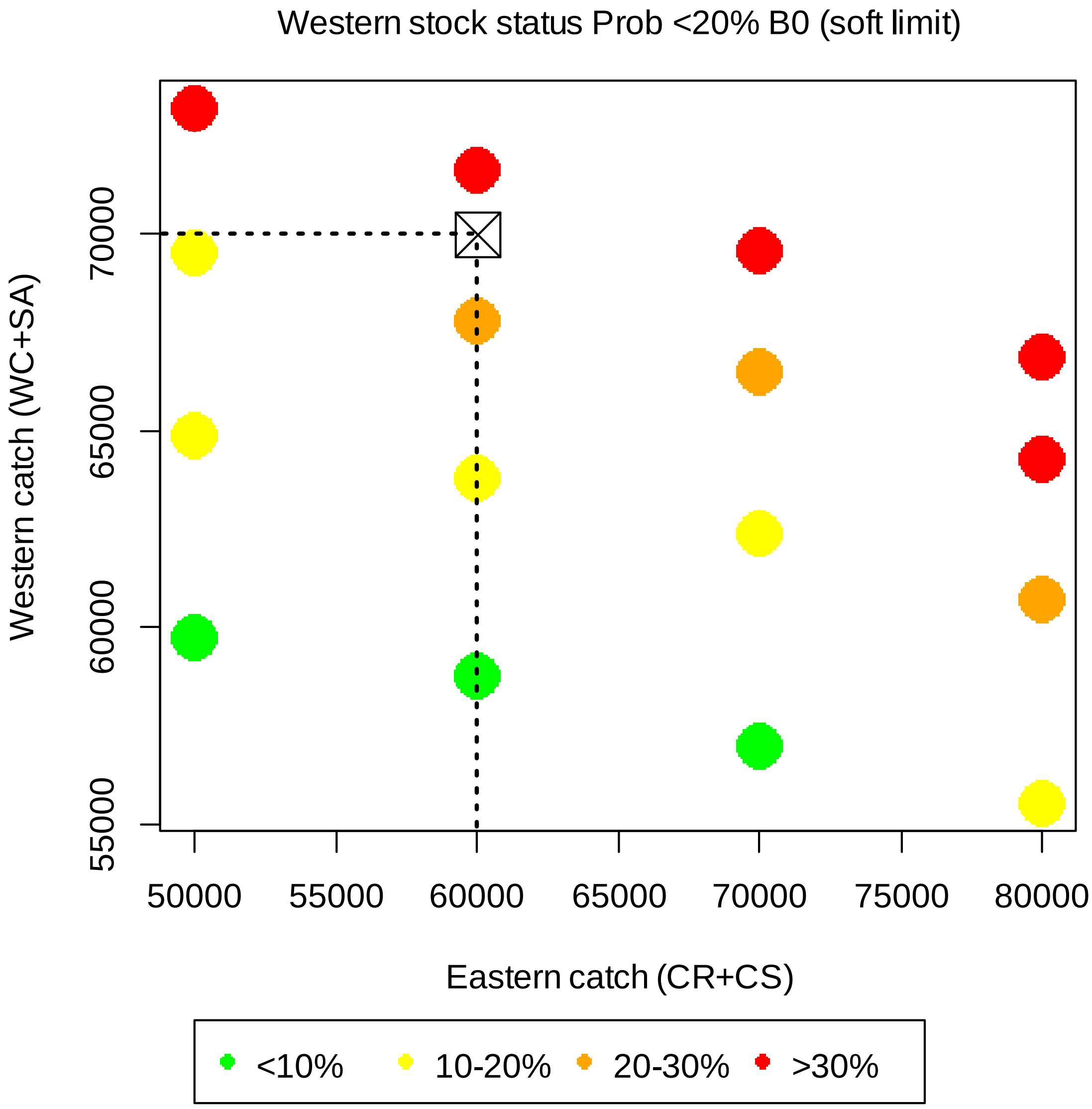

Figure 15. Probability of the western stock breaching the "soft limit" for different combinations of catch from the eastern fisheries (Chatham Rise and Cook Strait combined, x-axis) and the western fisheries (WCSI and Sub Antarctic combined, y-axis). The results are from the model option with annual Sub Antarctic trawl surveys.