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Tini a Tangaroa

Management strategy evaluation of New Zealand ling stocks

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PLAIN LANGUAGE SUMMARY

Ling (*Genypterus blacodes*) is an important commercial fish species in New Zealand middle depths waters and is caught mainly by bottom trawls, bottom longlines, and increasingly by potting.

This report summarises the management strategy evaluation of the three main ling stocks: the Chatham Rise (LIN 3&4), Sub-Antarctic (LIN 5&6 and LIN 6B) and the west coast of the South Island (LIN 7WC).

Results showed that the projected stock status was mostly affected by the assumptions of natural mortality and future recruitment. The different parameterisations of the harvest control rule had little effect. All simulations maintained biomass above the soft limit.

A potential target range was developed for ling, at 33–50% of initial biomass. Under such a target range, only a small subset of simulations would not achieve 50% probability of being above the lower end of target range.

EXECUTIVE SUMMARY

Mormede, S.[1] (2024). Management strategy evaluation of New Zealand ling stocks.
***New Zealand Fisheries Assessment Report 2024/86*. 33 p.**

Ling (*Genypterus blacodes*) are an important commercial species with adults found throughout the middle depths of the New Zealand Exclusive Economic Zone (EEZ) typically in depths of 100 m to 800 m. Ling are caught mainly by deepwater trawlers, demersal longliners and more recently by potting.

Full management strategy evaluation simulations were carried out for the three main New Zealand ling stocks. The simulations showed that the shape of the harvest control rule was not very influential, and nor was the maximum allowed total allowable catch change. This is not unexpected given that all three ling stocks are above the target spawning stock biomass of 40% of initial stock spawning biomass.

The main uncertainties associated with these stocks were tested, in particular, the value of natural mortality, the value of the stock recruit relationship steepness parameter, and future recruitment strength. As expected, the natural mortality term was the most influential, followed by the value of potential future recruitment, although there has been little change in the long-term strength of recruitment to date for these stocks. The value of steepness had some influence, particularly under the more extreme scenarios of low natural mortality and low future recruitment. All simulations had a 100% probability that SSB would remain above 20% B_0 (the soft limit for ling).

A potential target range was developed for ling based on the variability seen in the simulations:33–55% of initial biomass. Under such a target range, only a small number of simulations would not achieve 50% probability of being above the lower end of target range, under all conditions of low future recruitment and low natural mortality and/or low steepness.

[1] soFish Consulting Ltd.

1. INTRODUCTION

Ling (*Genypterus blacodes*) are an important commercial species with adults found throughout the middle depths of the New Zealand Exclusive Economic Zone (EEZ) typically in depths of 100 m to 800 m (Hurst et al. 2000). Ling are caught mainly by deepwater trawlers, often as bycatch in hoki (*Macruronus novaezelandiae*) target fisheries, by demersal longliners (Mormede et al. 2021a, 2022, 2023a), and more recently by potting (Mormede et al. 2024b). Small quantities of ling are also caught by inshore trawls and set nets.

Ling are managed as eight administrative Quota Management Areas (QMAs, Figure 1), with five (LIN 3, 4, 5, 6, and 7) reporting about 95% of landings. There are at least five major biological stocks of ling in New Zealand waters (Horn 2005)—the Chatham Rise, the Sub-Antarctic (including the Stewart-Snares shelf and Puysegur Bank), the Bounty Platform, the west coast of the South Island, and the Cook Strait. Recent analyses have indicated that the Bounty Platform might be an offshoot of the Sub-Antarctic stock (Mormede et al. 2024c), and these two areas were assessed as a single stock in 2024 (Mormede et al. 2024d).

The ling biological stocks were defined using statistical areas as described in Figure 1. Stock assessments are carried out regularly for the main ling stocks, and were last updated in 2022 for the Chatham Rise (LIN 3&4, Mormede et al. 2023b), in 2023 for the west coast South Island (LIN 7WC, Mormede et al. 2024a), and in 2024 for the Sub-Antarctic (LIN 5&6 and LIN 6B, Mormede et al. 2024d). These were carried out using a Bayesian stock model implemented using the general-purpose stock assessment program CASAL (Bull et al. 2012) or Casal2 (Doonan et al. 2016; Casal2 Development Team 2023). Stock status at the latest assessments was 56%, 66% and 51% of the initial spawning stock biomass for LIN 3&4, LIN 5&6 and LIN 6B, and LIN 7WC respectively. The status of ling stocks are summarised annually by Fisheries New Zealand (2024). Adjustments to the ling catch limits have been based on the stock assessments and five year projections (Fisheries New Zealand 2024).

Assessments for other stocks were last updated in 2007 (LIN 6B when assumed a stand-alone stock, Bounty Platform, with a CPUE update in 2014), and 2010 (LIN 7CK, Cook Strait, with an assessment in 2013 rejected). These are summarised by Fisheries New Zealand (2024) and not considered further in the present analysis.

This report summarises the results of a Management Strategy Evaluation (MSE) framework developed for the three regularly-assessed ling stocks (LIN 3&4, LIN 5&6 and LIN 6B, and LIN 7WC) using the latest population models used for management purposes (Fisheries New Zealand 2024). The work was funded by the Deepwater Council of Seafood New Zealand and reviewed by the Fisheries New Zealand Deepwater Working Group.

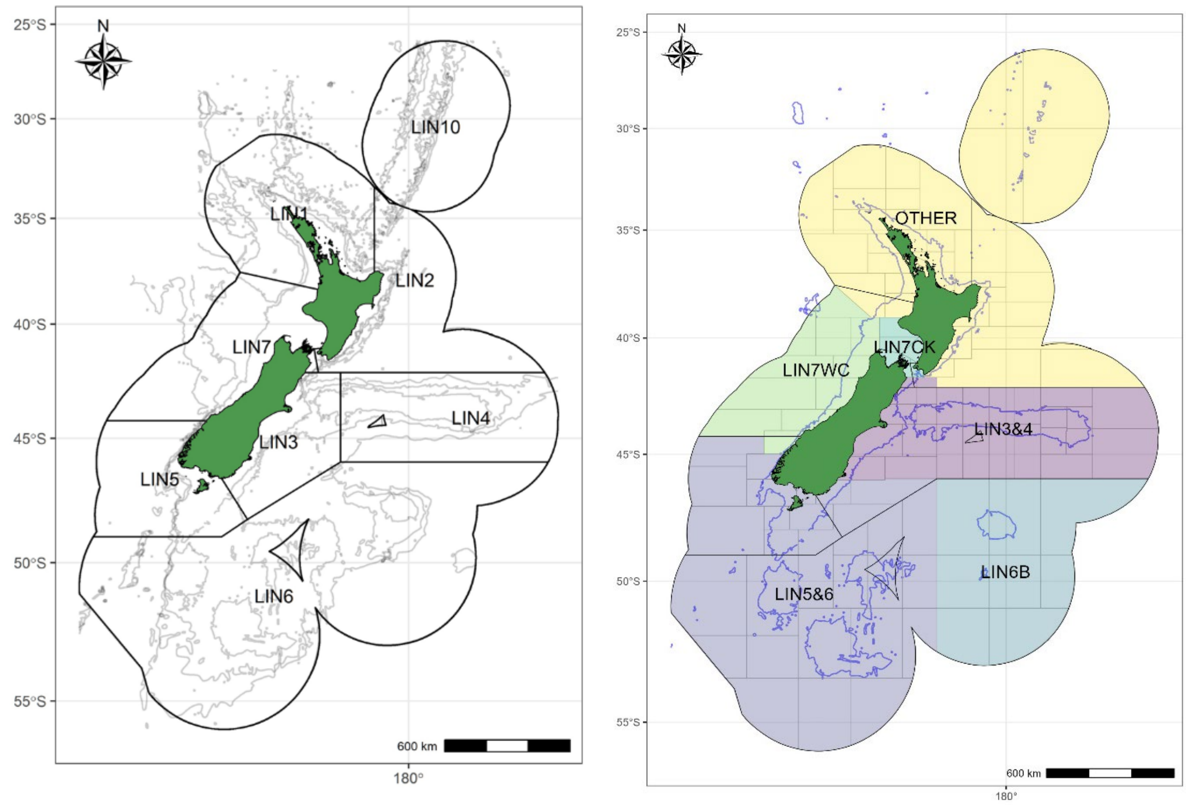


Figure 1: Quota Management Areas (QMAs, left) and biological stock boundaries (right) for ling, as used in this analysis. In 2024, LIN 5&6 and LIN 6B was assessed as a single stock for the first time.

2. METHODS

The MSE was carried out using Casal2 (Casal2 Development Team 2023) as the modelling platform. The base case models adopted for management purposes (Fisheries New Zealand 2024) were used, using the Markov Chain Monte Carlo (MCMC) outputs as a starting point for the projections, and modified as required for each simulation. Population models were updated and run for each simulation using the R Project for Statistical Computing software (R Core Team 2019). Simulation outputs were extracted and processed in R.

Ling stocks in New Zealand use a proxy for the average biomass resulting from taking an average catch of Maximum Sustainable Yield (B_{MSY}) of 40% of initial biomass (B_0), based on the Fisheries New Zealand Harvest Strategy Standard (Ministry of Fisheries 2011). This proxy has been used as the basis for the MSE, therefore throughout this document, B_{MSY} refers to 40% B_0. The exception is the last section where a maximum-sustainable yield calculation was carried out for ling stocks for the purposes of satisfying the Marine Stewardship Council (MSC) Fisheries Standard v3.0 (Marine Stewardship Council 2022).

2.1 Management framework

The investigation was guided by the Marine Stewardship Council (MSC) Fisheries Standard v3.0 (Marine Stewardship Council 2022), in particular:

- Performance Indicator (PI) 1.2.1 Scoring Guidepost (SG) 100 includes: “harvest strategy has been evaluated and is achieving the objectives in PI 1.1.1 including being clearly able to maintain stocks at target levels”.
- PI 1.2.2 SG 100 includes: “the HCR (harvest control rule) is expected to keep the stock fluctuating at or above the target level consistent with MSY (maximum sustainable yield)” and “HCR take account of a wide range of uncertainties {…} and robust to main uncertainties”.

Options for the shape of the harvest control rule were based on the harvest strategy standard developed by Fisheries New Zealand (Ministry of Fisheries 2008, 2011). The harvest strategy standard defines the default target spawning stock biomass (*SSB*) as 40% of initial spawning stock biomass (B_0), and soft and hard limits at 20% B_0 and 10% B_0 respectively (Figure 2). These values are currently used for the management of ling (Fisheries New Zealand 2024). F_{MSY} is defined as the long-term exploitation rate that achieves B_{MSY}, B_{40} in this instance, and could therefore actually more appropriately be named U_{40}.

Alternative shapes of harvest control rule were tested as part of this project, by varying the location of the two inflection points:

- The low inflection point was set at either 10% B_0 (as per Figure 2) or 20% B_0.
- The top inflection point was set at either 20% B_0, $(1 - M) \times 40\%$ B_0 (as per Figure 2) where M is natural mortality, or 40% B_0.

A top inflection point threshold of (1 – M) in B/B_{MSY} scale was recommended by Restrepo et al. (1998) as a stock fished at F_{MSY} is expected to fluctuate around B_{MSY} on a scale related to M (small fluctuations for low M and large fluctuations for high M).

Alternative targets and limits were not tested although a potential target range was developed based on the results of the simulations.

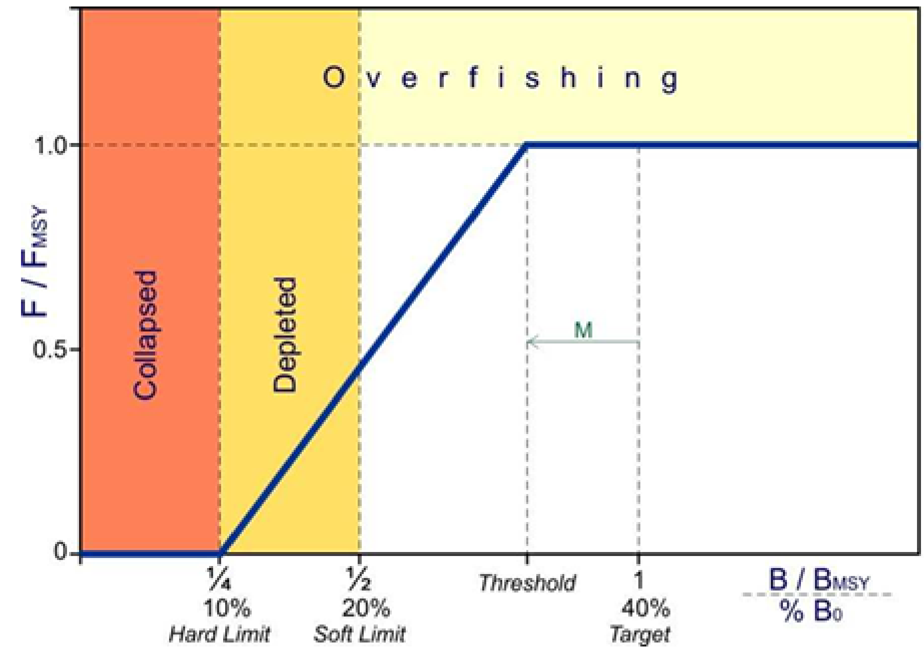


Figure 2: Example of harvest control rule provided in the Fisheries New Zealand Harvest Strategy Standard (Ministry of Fisheries 2011, Figure 6).

2.2 Calculation of U_{40}

U_{40} was calculated for each stock by projecting all 1000 MCMC chains of each stock assessment base case model forward 100 years under randomly sampled recruitment from the entire time series of estimated recruitment for that MCMC chain, with a constant exploitation rate *U* defined as catch divided by vulnerable biomass. Vulnerable biomass for all ling stocks was assumed equal to the trawl selected biomass as the trawl selectivity has a logistic shape and is to the left of the longline selectivity for all ling stocks (Mormede et al. 2023b, 2024a, 2024d).

The exploitation rate applied was iteratively changed. U_{40} for each stock was the highest exploitation rate that achieved the probability of projected *SSB* below 40% B_0 less than 0.5 over the last 50 years of the projections in all 1000 chains, with a tolerance of 0.0005.

2.3 Management Strategy Evaluation process applied

For each simulation scenario, the following process was carried out (Figure 3):

1. One of the MCMC chains was selected as the basis of the simulation run.
2. Future recruitment deviates (year class strength, YCS) were sampled from a pre-determined range of estimated YCS for all projected years, including the most recent years of the model where YCS was not estimated. The range tested was either all years, or the 10-year block of lowest YCS.
3. If an assessment year, a new total allowable catch (TAC) was calculated given the HCR tested. The simulations assumed a new TAC was calculated every three years, in line with the current assessment process. If not an assessment year, the TAC was rolled over.
4. If the simulation assumed a maximum TAC change allowed, the TAC calculated was mediated by that maximum allowed change. Maximum allowed TAC changes tested were either ±10%, ±20%, +10% / -20%, or none.
5. The model was updated by one year with the new TAC if applicable or existing TAC otherwise. The TAC was applied to the different fisheries in the same catch split as the average of last four years of the base case model (i.e. the last three years of the fishery, as the last year of the model assumes the same catch and catch split as the last year of the fishery).
6. If a "full" MSE was run (see below), an additional year of observations was simulated with the same error structure as the previous year (CV and process error). For survey observations, the same frequency was assumed in the future as per recent surveys (surveys carried out every two years in this instance).
7. If a "full" MSE, the parameters in the model were then re-estimated with the one additional year of catch and simulated observations. Sensitivities were carried out whereby the model was then run rather than re-estimated, also referred to as "shortcut" MSE, see below.
8. Points 3–7 were repeated for the 50 years of the projected simulation.
9. Points 1–7 were repeated for 50 simulation runs.
10. Performance indicators were calculated over the 50 simulation runs for each specific simulation scenario.

This process was repeated for combinations of up to six HCR rules, 12 model assumptions and four TAC limits assumptions although not all potential combinations were carried out for all stocks. Over 200 simulations were carried out.

The various simulation scenarios were compared with each other based on performance indicators, which included:

- the mean and 95% credible interval of *SSB* over the final 20 years of the projection,
- the probability that *SSB* in the last 20 years of the projection is above 20%, 33% and 40% B_0, or within 10% of 40% B_0 (a metric of 'fluctuating about the target'),
- the mean and 95% credible interval of the catch for the entire projection time,
- the median and maximum catch change over the entire projection time, and the next catch limit calculated,
- the mean future standardised CPUE (catch-per-unit-effort) by fishery and survey biomass when these were included in the model as observations, noting that these are standardised and therefore relative values,
- the mean future age of fish caught by fishery.

The option of running the model after each iteration as opposed to re-estimating parameters was investigated (points 6 and 7 above). Runs, also sometimes referred to as "shortcut" MSEs are fast and therefore allow the use of complex models and many investigations of alternative options. Such a process has been used for New Zealand rock lobster, with 100-year projections on all 1000 MCMCs typically run (Webber & Starr 2020). Alternatively, "full" MSEs require the simulation of observations and re-estimation of parameters each projected year and are therefore much slower to run than "shortcut" MSEs. They might also require a simplification of the model to allow each simulation to run in an acceptable amount of time. This was the case for the 2023 hoki MSE, for which "full" estimations were carried out on a simplified population model in R with 10-year projections and 100 simulations (Langley 2023). "Shortcut" MSE can speed up the simulations, but often provide less robust results and different outcomes (Punt et al. 2016; harveststrategies.org 2024). The two options were tested for one model for ling, with the "shortcut" MSE resulting in a higher status (see further results below). The "full" MSE process was taken forward in this instance.

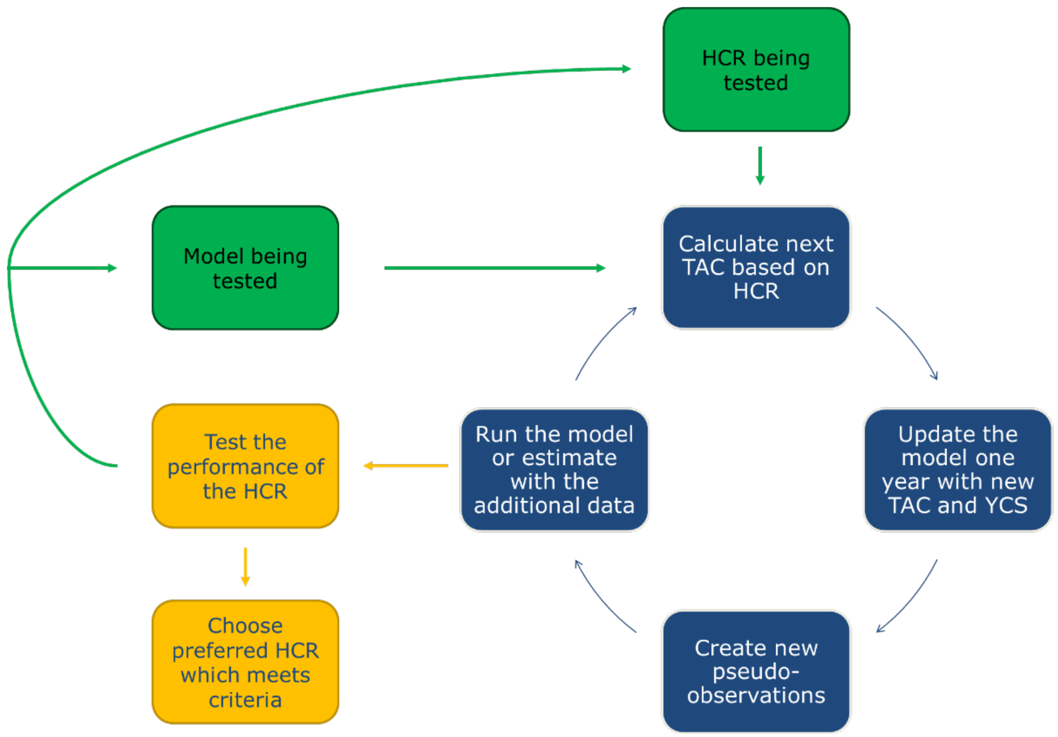


Figure 3: MSE process carried out. Note that final simulations all had re-estimations of the models. The blue boxes represent the process of each simulation scenario, the green boxes the inputs to the simulation scenarios, and the yellow boxes the analysis of the outputs of the simulation scenarios.

2.4 Range of model assumptions tested

The MSC Fisheries Standard v3.0 requires that the HCR takes account of a wide range of uncertainties (Marine Stewardship Council 2022). The main uncertainties in the stock assessments of ling tested here were natural mortality, the strength of future recruitment and, to a lesser extent, the steepness of the stock recruit relationship (Fisheries New Zealand 2024). Other uncertainties such as fisheries selectivities or future catch split between fisheries were, largely based on direct experience with previous ling stock assessments, expected to have very little influence and therefore were not tested. The effect of failing to deliver an accepted stock assessment and therefore adjusting the TAC in the three-year cycle was not tested; its effect is expected to be low over the 50-year period of the simulations. The effect of alternative catch histories have been shown to have little effect on the stock assessments of ling and therefore were not tested either (Horn et al. 2018).

Natural mortality (M) was estimated in the model for LIN 3&4 but assumed for the other stocks based on external analyses (Horn 2005; Edwards 2017); it was deemed to be poorly estimated for LIN 5&6, and with bias (Mormede et al. 2021b). For all three stocks, sensitivities are typically carried out with values of M which flank the value of the base case model (Fisheries New Zealand 2024). MSE simulation scenarios were carried out with the three values of M used in each stock assessment. Because the aim of the MSE was to test the robustness of the HCR to model misspecifications and uncertainties in the main parameters, F_{MSY} (U_{40}) was not recalculated for the simulations with alternative values of M. Similarly, the HCR with top inflection point of $(1 – M) \times 40\% \, B_0$ values were not updated to the alternative values of M but kept constant within each stock.

Any projection of a stock assessment will be affected by the assumption around the strength of future recruitment (year class strength, YCS). Projections used for assessing catch limits of New Zealand ling stocks usually resample from either all estimated YCS or the last ten estimated YCS (Fisheries New Zealand 2024). In the case of ling in New Zealand, recent recruitment has been close to average recruitment, and therefore for the purposes of MSE testing we resampled YCS from either all estimated YCS or the estimated YCS representing the lowest 10-year average YCS (as a precautionary, historic low recruitment scenario). In all instances, this period was early in the models (in the 1980s).

The three ling stocks investigated assumed a Beverton-Holt stock-recruit relationship with steepness $h = 0.84$. The value of steepness is unknown for these ling stocks because their status is not expected to have dropped below 50% B_0 (e.g., Mormede et al. 2024d). Because the SSB target is 40% B_0, it is expected that alternative values of steepness are unlikely to be strongly influential in this instance. A subset of simulation scenarios was carried out with an alternative steepness value of $h = 0.59$, based on estimates from other ling stocks worldwide (Horn 2022).

2.1 Calculation of Maximum Sustainable Yield biomass values

The biomass which sustains the maximum sustainable yield (B_{MSY}) was calculated for each stock by projecting all 1000 MCMC chains of each stock assessment base case model forward 100 years under randomly sampled recruitment from the entire time series of estimated recruitment for that MCMC chain, and a constant exploitation rate U defined as catch divided by vulnerable biomass. Vulnerable biomass for all ling stocks was assumed equal to the trawl selected biomass as the trawl selectivity has a logistic shape and is to the left of the longline selectivity for all ling stocks (Mormede et al. 2023b, 2024a, 2024d).

The exploitation rate applied was iteratively changed. The corresponding mean biomass and mean catch at equilibrium were calculated. B_{MSY} for each stock was the biomass corresponding to the highest mean catch.

3. RESULTS

3.1 Deriving U_{40} values

The target exploitation rate value (U_{40}) is affected by the vulnerable selectivity as well as many other characteristics of the model such as when in the model the catch it taken. This resulted in different values of U_{40} values in the three ling stocks:

- LIN 3&4: $U_{40} = 0.090$
- LIN 5&6 and LIN 6B: $U_{40} = 0.139$
- LIN 7WC: $U_{40} = 0.169$

Furthermore, the target exploitation rate initially calculated for LIN 3&4 externally from the simulations was higher, at 0.14, and resulted in simulations with final *SSBs* well below the target of 40% B_0. This value was reduced until simulations using the base case stabilised at 40% B_0. The reason for this behaviour was investigated but not resolved. In the other two stocks, the externally calculated U_{40} resulted in a long-term SSB of about 40% B_0 as expected (see Section 3.4).

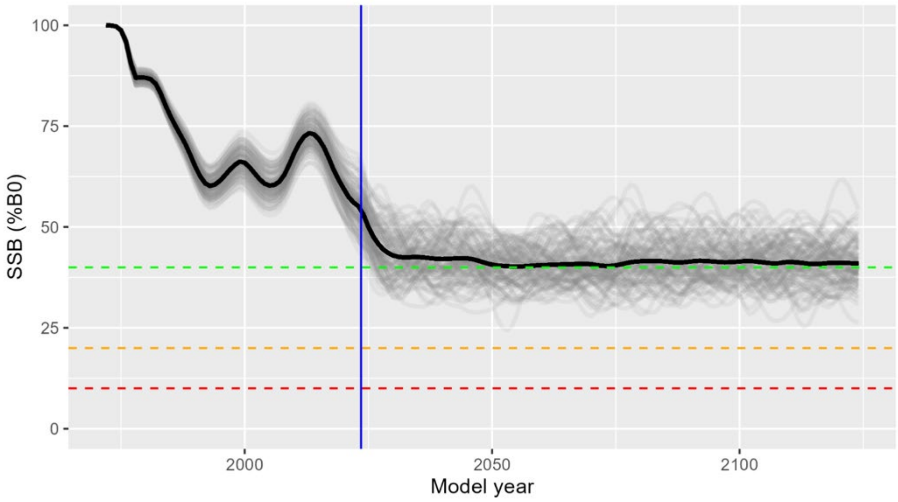
3.2 Investigating “shortcut” vs. “full” MSE

In the initial stages of developing an MSE framework for ling, the option of “shortcut” or “full” MSE was tested. The base case model for LIN 7WC was used, 100 simulations carried out sampled from the MCMC chain and projected for 100 years. Future YCS were resampled from all estimated YCS in the relevant MCMC chain, the HCR rule applied was as per Figure 2 (upper inflection point at (1 – M) × 40% B_0), and no maximum allowed TAC change was applied.

The “shortcut” MSE resulted in a higher long-term stock status compared with the “full” MSE (Figure 4). The “full” MSE resulted in a long-term *SSB* of about 41% B_0, consistent with the target of 40% B_0 as defined by the target exploitation rate U_{40}. The “shortcut” MSE was more optimistic at about 46% B_0 and therefore inconsistent with the definition of U_{40}. This result is consistent with those reported elsewhere (e.g., Punt et al. 2016; harveststrategies.org 2024).

Based on these results, all further work on the ling MSE was carried out using a “full” MSE framework whereby the model parameters were re-estimated at each timestep given the new TAC and simulated observations.

“Full” MSE



“Shortcut” MSE

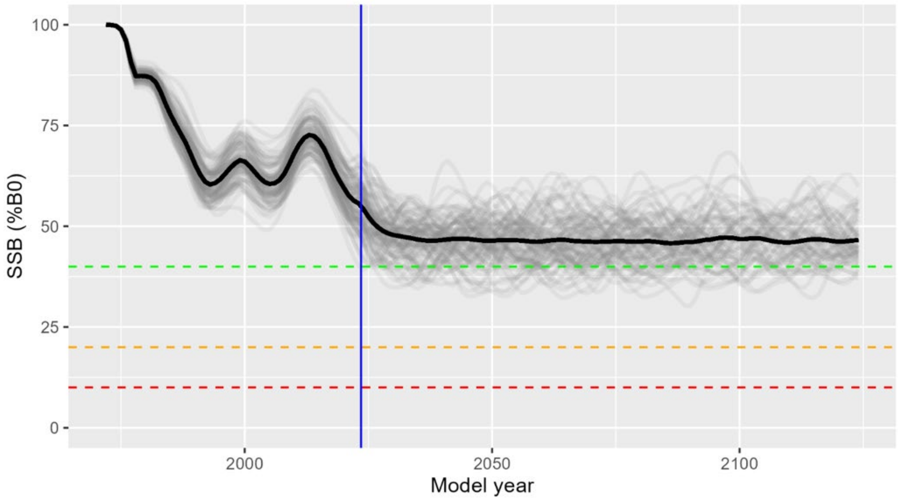


Figure 4: Projected stock spawning stock biomass (*SSB*) as a proportion of initial spawning stock biomass (B_0) for a “full” (top) or “shortcut” (bottom) MSE simulation for LIN 7WC. Each grey line represents one of the 100 simulations, and the black line is the median of all simulations. The green horizontal line represents B_{target} = 40% B_0, the orange line the soft limit of 20% B_0 and the red line the hard limit of 10% B_0. The vertical blue line represents the start of the projections.

3.3 Choosing the base HCR setup

Initial simulation scenarios were carried out using LIN 7WC as a test case to help determine the preferred shape of the harvest control rule and other parameters. “Full” MSE simulations were carried out following the parameters detailed in Section 3.3, with the full combination of:

- *M* = low (0.15), base (0.18) or high (0.21) value as per the LIN 7WC assessment
- YCS range of all estimated YCS or the lowest 10-year block of estimated YCS
- Maximum TAC change allowed of ±10%, ±20%, or +10% / -20%
- HCR low inflection point of 10% B_0 or 20% B_0
- HCR top inflection point of 20% B_0, 40% B_0 or (1 – *M*) × 40% B_0

The lowest 10-year block of estimated YCS and mean recruitment strength during that period are summarised for the three ling stocks in Table 1. The lowest 10-year block was early in the model for all three stocks, in the 1980s. The mean low recruitment strength varied between stocks, from 0.76 to 0.88 on average.

Table 1: Timing of the low recruitment (YCS) range for each stock, mean recruitment strength during that period and 95% credible interval (CI) of the estimated YCS and low YCS.

Stock	Estimated YCS recruitment multiplier CI	Low YCS years range	Low YCS mean recruitment multiplier	Low YCS recruitment multiplier CI
LIN 3&4	0.54–1.92	1981–1990	0.85	0.46–1.31
LIN 5&6 and LIN 6B	0.43–1.75	1983–1992	0.88	0.53–1.35
LIN 7WC	0.38–1.85	1976–1985	0.76	0.28–1.46

Results showed that the two parameters of most influence on stock status, mean future catch and mean future CPUE, were the value of the natural mortality *M* and the range of YCS resampled (Figure 5). Increasing stock status estimates were obtained with higher projected average YCS and / or lower natural mortality values, whilst base case mortality and average long-term recruitment resulted in a final *SSB* close to 40% B_0, which is the design of this HCR.

The other parameters tested had little influence on the outcome in this instance, which is not surprising given that the stock is estimated to be well above 40% B_0.

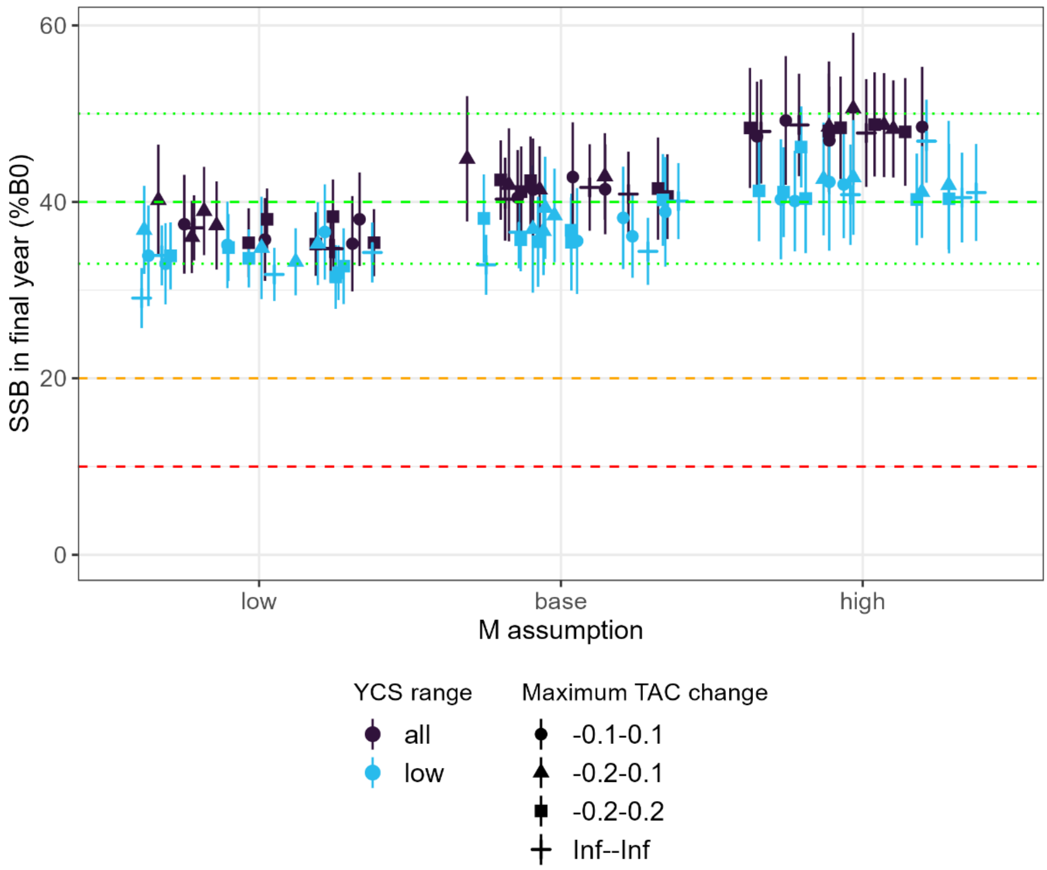
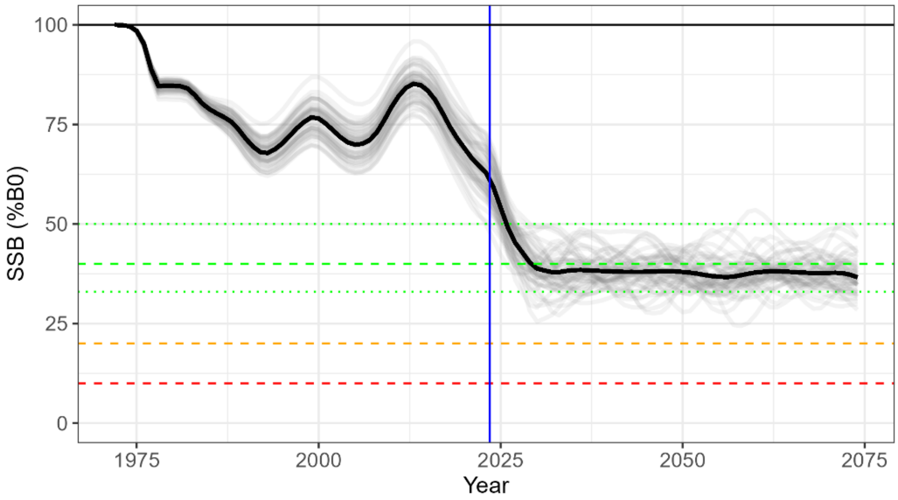


Figure 5: Projected stock spawning stock biomass (*SSB*) in the final year of the projections as a proportion of initial spawning stock biomass (B_0) for LIN 7WC simulations testing various HCR options. Each point represents the median of a simulation scenario and the bar represents the 95% credible interval of all 50 simulation runs for that scenario. The thick green horizontal line represents B_{target} = 40% B_0, the dashed thin green horizontal lines the 33–50% B_0 range (see below), the orange line the soft limit of 20% B_0 and the red line the hard limit of 10% B_0.

An extreme value of 20% B_0 was tested for the top inflection point. However, it resulted in a lower *SSB* on average, and a lower proportion of the time above the *SSB* target of 40% B_0, particularly under the assumptions of low natural mortality *M* or low future recruitment (Figure 6). Therefore, this option was not carried forward.

Low future YCS, top inflection point of 40% B_0



Low future YCS, top inflection point of 20% B_0

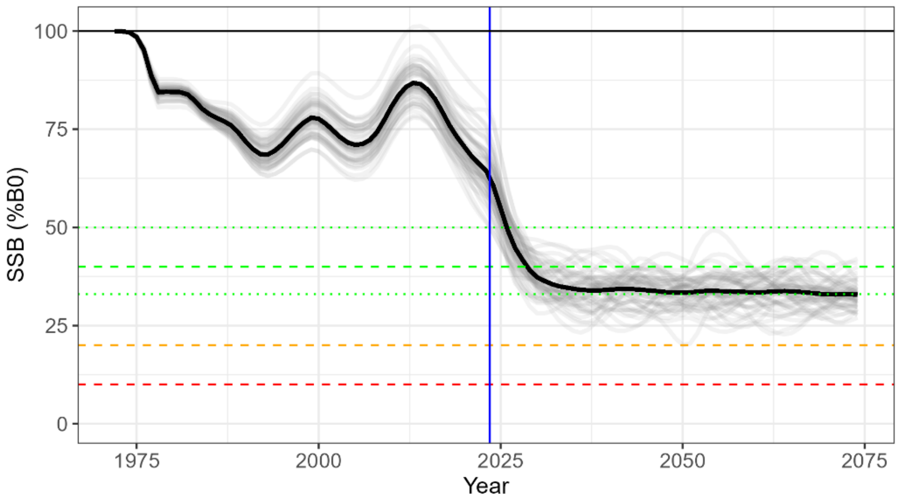


Figure 6: Projected stock spawning stock biomass (*SSB*) as a proportion of initial spawning stock biomass (B_0) for the MSE simulation scenario for LIN 7WC with low future YCS and a top inflection point of either 40% B_0 (top) or 20% B_0 (bottom). Each grey line represents one of the simulations, and the black line is the median of all simulations. The thick green horizontal line represents B_{target} = 40% B_0, the dashed thin green horizontal lines the 33–50% B_0 range (see below), the orange line the soft limit of 20% B_0 and the red line the hard limit of 10% B_0. The vertical blue line represents the start of the projections.

3.4 Final simulation scenarios for all ling stocks

Based on these investigations, the final MSE simulation scenarios carried out on all three ling stocks were chosen in conjunction with industry representatives and Fisheries New Zealand:

- Harvest control rule: low inflection point at 10% B_0 and top inflection point at (1 – M) ×40% B_0
- Maximum TAC change allowed: ±20% or no maximum
- YCS: resampled from all estimated YCS or from the lowest estimated 10-year period
- Natural mortality: the three values of *M* used in each of the stock assessments

- Steepness: $h = 0.84$ as per the base case models, and $h = 0.59$ for two scenarios

Full results are summarised in Appendix A and outcomes of the base case scenarios for all three stocks are plotted in Appendix B. Spawning stock biomass was most sensitive to the assumptions of natural mortality and recruitment (Table A.1 to Table A.3). This result is unsurprising as U_{40} is dependent upon the assumption of natural mortality and average future recruitment. Any change to these assumptions affects the final status of the stock through the HCR. The LIN 7WC stock was most sensitive to the simulation assumptions (Table A.3), possibly because it has the highest U_{40} (Section 3.1), a lower mean low recruitment strength, and a slightly higher variability in YCS than the other stocks (Table 1 and Figure B.8). All simulations had a 100% probability that SSB would remain above 20% B_0 (the soft limit for ling).

The assumption of steepness had a bearing on the outcome of the simulations, particularly on the more extreme case of low *M* and low future recruitment, but also to a lesser extent on the base simulation with base *M* and average future recruitment.

Mean future catch (Table A.4 to Table A.6) followed a similar pattern to that of *SSB*, with higher catches associated with higher natural mortality and/or higher average future YCS (and higher SSB). The relative increase in catch with increase in natural mortality was highest for LIN 3&4, because for this stock natural mortality was estimated for both sexes separately; moving to a single natural mortality affected fishing selectivities as well as productivity. Maximum allowed catches were associated with scenarios with no TAC change limitations, as were the next catch.

Where relative indices of biomass were used in the model, projected future values were calculated: relative fishery CPUE or survey biomass, noting that these are not comparable between models. Future relative indices of biomass showed similar trends to future spawning stock biomass although they were less marked: the increase in relative indices of biomass with increasing natural mortality or recruitment strength was only small. The mean age of fish caught followed the opposite trend to spawning stock biomass as expected (with older fish at lower natural mortality), although there again the differences between the scenarios were small (Table A.7 to Table A.9).

3.5 Deriving a potential target range for ling

Ling stocks in New Zealand have a single target spawning stock biomass status of 40% of initial biomass, the default value from the Fisheries New Zealand Harvest Strategy Standard (Ministry of Fisheries 2011). Other stocks such as orange roughy or hoki have a target range (Fisheries New Zealand 2024).

A range of naturally varying *SSB* for the ling stocks with fishing occurring could be defined as the range of *SSB* that the base case population models projected with a B_{MSY} target of 40% B_0 and average recruitment could achieve (the base simulation scenarios). Based on the 95% credible interval of those simulations, a target range for all ling stocks could be defined as 33–50% B_0 (Table 2). The value of $(1 – M) \times 40\%$ B_0 used in the harvest control rule was designed to capture that same variability in stock status (Restrepo et al. 1998; Ministry of Fisheries 2008), and would result in a lower target range for ling of about 33%.

Based on a target range lower value of 33% B_0, all simulations for LIN 3&4 would have a probability of being above the target range lower value greater than 50% (Table A.1). Only one simulation for LIN 5&6 and LIN 6B would not have the probability of being above the target range lower value greater than 50%, under a combination of low future recruitment and low steepness assumptions (Table A.2). As discussed above, LIN 7WC was the stock most sensitive to simulation assumptions, and four out of the 14 final simulation scenarios would result in long-term SSB below the lower target range with over 50% probability: the two scenarios with low natural mortality and low recruitment assumptions combined, and the two scenarios with low steepness assumption (Table A.3).

Table 2: Potential B_{target} range for ling, based on the 95% credible interval of the last 20 years of the simulated *SSB* for the base simulations of each ling stock. The base simulations are defined as the simulation scenarios with base case natural mortality (*M*), future recruitment sampled from all estimated past recruitment, base steepness of 0.84 and either no limit of TAC change or a maximum of 20% change. The lower range is compared with the (1 – *M*) × 40% B_0 value.

	Lower range (*SSB* as % B_0)		Upper range (*SSB* as % B_0)
Stock	1 - *M*	2.5%ile of base simulation	97.5%ile of base simulation
LIN 3&4	33.6	32.7 – 33.6	50.7 – 50.9
LIN 5&6 and LIN 6B	32.8	32.9 – 34.0	51.5 – 51.9
LIN 7WC	32.8	32.6 – 32.8	49.9 – 50.1
All stocks (proposed)		33	50

3.6 Deriving Maximum Sustainable Yield biomass values

B_{MSY} is affected by the vulnerable selectivity as well as many other characteristics of the model such as natural mortality. This resulted in slightly different values of B_{MSY} in the three ling stocks (Figure 7):

- LIN 3&4: B_{MSY} = 22.9% B_0
- LIN 5&6 and LIN 6B: B_{MSY} = 20.0% B_0
- LIN 7WC: B_{MSY} = 25.0% B_0

These values of B_{MSY} were, as expected, lower than the proxy B_{MSY} of 40% B_0 used for ling and many other New Zealand fish stocks. The B_{MSY} proxy was designed to include many additional considerations including ecosystem interactions and population / stock variability (Ministry of Fisheries 2011).

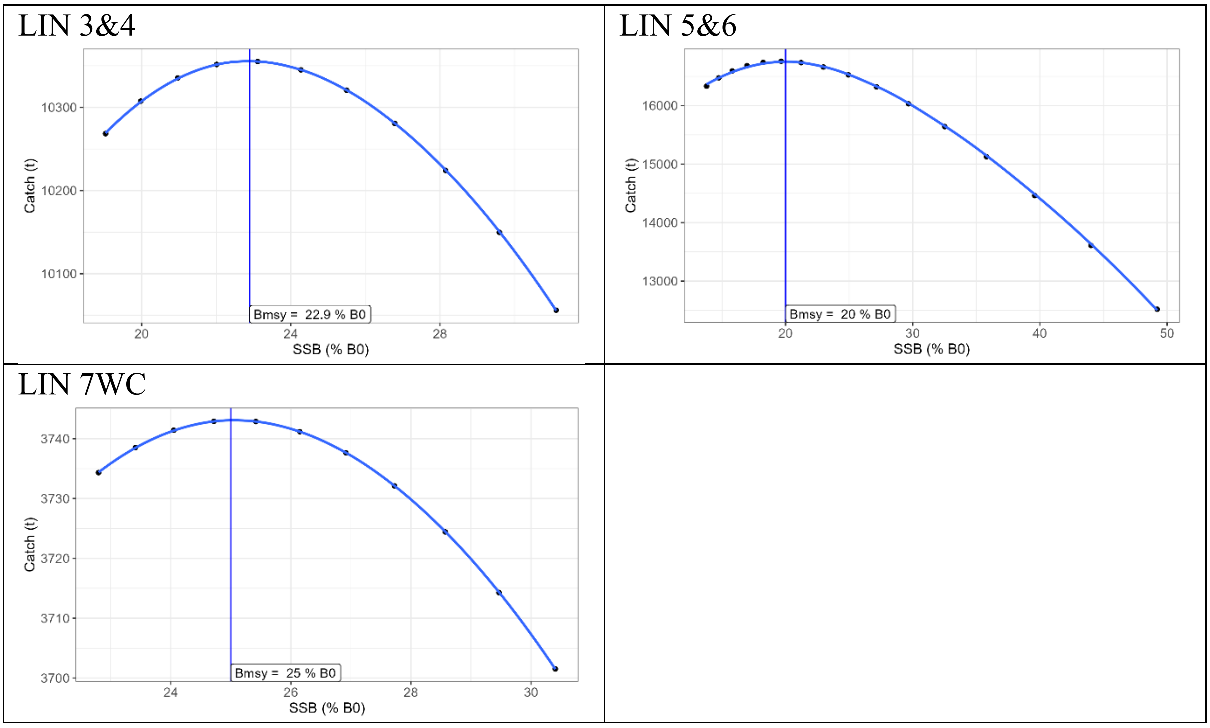


Figure 7: Projected stock spawning stock biomass (*SSB*) as a proportion of initial spawning stock biomass (B_0) as a function of the average long term catch for the three main ling stocks. The vertical line corresponds to B_{MSY}, which is also reported.

4. DISCUSSION

Full management strategy evaluation simulations were carried out for the three main New Zealand ling stocks. A summary of some of the results is provided in Table 3.

The simulations showed that the shape of the harvest control rule was not very influential, and nor was the maximum allowed total allowable catch change. This is not unexpected given that all three ling stocks are above the target spawning stock biomass of 40% of initial stock spawning biomass.

The main uncertainties in these stocks were tested, namely the value of natural mortality, the value of the stock recruit relationship steepness parameter, and future recruitment strength. As expected, the natural mortality term was the most influential, followed by the value of potential future recruitment, although there has been little change in the long-term strength of recruitment to date for those stocks compared with some other stocks. The value of steepness had some influence, particularly on the more extreme scenarios of low natural mortality and low future recruitment. None of the stocks went below the soft limit of 20% of initial spawning biomass.

Because low recruitment strength was between 0.76 and 0.88 for the different stocks, the results from the different stocks are not directly comparable: a stock with stronger projected recruitment strength is more likely to achieve targets than one with lower projected recruitment strength. As a result, as LIN 7WC had the lowest low average recruitment it also had the highest proportion of simulation runs not achieving 50% of the lower end of the target range (all with low future recruitment and either low natural mortality or steepness). LIN 7WC also had the highest U_{40} value, which might have a compounding effect.

As all stocks in 2024 are expected to be well above the 40% initial biomass target, all projections showed an initial period of higher future catches necessary to reduce the biomass to the target, thereafter, future catches settled to a fairly stable level (Figures B.3, B.6 and B.9).

A potential target range suitable for management was developed for ling based on the variability seen in the simulations. This potential range was 33–55% of initial biomass. With such a target range, only a small number of final simulations did not achieve a 50% probability of being above the lower end of the target range and none were below the soft limit (Table 3).

Table 3: Summary of the main results for the three ling stocks. pab33 < 0.5 is the percentage of the final simulations where the probability of being above 33% (the lower end of the proposed target range) was less than 0.5, and pbe20 is the percentage of final simulations where the probability of being below 20% B_0 (the soft limit) was more than 0.

Stock	LIN 3&4	LIN 5&6 and LIN 6B	LIN 7WC
$B_{current}$ at last assessment in 2021-2024 (% B_0)	55.8	66.3	51.1
U_{40}	0.090	0.139	0.169
Low YCS mean recruitment multiplier	0.85	0.88	0.76
pab33 < 0.5 (% of final simulations)	0.0	7.0	28.5
pbe20 > 0 (% of final simulations)	0.0	0.0	0.0
$B_{MSYproxy}$ (referred to as B_{MSY} in most of this document)	40.0	40.0	40.0
B_{MSY} (% B_0)	22.9	20.0	25.0

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7. Appendix A – results of the final simulations

Table A.1: Summary of the spawning stock biomass (SSB) in the last 20 years of the simulations for stock LIN 3&4 with U_{40} = 0.09. Stock recruit steepness (*h*), natural mortality (*M*), maximum TAC change allowed (Max change) and YCS recruitment range for future recruitment (YCS range) assumptions are reported for each scenario. YCS resample range: all = 1978 – 2016, low = 1981 – 1990. * denotes that natural mortality was estimated in the base case model. The mean SSB for the last 20 years of the simulation over all the simulations, 95% credible interval (CI) as well as the probability of being above 40% B_0 (pab40), above 33% B_0 (pab33) and within 10% of 40% B_0 (p36to44) are reported. Base case assumptions of natural mortality and steepness are highlighted in grey. Sensitivities on steepness are reported below the empty line and values with base steepness duplicated in blue to allow easy comparison.

h	*M*	YCS range	Max change	SSB mean (% B_0)	SSB CI (% B_0)	pab40	pab33	p36to44
0.84	0.13	all	20%	37.3	32.3–43.3	16.4	95.0	65.2
0.84	0.13	all	any	37.3	32.1–44.1	19.1	95.1	59.5
0.84	0.13	low	20%	36.3	30.5–42.2	14.1	85.7	54.0
0.84	0.13	low	any	36.4	31.2–43.2	12.5	89.7	48.7
0.84	0.16*	all	20%	41.5	33.6–50.9	60.4	98.0	64.2
0.84	0.16*	all	any	40.0	32.7–50.7	43.8	96.6	64.7
0.84	0.16*	low	20%	39.8	31.0–50.9	46.5	92.9	59.1
0.84	0.16*	low	any	39.2	31.7–49.7	36.1	93.7	62.7
0.84	0.18	all	20%	40.2	33.0–49.2	50.5	97.3	67.2
0.84	0.18	all	any	39.1	33.0–48.5	37.2	97.5	57.6
0.84	0.18	low	20%	38.7	31.1–48.9	36.3	92.3	60.3
0.84	0.18	low	any	38.4	31.7–47.5	30.9	92.6	60.9
0.84	0.13	low	any	36.4	31.2–43.2	12.5	89.7	48.7
0.59	0.13	low	any	33.2	27.8–40.0	2.6	51.6	18.6
0.84	0.16*	all	any	40.0	32.7–50.7	43.8	96.6	64.7
0.59	0.16*	all	any	34.1	28.0–41.7	6.7	58.7	26.4

Table A.2: Summary of the spawning stock biomass (SSB) in the last 20 years of the simulations for stock LIN 5&6 and LIN 6B with U_{40} = 0.139. Stock recruit steepness (*h*), natural mortality (*M*), maximum TAC change allowed (Max change) and YCS recruitment range for future recruitment (YCS range) assumptions are reported for each scenario. YCS resample range: all = 1976 – 2020, low = 1983 – 1992. The mean SSB for the last 20 years of the simulation over all the simulations, 95% credible interval (CI) as well as the probability of being above 40% B_0 (pab40), above 33% B_0 (pab33) and within 10% of 40% B_0 (p36to44) are reported. Base case assumptions of natural mortality and steepness are highlighted in grey. Sensitivities on steepness are reported below the empty line and values with base steepness duplicated in blue to allow easy comparison.

h	*M*	YCS range	Max change	SSB mean (% B_0)	SSB CI (% B_0)	pab40	pab33	p36to44
0.84	0.16	all	20%	39.6	32.6–49.2	44.6	96.9	63.4
0.84	0.16	all	any	39.0	32.6–48.1	36.8	96.4	63.2
0.84	0.16	low	20%	38.8	29.5–48.4	37.7	91.2	60.7
0.84	0.16	low	any	38.7	29.5–47.9	36.9	90.8	60.0
0.84	0.18	all	20%	41.4	34–51.8	59.8	99.1	65.2
0.84	0.18	all	any	41.6	32.9–51.5	58.4	97.4	55.5
0.84	0.18	low	20%	41.2	32.6–49.9	60.8	96.5	67.4
0.84	0.18	low	any	41.1	31.9–52.1	56.6	95.3	59.9
0.84	0.20	all	20%	43.1	31.8–55.0	72.3	96.5	47.5
0.84	0.20	all	any	44.5	34.9–55.5	81.1	99.3	43.8
0.84	0.20	low	20%	43.6	32.8–55.8	71.4	97.3	47.1
0.84	0.20	low	any	43.1	35–52.8	73.7	99.0	53.7
0.84	0.16	low	any	38.7	29.5–47.9	36.9	90.8	60.0
0.59	0.16	low	any	33.0	27.6–39.9	2.5	45.4	15.3
0.84	0.18	all	any	41.6	32.9–51.5	58.4	97.4	55.5
0.59	0.18	all	any	33.8	28.2–42.1	5.5	54.7	22.0

Table A.3: Summary of the spawning stock biomass (SSB) in the last 20 years of the simulations for stock LIN 7WC with U_{40} = 0.169. Stock recruit steepness (*h*), natural mortality (*M*), maximum TAC change allowed (Max change) and YCS recruitment range for future recruitment (YCS range) assumptions are reported for each scenario. YCS resample range: all = 1976 – 2016, low = 1976 – 1985. The mean SSB for the last 20 years of the simulation over all the simulations, 95% credible interval (CI) as well as the probability of being above 40% B_0 (pab40), above 33% B_0 (pab33) and within 10% of 40% B_0 (p36to44) are reported. Base case assumptions of natural mortality and steepness are highlighted in grey. Sensitivities on steepness are reported below the empty line and values with base steepness duplicated in blue to allow easy comparison.

h	*M*	YCS range	Max change	SSB mean (% B_0)	SSB CI (% B_0)	pab40	pab33	p36to44
0.84	0.15	all	20%	37.0	29.3–44.8	23.5	80.8	54.0
0.84	0.15	all	any	36.8	29.8–44.5	18.3	84.5	56.3
0.84	0.15	low	20%	33.2	25.0–40.8	3.8	49.7	20.1
0.84	0.15	low	any	32.2	25.8–39.5	2.3	39.7	13.2
0.84	0.18	all	20%	40.9	32.6–50.1	59.7	96.5	59.5
0.84	0.18	all	any	41.1	32.8–49.9	58.2	96.9	58.5
0.84	0.18	low	20%	35.6	27.1–45.0	14.6	73.5	39.7
0.84	0.18	low	any	35.4	28.5–43.1	13.1	70.2	40.7
0.84	0.21	all	20%	47.0	35.7–59.0	90.2	100.0	29.0
0.84	0.21	all	any	46.9	36.3–58.5	88.9	99.7	28.2
0.84	0.21	low	20%	40.3	30.2–52.1	50.7	91.4	55.1
0.84	0.21	low	any	39.0	29.4–49.5	41.9	86.6	54.2
0.84	0.15	low	any	32.2	25.8–39.5	2.3	39.7	13.2
0.59	0.15	low	any	29.0	24.2–34.5	0.0	6.3	1.4
0.84	0.18	all	any	41.1	32.8–49.9	58.2	96.9	58.5
0.59	0.18	all	any	33.8	27.2–40.8	4.7	59.6	23.6

Table A.4: Summary of the future catches in the simulations for stock LIN 3&4 with U_{40} = 0.09. Stock recruit steepness (*h*), natural mortality (*M*), maximum TAC change allowed (Max change) and YCS recruitment range for future recruitment (YCS range) assumptions are reported for each run. YCS resample range: all = 1978 – 2016, low = 1981 – 1990. Mean and 95% credible interval (CI) of future catches are reported, as well as maximum catch, median change and the catch limit to be assigned in the first year of simulations (next). Base case assumptions of natural mortality and steepness are highlighted in grey. Sensitivities on steepness are reported below the empty line and values with base steepness duplicated in blue to allow easy comparison.

h	*M*	YCS range	Max change	Catch (t) mean	Catch (t) CI	Change (t) max	Change (t) median	Catch (t) next
0.84	0.13	all	20%	4 645	3 609 – 5 599	932	207	3 885
0.84	0.13	all	any	4 626	3 590 – 5 587	1 260	121	4 962
0.84	0.13	low	20%	4 454	3 361 – 5 418	909	235	3 885
0.84	0.13	low	any	4 497	3 363 – 5 572	1 492	130	5 067
0.84	0.16*	all	20%	5 923	3 885 – 7 724	1 611	402	3 885
0.84	0.16*	all	any	6 137	4 614 – 8 324	1 359	187	7 367
0.84	0.16*	low	20%	5 536	3 884 – 7 946	1 611	428	3 885
0.84	0.16*	low	any	5 800	3 840 – 8 381	2 709	197	7 461
0.84	0.18	all	20%	8 699	3 885 -–13 010	2 319	932	3 885
0.84	0.18	all	any	9 731	7 067 – 13 523	2 920	249	12 904
0.84	0.18	low	20%	8 086	3 885 – 11 672	2 319	890	3 885
0.84	0.18	low	any	9 407	6 386 – 14 008	3 847	297	12 998
0.84	0.13	low	any	4 497	3 363 – 5 572	1 492	130	5 067
0.59	0.13	low	any	2 636	1 001 – 3 937	2 531	219	1 231
0.84	0.16*	all	any	6 137	4 614 – 8 324	1 359	187	7 367
0.59	0.16*	all	any	5 036	2 898 – 7 476	3 851	294	6 309

Table A.5: Summary of the future catches in the simulations for stock LIN 5&6 and LIN 6B with U_{40} = 0.139. Stock recruit steepness (*h*), natural mortality (*M*), maximum TAC change allowed (Max change) and YCS recruitment range for future recruitment (YCS range) assumptions are reported for each run. YCS resample range: all = 1976 – 2020, low = 1983 – 1992. Mean and 95% credible interval (CI) of future catches are reported, as well as maximum catch, median change and the catch limit to be assigned in the first year of simulations (next). Base case assumptions of natural mortality and steepness are highlighted in grey. Sensitivities on steepness are reported below the empty line and values with base steepness duplicated in blue to allow easy comparison.

h	*M*	YCS range	Max change	Catch (t) mean	Catch (t) CI	Change (t) max	Change (t) median	Catch (t) next
0.84	0.16	all	20%	13 239	9 530 – 18 033	2 842	724	11 181
0.84	0.16	all	any	13 655	9 423 – 21 692	5 440	544	21 089
0.84	0.16	low	20%	12 845	8 983 – 17 519	3 229	632	11 181
0.84	0.16	low	any	13 223	8 956 – 21 832	5 764	462	20 617
0.84	0.18	all	20%	15 037	10 798 – 20 853	4 238	1 102	11 181
0.84	0.18	all	any	15 606	10 969 – 23 544	5 777	555	21 965
0.84	0.18	low	20%	15 276	10 947 – 21 913	4 637	1 029	11 181
0.84	0.18	low	any	15 915	9 905 – 24 080	6 189	484	23 629
0.84	0.20	all	20%	16 369	11 180 – 23 182	4 637	1 575	11 181
0.84	0.20	all	any	17 809	11 195 – 33 508	18 885	863	23 463
0.84	0.20	low	20%	16 139	11 011 – 23 183	4 637	1 536	11 181
0.84	0.20	low	any	17 472	11 335 – 31 478	17 800	810	23 467
0.84	0.16	low	any	13 223	8 956 – 21 832	5 764	462	20 617
0.59	0.16	low	any	11 999	6 989 – 21 504	5 912	600	21 117
0.84	0.18	all	any	15 606	10 969 – 23 544	5 777	555	21 965
0.59	0.18	all	any	13 073	7 478 – 22 104	7 475	494	21 077

Table A.6: Summary of the future catches in the simulations for stock LIN 7WC with U_{40} = 0.169. Stock recruit steepness (*h*), natural mortality (*M*), maximum TAC change allowed (Max change) and YCS recruitment range for future recruitment (YCS range) assumptions are reported for each scenario. YCS resample range: all = 1976 – 2016, low = 1976 – 1985. Mean and 95% credible interval (CI) of future catches are reported, as well as maximum catch, median change and the catch limit to be assigned in the first year of simulations (next). Base case assumptions of natural mortality and steepness are highlighted in grey. Sensitivities on steepness are reported below the empty line and values with base steepness duplicated in blue to allow easy comparison.

h	*M*	YCS range	Max change	Catch (t) mean	Catch (t) CI	Change (t) max	Change (t) median	Catch (t) next
0.84	0.15	all	20%	2 993	1 978 – 3 923	679	174	3 580
0.84	0.15	all	any	3 161	2 030 – 4 588	1 308	206	4 359
0.84	0.15	low	20%	2 259	1 245 – 3 923	543	225	3 649
0.84	0.15	low	any	2 208	1 211 – 4 136	1 256	199	4 078
0.84	0.18	all	20%	3 587	2 571 – 4 708	889	188	3 861
0.84	0.18	all	any	3 655	2 616 – 5 313	2 754	191	4 991
0.84	0.18	low	20%	2 743	1 518 – 4 361	785	250	3 904
0.84	0.18	low	any	2 723	1 490 – 4 996	1 258	185	4 989
0.84	0.21	all	20%	3 978	2 779 – 5 518	1 130	260	3 910
0.84	0.21	all	any	4 222	2 866 – 6 229	2 635	226	5 588
0.84	0.21	low	20%	3 057	1 707 – 4 708	942	210	3 902
0.84	0.21	low	any	3 054	1 680 – 5 748	4 165	178	5 328
0.84	0.15	low	any	2 208	1 211 – 4 136	1 256	199	4 078
0.59	0.15	low	any	1 507	753 – 3 165	1 105	136	3 021
0.84	0.18	all	any	3 655	2 616 – 5 313	2 754	191	4 991
0.59	0.18	all	any	2 920	1 780 – 4 194	1 631	183	3 913

Table A.7: Summary of the mean relative future CPUE, survey biomass and mean fish age (in years) by fishery in the simulations for stock LIN 3&4 with U_{40} = 0.09. Stock recruit steepness (*h*), natural mortality (*M*), maximum TAC change allowed (Max change) and YCS recruitment range for future recruitment (YCS range) assumptions are reported for each scenario. YCS resample range: all = 1978 – 2016, low = 1981 – 1990. Base case assumptions of natural mortality and steepness are highlighted in grey. Sensitivities on steepness are reported below the empty line and values with base steepness duplicated in blue to allow easy comparison. "-" denotes no CPUE observations are used in the model.

h	*M*	YCS range	Max change	CPUE line	CPUE trawl	Survey biomass (t)	Mean age line	Mean age trawl
0.84	0.13	all	20%	-	-	8 386	13.7	9.9
0.84	0.13	all	any	-	-	8 210	13.7	9.8
0.84	0.13	low	20%	-	-	7 995	13.8	9.9
0.84	0.13	low	any	-	-	7 968	13.7	9.9
0.84	0.16*	all	20%	-	-	7 728	13.3	9.5
0.84	0.16*	all	any	-	-	7 291	13.2	9.4
0.84	0.16*	low	20%	-	-	7 341	13.4	9.6
0.84	0.16*	low	any	-	-	7 044	13.2	9.5
0.84	0.18	all	20%	-	-	7 199	13.0	9.3
0.84	0.18	all	any	-	-	6 421	12.5	9.0
0.84	0.18	low	20%	-	-	6 679	13.0	9.3
0.84	0.18	low	any	-	-	6 181	12.6	9.0
0.84	0.13	low	any	-	-	7 968	13.7	9.9
0.59	0.13	low	any	-	-	6 954	14.1	10.1
0.84	0.16*	all	any	-	-	7 291	13.2	9.4
0.59	0.16*	all	any	-	-	6 143	13.2	9.5

Table A.8: Summary of the mean relative future CPUE, survey biomass and mean fish age (in years) by fishery in the simulations for stock LIN 5&6 and LIN 6B with U_{40} = 0.139. Stock recruit steepness (*h*), natural mortality (*M*), maximum TAC change allowed (Max change) and YCS recruitment range for future recruitment (YCS range) assumptions are reported for each scenario. YCS resample range: all = 1976 – 2020, low = 1983 – 1992. Base case assumptions of natural mortality and steepness are highlighted in grey. Sensitivities on steepness are reported below the empty line and values with base steepness duplicated in blue to allow easy comparison. "-" denotes no CPUE observations are used in the model.

h	*M*	YCS range	Max change	CPUE line	CPUE trawl	Survey biomass (t)	Mean age line	Mean age trawl
0.84	0.16	all	20%	-	-	15 786	12.0	9.7
0.84	0.16	all	any	-	-	15 260	11.9	9.6
0.84	0.16	low	20%	-	-	15 423	12.0	9.7
0.84	0.16	low	any	-	-	14 898	11.9	9.6
0.84	0.18	all	20%	-	-	16 210	11.6	9.4
0.84	0.18	all	any	-	-	15 736	11.4	9.3
0.84	0.18	low	20%	-	-	16 217	11.6	9.4
0.84	0.18	low	any	-	-	15 144	11.4	9.3
0.84	0.20	all	20%	-	-	17 025	11.2	9.1
0.84	0.20	all	any	-	-	16 082	11.0	9.0
0.84	0.20	low	20%	-	-	16 953	11.2	9.1
0.84	0.20	low	any	-	-	15 794	10.9	9.0
0.84	0.16	low	any	-	-	14 898	11.9	9.6
0.59	0.16	low	any	-	-	13 309	12.0	9.7
0.84	0.18	all	any	-	-	15 736	11.4	9.3
0.59	0.18	all	any	-	-	13 352	11.5	9.3

Table A.9: Summary of the mean relative future CPUE, survey biomass and mean fish age (in years) by fishery in the simulations for stock LIN 7WC with U_{40} = 0.169. Stock recruit steepness (*h*), natural mortality (*M*), maximum TAC change allowed (Max change) and YCS recruitment range for future recruitment (YCS range) assumptions are reported for each scenario. YCS resample range: all = 1976 – 2016, low = 1976 – 1985. Base case assumptions of natural mortality and steepness are highlighted in grey. Sensitivities on steepness are reported below the empty line and values with base steepness duplicated in blue to allow easy comparison. "-" denotes no CPUE observations are used in the model.

h	*M*	YCS range	Max change	CPUE line	CPUE trawl	Survey biomass (t)	Mean age line	Mean age trawl
0.84	0.15	all	20%	832	19 761	1 021	13.0	10.7
0.84	0.15	all	any	794	19 446	1 007	13.0	10.6
0.84	0.15	low	20%	675	15 489	818	13.3	10.8
0.84	0.15	low	any	680	15 580	834	13.1	10.8
0.84	0.18	all	20%	801	20 166	1 020	12.3	10.2
0.84	0.18	all	any	782	19 622	995	12.2	10.1
0.84	0.18	low	20%	623	15 355	791	12.4	10.3
0.84	0.18	low	any	612	15 032	771	12.4	10.3
0.84	0.21	all	20%	783	20 799	1 019	11.8	9.8
0.84	0.21	all	any	740	20 423	1 023	11.7	9.7
0.84	0.21	low	20%	587	15 501	774	11.9	9.8
0.84	0.21	low	any	583	15 150	770	11.7	9.8
0.84	0.15	low	any	680	15 580	834	13.1	10.8
0.59	0.15	low	any	682	14 915	817	13.7	11.3
0.84	0.18	all	any	782	19 622	995	12.2	10.1
0.59	0.18	all	any	705	17 621	897	12.4	10.3

8. Appendix B – Outcomes of the base simulations

The base simulations are defined as those scenarios with the natural mortality and steepness used in the base case of each stock assessment model.

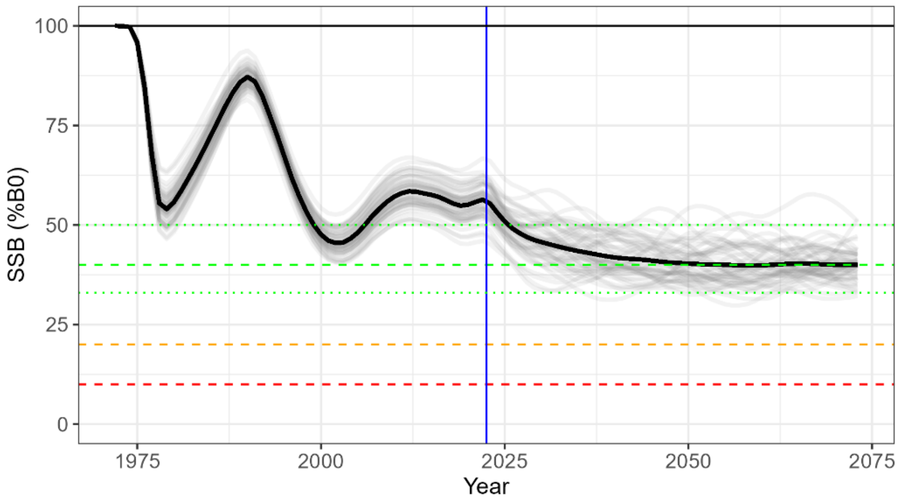

Figure B.1: LIN 3&4 base simulation projected stock spawning stock biomass (*SSB*) as a proportion of initial spawning stock biomass (B_0) for the MSE simulation with average future YCS, a top inflection point of (1 – M) × 40% B_0 and no TAC constraint. Each grey line represents one of the simulations, and the black line is the median of all simulations. The thick green horizontal line represents B_{target} = 40% B_0, the dashed thin green horizontal lines represent the 33–50% B_0 range, the orange line the soft limit of 20% B_0 and the red line the hard limit of 10% B_0. The vertical blue line represents the start of the projections.

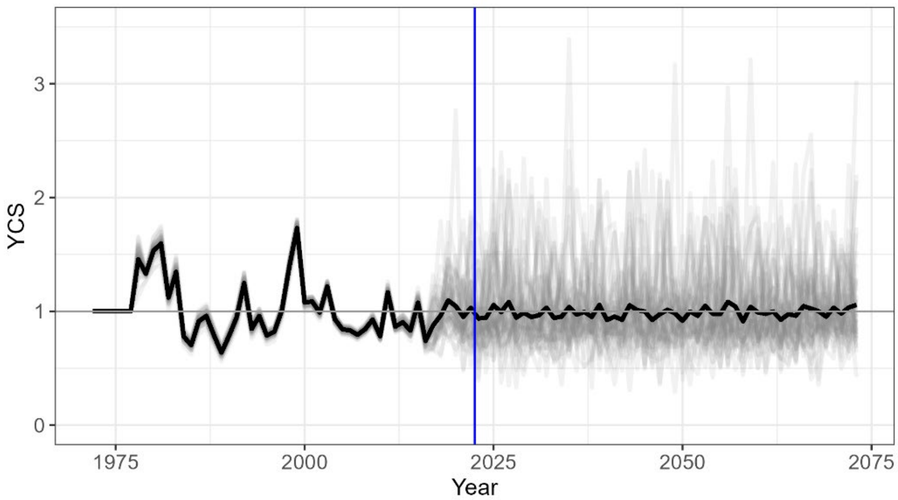

Figure B.2: LIN 3&4 base simulation resampled YCS for the MSE simulation with average future YCS, a top inflection point of (1 – M) × 40% B_0 and no TAC constraint. Each grey line represents one of the simulations, and the black line is the median of all simulations. The vertical blue line represents the start of the projections.

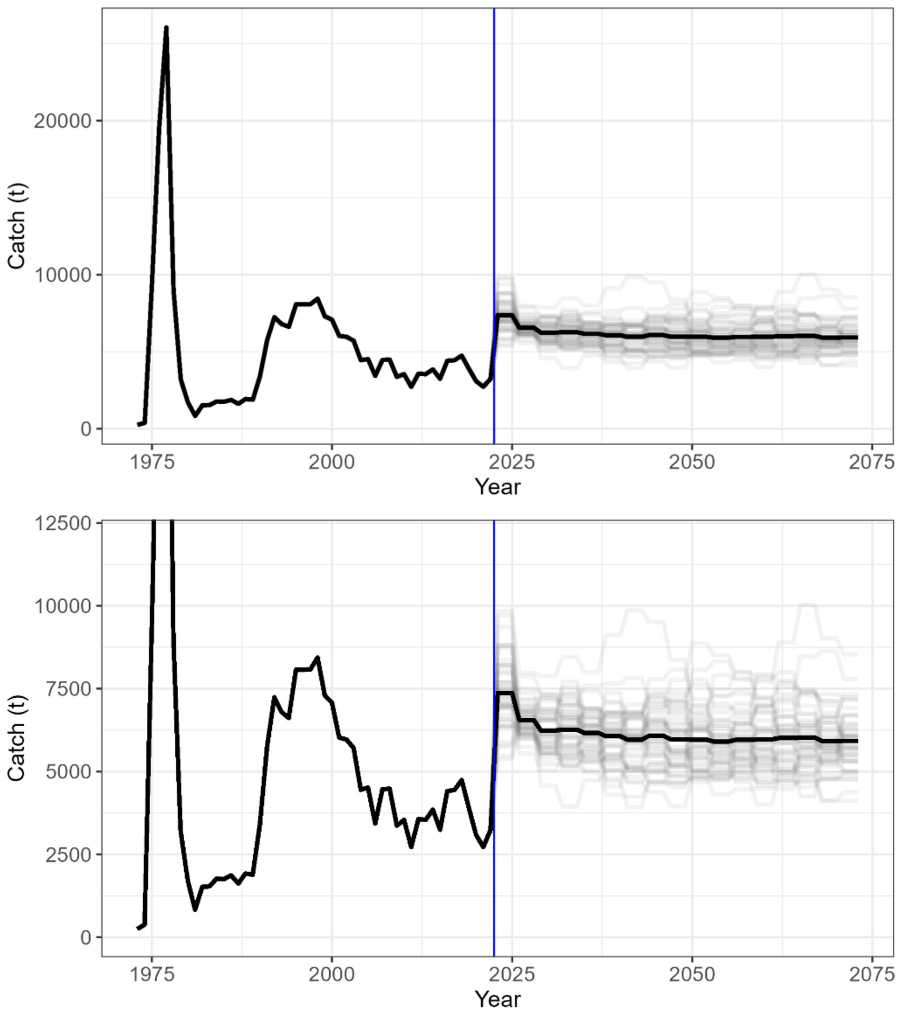

Figure B.3: LIN 3&4 base simulation catch for the MSE simulation with average future YCS, a top inflection point of (1 – M) × 40% *B_0* and no TAC constraint. Each grey line represents one of the simulations, and the black line is the median of all simulations. The vertical blue line represents the start of the projections. For ease of interpretation, the y axis was cropped, leaving out the 19 536 t catch in 1976 and 26 049 t catch in 1977.

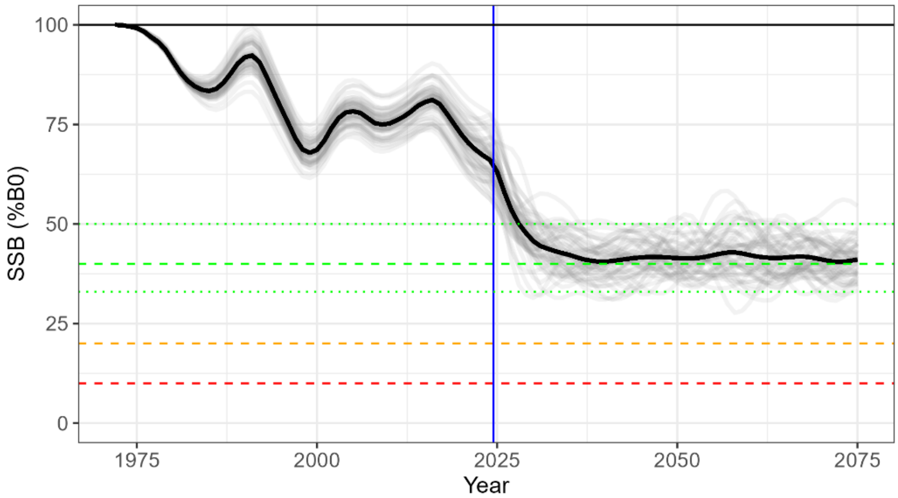

Figure B.4: LIN 5&6 and LIN 6B base simulation projected stock spawning stock biomass (*SSB*) as a proportion of initial spawning stock biomass (B_0) for the MSE simulation with average future YCS, a top inflection point of (1 – M) × 40% B_0 and no TAC constraint. Each grey line represents one of the simulations, and the black line is the median of all simulations. The thick green horizontal line represents B_{target} = 40% B_0, the dashed thin green horizontal lines the 33–50% B_0 range, the orange line the soft limit of 20% B_0 and the red line the hard limit of 10% B_0. The vertical blue line represents the start of the projections.

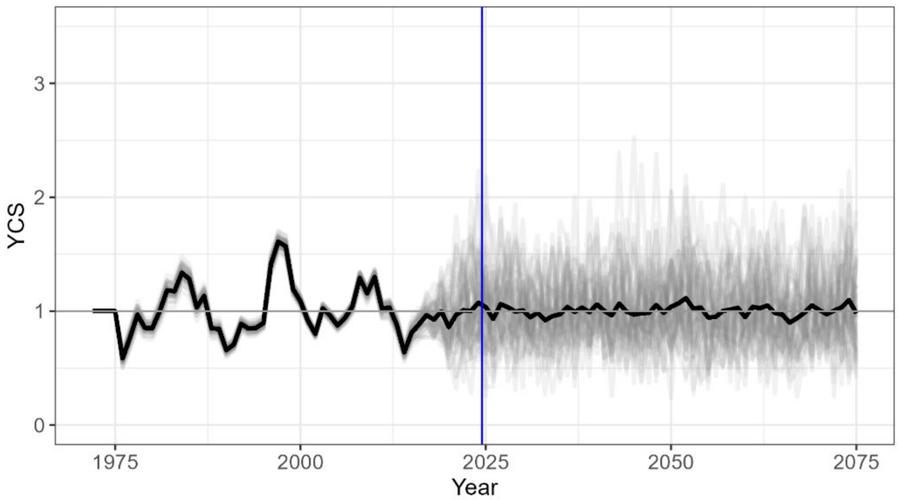

Figure B.5: LIN 5&6 and LIN 6B base simulation resampled YCS for the MSE simulation with average future YCS, a top inflection point of (1 – M) × 40% B_0 and no TAC constraint. Each grey line represents one of the simulations, and the black line is the median of all simulations. The vertical blue line represents the start of the projections.

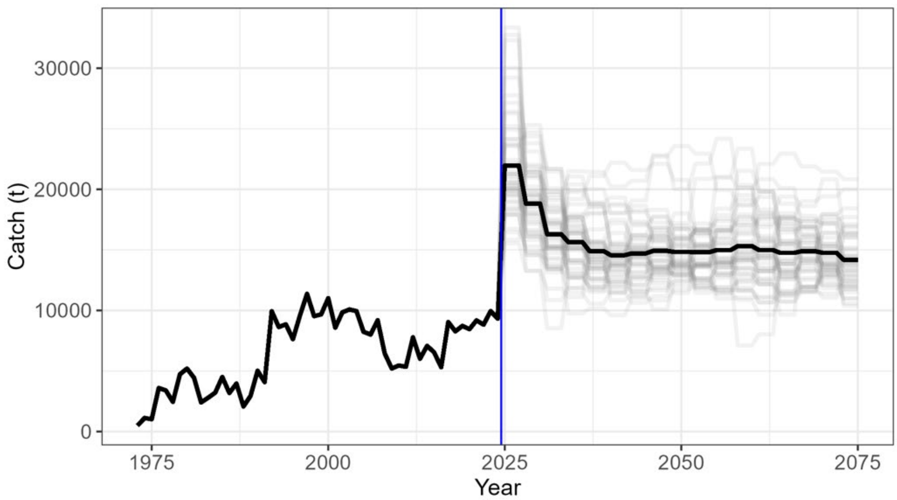

Figure B.6: LIN 5&6 and LIN 6B base simulation catch for the MSE simulation with average future YCS, a top inflection point of (1 – M) × 40% B_0 and no TAC constraint. Each grey line represents one of the simulations, and the black line is the median of all simulations. The vertical blue line represents the start of the projections.

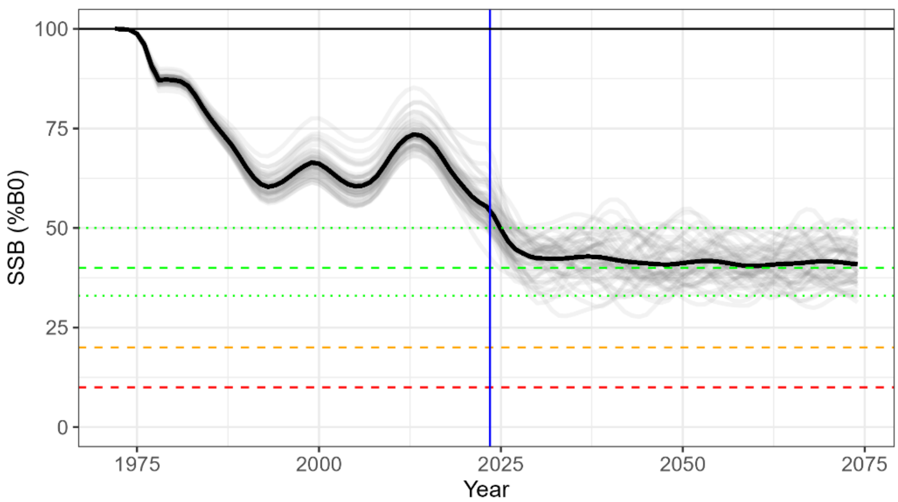

Figure B.7: LIN 7WC base simulation projected stock spawning stock biomass (*SSB*) as a proportion of initial spawning stock biomass (B_0) for the MSE simulation with average future YCS, a top inflection point of (1 – M) × 40% B_0 and no TAC constraint. Each grey line represents one of the simulations, and the black line is the median of all simulations. The thick green horizontal line represents B_{target} = 40% B_0, the dashed thin green horizontal lines the 33–50% B_0 range, the orange line the soft limit of 20% B_0 and the red line the hard limit of 10% B_0. The vertical blue line represents the start of the projections.

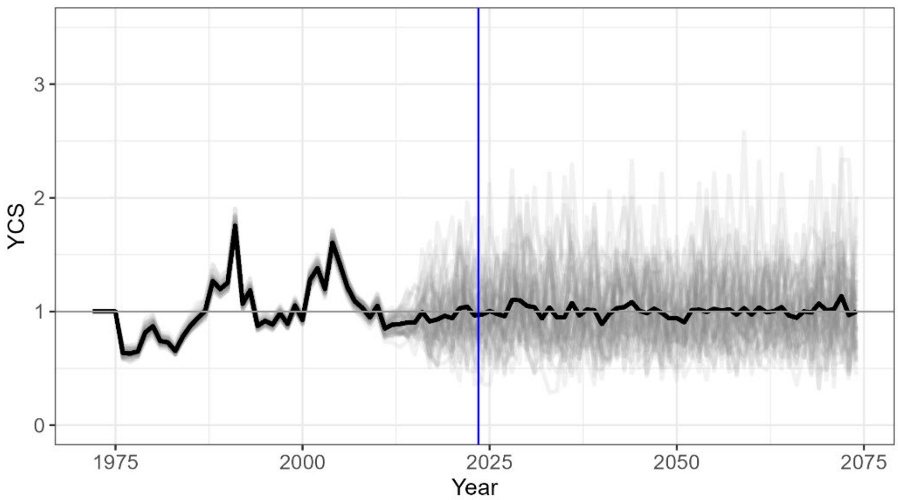

Figure B.8: LIN 7WC base simulation resampled YCS for the MSE simulation with average future YCS, a top inflection point of (1 – M) × 40% B_0 and no TAC constraint. Each grey line represents one of the simulations, and the black line is the median of all simulations. The vertical blue line represents the start of the projections.

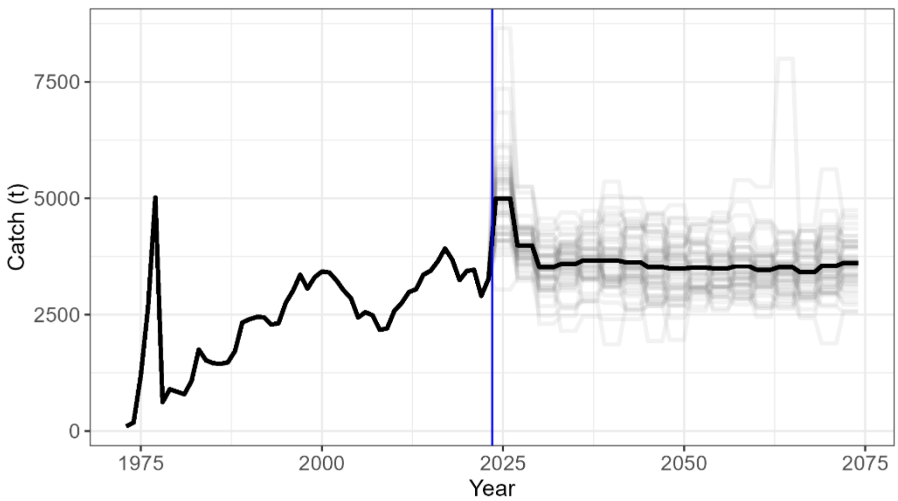

Figure B.9: LIN 7WC base simulation catch for the MSE simulation with average future YCS, a top inflection point of (1 – M) × 40% B_0 and no TAC constraint. Each grey line represents one of the simulations, and the black line is the median of all simulations. The vertical blue line represents the start of the projections.