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The 2023 Management Strategy Evaluation for hoki (*Macruronus novaezelandiae*)

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EXECUTIVE SUMMARY

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The stock assessment of hoki (*Macruronus novaezelandiae*) is primarily conducted assuming two stock units: eastern and western. The recent (2022) stock assessment estimated a higher stock biomass (51–55% B_0) for the eastern stock compared with the western stock (28–31% B_0). Hoki are relatively short-lived and recruitment is variable between years. Consequently, estimates of current and projected (5 year) stock biomass are imprecise due to the uncertainty in recent and future recruitments, especially for the western stock unit.

Management Strategy Evaluation (MSE) provides a framework for determining an appropriate management regime for hoki, accounting for the uncertainty in recent recruitments and delay in management response (assessment and TACC setting). The MSE approach simulated the dynamics of the hoki stocks and associated fisheries under different catch scenarios specified by candidate Harvest Control Rules (HCRs). The performance of the individual HCRs was evaluated based on a set of performance indicators incorporating sustainability and utilisation criteria.

The hoki MSE was conducted based on the recent (2022) stock assessment model. The MSE evaluated a set of HCRs that defined a target biomass range and corresponding base levels of catch associated for each main fishery area: Chatham Rise, Cook Strait, and west coast South Island (WCSI) and Sub-Antarctic combined. The HCRs set the catches at that base level when the respective stock (eastern or western) was assessed to be within a specified target biomass range. Annual catches were decreased when the stock was below the lower range of the target biomass or increased when the stock was above the upper range of the target biomass. The evaluation assumed future recruitments for the eastern and western stocks at levels comparable with the last 20 years in the stock assessment model (2001–2020). For the western stock, the recent level of recruitment is below (78%) the long-term average level of recruitment.

The study reaffirmed the status quo target biomass range (35–50% SB_0), maintaining the stock well above the sustainability threshold (of 20% B_0) and maintained the eastern and western stocks at levels for the economic operation of the main commercial fisheries.

The base levels of catch evaluated for the final set of HCRs yielded average total annual catches of about 112–118 thousand tonnes (kt), approximately partitioned 47 kt Chatham Rise, 40–46 kt WCSI, 10 kt Sub-Antarctic, and 15 kt Cook Strait. However, there is considerable variability in annual catches between years, primarily in response to variability in annual recruitments. The study highlighted the need to make frequent changes to fishery catch allocations to maintain the stock within the target biomass range and avoid large changes in stock biomass. HCRs that yielded lower levels of total catch (approximately 100 kt) resulted in higher overall biomass levels and less frequent large changes in annual catches.

The robustness of the MSE results, including the selection of specific HCRs, is dependent on the fundamental stock structure assumptions of the assessment model, particularly the assumption of separate eastern and western stocks with a common nursery ground on the Chatham Rise (natal fidelity). Alternative stock assumptions may influence the potential yields from key fisheries, in particular the relative impact of the Chatham Rise catches on the magnitude of recruitment to the western fisheries.

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The 2023 Plenary did not adopt a specific HCR for the management of the hoki fishery. Instead, the results of the MSE were considered useful to inform managers regarding the likely level of yields available from the hoki fishery and the scale of management responses required to maintain the stock at the optimal target biomass levels. The adoption of a specific HCR would require wider consultation to fully evaluate the relative trade-offs between stock outcomes (informed by key performance indicators). Implementation of a specific HCRs would also require the specification of a set of break out rules for managing the stock beyond the scope of the current operating model, for example, in response to a sustained period of low recruitment.

1. INTRODUCTION

The stock assessment of hoki (*Macruronus novaezelandiae*) is primarily conducted assuming two stock units: eastern and western (Fisheries New Zealand 2022). The recent (2022) stock assessment estimated a higher stock biomass (51–55% B_0) for the eastern stock compared with the western stock (28–31% B_0) (McGregor et al. 2023). Hoki are relatively short-lived and recruitment is variable between years. Consequently, estimates of current and projected (5 year) stock biomass are imprecise due to the uncertainty in recent and future recruitments, especially for the western stock unit.

Recent hoki stock assessments have used the target biomass range of 35% B_0 to 50% B_0 as a proxy for the likely range of credible B_{MSY} estimates (Fisheries New Zealand 2022). The target range was informed by previous simulation analyses (Langley 2009a, 2012) that minimised the probability of the hoki stocks declining below a sustainability threshold of 20% B_0 as specified by the Harvest Strategy Standard (Ministry of Fisheries 2008). Those two previous analyses indicated that the hoki stocks could sustain average annual total catches of about 130 000 t (based on "recent" levels of recruitment). An earlier study had indicated higher potential yields of about 150 000 t based on long-term average levels of recruitment (Langley 2009b). In the interim, there have been considerable changes to the hoki stock assessment and recent estimates of yields are substantially lower than previous estimates, largely due to persistent lower levels of recruitment to the western stock.

Management Strategy Evaluation (MSE) provides a framework for determining an appropriate management regime for hoki, accounting for the uncertainty in recent recruitments and delay in management response (assessment and Total Allowable Commercial Catch setting) (Punt et al. 2016). The MSE approach simulates the dynamics of the hoki stocks and associated fisheries under different catch scenarios specified by candidate Harvest Control Rules (HCRs). The performance of the individual HCRs is evaluated based on a set of performance indicators incorporating sustainability and utilisation criteria.

This study re-evaluates the target biomass levels for hoki and provides indications of the corresponding levels of yield, via specific HCRs, for the hoki fishery based on recent stock dynamics. The project was funded by HOK 1 quota owners via the Deepwater Council of Seafood New Zealand.

2. METHODOLOGY

The MSE was based on the recent (2022) hoki stock assessment (McGregor et al. 2023). The main assessment models assumed two stock units (eastern and western) with a shared nursery ground on the Chatham Rise and spatially separate adult stocks. The western stock migrates from the Chatham Rise to reside on the western home grounds (Sub-Antarctic) and spawns off the west coast of the South Island (WCSI). The eastern stock remains resident on the Chatham Rise and migrates to spawn in Cook Strait.

The MSE operating model was implemented in *R* statistical programming software (R Core Team 2020), replicating the configuration of the main assessment model (model 2022A) (Fisheries New Zealand 2022, McGregor et al. 2023). The model was initialised in 1972 and terminated in 2022 (2021/22 fishing year). The model structure included 11 fisheries defined by area and season with separate selectivity functions estimated for each fishery. Age-specific migration ogives were estimated for the emigration of western fish from the Chatham Rise to the Sub-Antarctic home ground. All mature fish were assumed to migrate to the respective eastern and western spawning grounds (Cook Strait and WCSI, respectively).

Recruitment for each stock was modelled as a Beverton-Holt stock-recruitment relationship with an assumed value of steepness of 0.75. Annual recruitment deviates were estimated for the eastern and western stocks for 1975 to 2020. For each stock, the overall average level of recruitment (R_0) was used to determine the initial, equilibrium spawning biomass (B_0). Natural mortality (M) by sex was assumed to be constant over time, and the same for each stock, with female M = 0.25 y^{-1} and male M = 0.30 y^{-1} (model 2022A).

The first phase of the operating model utilised the estimated model parameters from the assessment model and fishery catches to determine the population age structure (numbers at age) of the eastern and western stocks in the terminal year of the model (2022). The second phase of the operating model projected the population age structures for a 100 year evaluation period (evaluation phase).

The biomass trajectories for the eastern and western stocks from the operating model closely approximated results from the 2022A stock assessment model (Figure 1). There was a minor divergence in the biomass trajectory for the eastern stock from about 2000 onwards. A thorough examination of the parameterisation of the operating model was unable to resolve this difference. However, the difference is considered to be minor and unlikely to appreciably influence the results of the evaluation phase of the MSE.

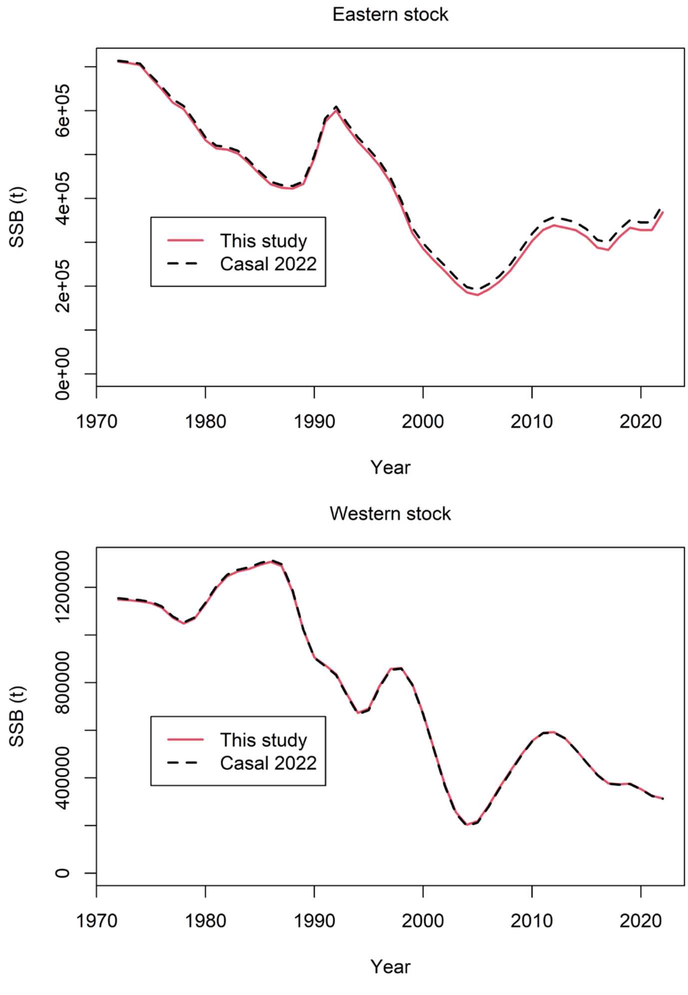

Figure 1: A comparison between the biomass trajectories for the eastern (top panel) and western (bottom panel) hoki stocks from the CASAL 2022 stock assessment model (2022A MPD, McGregor et al. 2023) (dashed black line) and the MSE operating model (this study) (red line).

Recruitment for the 100 year evaluation period was resampled from the recruitment deviates from the last 20 years of the stock assessment model (2001–2020). This period included below average (78%) recruitment deviates for the western stock. Annual recruitments were resampled as pairs of eastern and western recruitment deviates to maintain the correlation between the estimates of recruitment from the two stocks (corr. coef. 0.6). There was no indication of persistent autocorrelation between annual recruitment estimates during the last 20 years (western h=0.3, eastern h=-0.3). Nonetheless, the random generation of sets of recruitment deviates included successive years of low and high recruitments; for example, 42% of the sets of western recruitment deviates included periods of at least 4 years of consecutively low recruitment (deviates less than 0.5).

The annual hoki stock assessment process is computationally intensive, integrating multiple fishery age composition and survey data sets. It was not considered practical to simulate the data generation and annual assessment process within the projection period of the operating model. Instead, a simpler approach was applied to determine annual estimates of stock status, whereby, the observed stock status (eastern or western), expressed relative to B_0 (B_{year}/B_0), was sampled from the "true" stock status with an assumed level of sampling error. For both stocks, the sampling error was normally distributed with a CV of 20%. This was based on the level of uncertainty associated with estimates of current stock status from the 2022 stock assessment (approximate CV of 15%).

During the evaluation period, the annual fishery catches were set based on the specific candidate HCRs. The HCRs are based on the annual estimates of stock status (B_{year}/B_0). To reflect the current management process, the assessment occurs in the year following the estimate of stock status (*year* + 1) and changes in catch are implemented in the subsequent year (*year* + 2); i.e., a two year delay in the management response.

For each candidate HCR, a set of 100 simulations was conducted based on a random set of the Markov chain Monte Carlo samples from the 2022A stock assessment model and an equivalent set of sampled recruitment deviates to determine annual eastern and western recruitments for the evaluation (projection) period.

The range of HCRs was configured with base levels of catch associated with each main fishery area: Chatham Rise, Cook Strait, and WCSI and Sub-Antarctic combined (Figure 2 and Table 1). The HCRs set the catches at that base level while the respective stock (eastern or western) was assessed to be within a specified target biomass range. During the simulation period, annual catches were decreased when the stock was below the lower range of the target biomass or increased when the stock was above the upper range of the target biomass (Figure 2).

The Chatham Rise fishery is assumed to catch both eastern (juvenile and adult) and western (juvenile) hoki. This component of the HCR was informed by the stock status of both the eastern and western stock status with a variable relative weighting. Most HCR scenarios assigned 70% of the Chatham Rise catch based on the eastern stock status and the remaining 30% of the catch based on the western stock status (proportion eastern stock *PropE* = 0.7) (Figure 2). This was based on the derived quantities of the 2022 stock assessment that estimated that western hoki accounted for approximately 30% of the catch of immature hoki from the Chatham Rise fishery (but only 13% of the total catch). Additional HCR scenarios based the Chatham Rise catch entirely on the stock status of the eastern stock (*PropE* = 1.0).

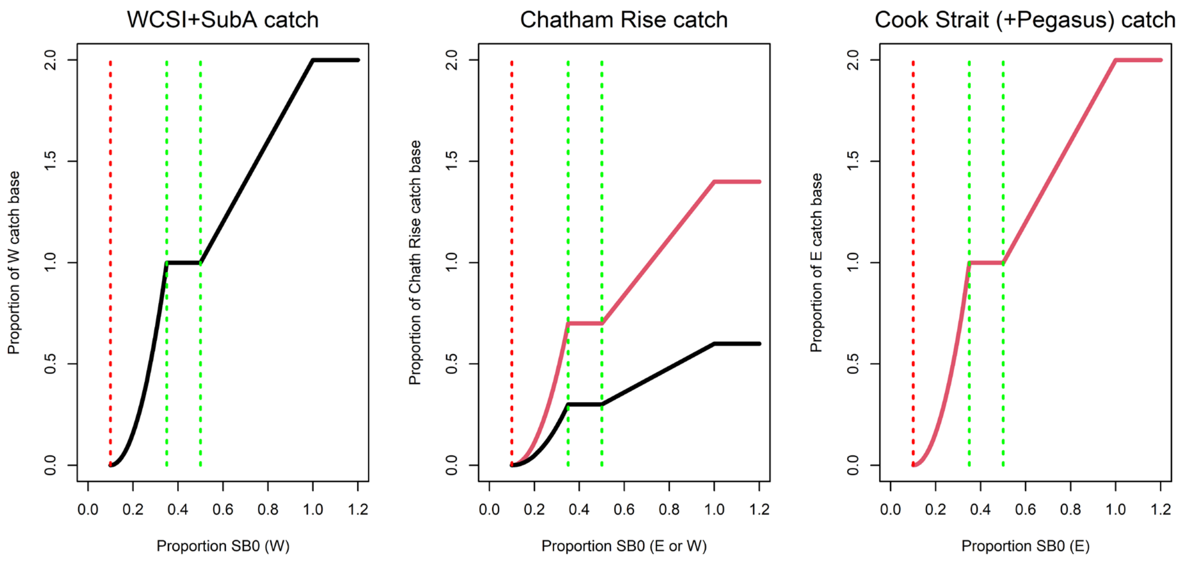

Figure 2: Generic structure of the candidate Harvest Control Rules. The red and black lines are associated with the status of the eastern and western stocks, respectively. The example apportions 70% of the Chatham Rise catch based on the eastern stock status and 30% based on the western stock status (*PropE* 0.7). The red dashed vertical line represents the hard limit (10% B_0) and the green dashed vertical lines represent the lower and upper limits of the target biomass level (in this case 35% and 50%, respectively).

The HCR scenarios investigated a range of base levels of catch for the Chatham Rise fishery (30 thousand tonnes (kt), 40 kt, 50 kt, and 60 kt) and combined WCSI and Sub-Antarctic catch (40 kt, 50 kt, and 60 kt), while maintaining a single base catch of 15 kt for the Cook Strait spawning fishery (including the catch from the spawning fisheries off the east coast of the South Island) (Table 1). The base level of Cook Strait catch corresponded to recent annual catches from the fishery. The overall magnitude of the catch from the fishery is currently limited by operational constraints relating to vessel size and onshore processing capacity.

Table 1: Base levels of catch in the final set of candidate HCRs (*PropE* = 0.7).

HCR	HCR component		
	WCSI+SubA	Chatham Rise	Cook Strait
38	50 000 t	50 000 t	15 000 t
39	50 000 t	40 000 t	15 000 t
40	50 000 t	60 000 t	15 000 t
41	50 000 t	30 000 t	15 000 t
42	40 000 t	50 000 t	15 000 t
43	40 000 t	40 000 t	15 000 t
44	40 000 t	60 000 t	15 000 t
45	40 000 t	30 000 t	15 000 t
46	60 000 t	50 000 t	15 000 t
47	60 000 t	40 000 t	15 000 t
48	60 000 t	60 000 t	15 000 t
49	60 000 t	30 000 t	15 000 t

In each of the three areas, the annual catches derived from the individual HCRs were distributed amongst the constituent fisheries in proportion to the catch distribution from the terminal year (2022) of the stock assessment (McGregor et al. 2023) (Table 2).

Table 2: Proportional catch distribution of HCR specified catches amongst constituent fisheries (equivalent to 2022 assessment model catch distributions).

Model fishery	HCR component		
	WCSI+SubA	Chatham Rise	Cook Strait
fishery_CR_deep		0.865	
fishery_CR_shallow		0.135	
fishery_CS_spwn			1.000
fishery_PUY_spwn	0.005		
fishery_SA_auck	0.073		
fishery_SA_snares	0.079		
fishery_SA_suba	0.028		
fishery_WC_inside	0.244		
fishery_WC_north	0.311		
fishery_WC_south	0.260		

To maintain stability in the level of annual catches from the fishery, additional constraints were applied to the magnitude of the change in annual catches. Changes in the annual catches were limited to ±10% when biomass was above the target range and ±20% below the target range. Further, increases in catch levels were not applied if the most recent recruitment was well below average (rec. dev. less than 0.75). Catches reverted to the base level when the specific stock was assessed to be within the target biomass range.

The individual HCRs were evaluated based on a range of performance indicators. The performance indicators included a number of criteria relating to minimum levels of spawning biomass required to maintain the productivity of the stock, essentially ensuring the eastern and western stocks are maintained above 20% of the virgin biomass level (B_0) (specified by the Fisheries New Zealand Harvest Strategy Standard) and reasonable rates of rebuild to the target biomass level. The other set of performance indicators related to the utilisation of the stock and the trade-offs between the overall magnitude of hoki catch and the maintenance of economic catch rates (CPUE), fish size, and stability in annual catches (Table 3). Discussions with HOK 1 quota owners indicated that the Chatham Rise hoki fishery had performed at an appropriate level over the previous decade (2010–2020), while the WCSI fishery performed well during 2012–2016. These respective periods corresponded to spawning biomass levels of 45–50% B_0 for both the eastern and western stocks. This level of biomass was used to inform stock-specific target biomass levels for both stocks, reaffirming the appropriateness of the status quo target biomass range of 35%–50% B_0.

The results of the simulations (100 simulations, 100 years) were summarised for each candidate HCR to derive summary metrics for each performance indicator for the eastern and western stocks (Table 3). The HCRs were assessed based on selection criteria for a key set of performance indicators (Table 4).

Table 3: Performance indicators for evaluating HCRs for each stock (eastern and western) and the main fisheries.

Code	Performance indicator
P1	Median biomass relative to B_0.
P2	Proportion of years below hard limit (10% B_0).
P3	Proportion of years below soft limit (20% B_0).
P4	Proportion of years below 25% B_0.
P5	Proportion of years below 30% B_0.
P6	Proportion of years below lower bound of target biomass.
P7	Proportion of years above upper bound of target biomass.
P8	Proportion of years above 50% B_0.
P9	Number of periods below lower bound of target biomass (average of simulations).
P10	Average duration (years) of periods below lower bound of target biomass.
P11	Maximum number of years to rebuild to lower bound of target biomass (average of simulations).
C1	Average annual catch (1000s t) Chatham Rise.
C2	Average annual catch (1000s t) Cook Strait.
C3	Average annual catch (1000s t) Sub-Antarctic.
C4	Average annual catch (1000s t) west coast South Island.
C5	Average total annual catch (1000s t).
C6	Standard deviation of annual catches (1000s t) Chatham Rise.
C7	Standard deviation of annual catches (1000s t) Cook Strait.
C8	Standard deviation of annual catches (1000s t) Sub-Antarctic.
C9	Standard deviation of annual catches (1000s t) west coast South Island.
C10	Standard deviation of total annual catch (1000s t).
C11	Proportion of years with change in annual catch of WCSI+Sub-Ant greater than 5000 t.
C12	Proportion of years with change in annual catch of Chatham Rise greater than 5000 t.
W1	Average weight (kg) of individual hoki in Chatham Rise catch.
W2	Average weight (kg) of individual hoki in Cook Strait catch.
W3	Average weight (kg) of individual hoki in Sub-Antarctic catch.
W4	Average weight (kg) of individual hoki in west coast South Island catch.
VB1	Average Chatham Rise vulnerable biomass relative to 2022.
VB2	Average west coast South Island (North) vulnerable biomass relative to 2022.

Table 4: Selection criteria for the key performance indicators.

Code	Performance indicator	Selection criteria
P2	Proportion of years below hard limit (10% B_0).	<0.01
P3	Proportion of years below soft limit (20% B_0).	<0.05
P5	Proportion of years below 30% B_0.	<0.10
P6	Proportion of years below lower bound of target biomass.	<0.25
P8	Proportion of years above 50% B_0.	<0.50
P10	Average duration (years) of periods below lower bound of target biomass.	< 5
P11	Maximum number of years to rebuild to lower bound of target biomass (average of simulations).	< 10

3. RESULTS

The initial phase of the MSE evaluated different levels of lower and upper target biomass levels (the status quo 35–50% B_0, 35–45%, 30–50%, and 30–40%) and different levels of base fishery catches. These scenarios indicated that a lower target biomass of either 30% or 35% B_0 was appropriate to minimise the likelihood of the stock declining below 20% B_0. However, the lower target value (30%) increased the likelihood that the stocks were 25–30% B_0 (i.e., well below the level of biomass to support the higher level of CPUE at 45–50% B_0) but did not appreciably increase the total overall catch. A lower bound of 35% also ensured the stocks were maintained above the deterministic B_{MSY}

level (approx. 27% B_0, Fisheries New Zealand 2018). The wider target range of 35–50% B_0 reduced the frequency of changes in annual catches as there were fewer years when the stocks were either above or below the target range (compared with the narrower target ranges of 35–45% and 30–40%). Thus, the status quo target biomass range (35–50% SB_0) was retained for the final set of HCRs.

The final set of 12 HCRs evaluated alternative combinations of base levels of catch (Table 1). Of those scenarios, only HCR #38 met all the selection criteria associated with the key performance indicators related to sustainability of the eastern and western stocks (Table 5 and Table 6) and maintaining the two stocks at levels commensurate with the desired level of fleet CPUE in the key fisheries (biomass levels 45–50% B_0) (Figure 3). The HCR had associated base levels of catch of 50 kt for the Chatham Rise and 50 kt for the combined WCSI and Sub-Antarctic fisheries.

HCRs (#46–49) with a higher base catch (60 kt) for the WCSI and Sub-Antarctic fisheries had a longer period (greater than or equal to 5 years, P10) for the western stock to rebuild to the target biomass level biomass (above 35% B_0) (Table 6).

HCRs (#42–45) with a lower base catch (40 kt) for the WCSI and Sub-Antarctic fisheries resulted in a higher overall level of western biomass (above 50% B_0 P8) and, correspondingly, achieved an overall lower level of total average catch (Table 7).

HCRs (#40, #44, #48) with a higher base catch (60 kt) for the Chatham Rise fishery had a lower (~ 0.43 B_0) biomass for the eastern stock with a higher probability of being below 30% B_0 (P5) and 35% B_0 (P6) and a longer rebuild period (P10) (Table 5).

Conversely, the HCRs with a lower Chatham Rise base catch of 30 kt (HCRs #41, #45, #49) or 40 kt (HCRs #39, #43, #47) resulted in a higher overall stock size (exceeding 50% B_0 P8) (Table 5) and lower levels of total average catch (Table 7).

There were no appreciable differences in the average weight of individual hoki in the fishery specific catches expected from the range of candidate HCRs (Table 8). However, there were appreciable differences between the levels of fishery specific vulnerable biomass; all HCRs resulted in an appreciable increase in the WCSI North fishery vulnerable biomass relative to the 2022 level reflecting an initial rebuild of the western stock (Figure 3 and Table 8). The Chatham Rise vulnerable biomass remained at about the 2022 level or increased slightly, depending on the base level of Chatham Rise catch (Table 8).

Overall, the average total annual yields between the individual HCRs are similar, typically about 105–115 kt per annum (Table 7), reflecting the relatively limited range of overall average biomass levels (approximately 45–55% B_0 for both eastern and western) (Table 5 and Table 6). For example, comparing HCR #38 with the scenario with a higher base catch of 60 kt (HCR #46) for combined WCSI and Sub-Antarctic fisheries resulted in a reduction of western biomass from 49% to 46% B_0 (Figure 3) with an increase in average yield of 6 kt, primarily from the WCSI fishery (Table 7). There was a small increase in the probability of the western stock declining below the lower bound of the target biomass level (P6) and a small increase in the rebuild period (P10) (Table 6). The preference for the HCR #38 was based on the subjective criteria used to define the length of the rebuild period.

For two scenarios (#38 and #46), the HCRs were rerun with the Chatham Rise catch defined based on the eastern stock status only (i.e., *PropE* = 1.0). There were no appreciable differences in the results compared with the *PropE* = 0.7 scenarios (Table 5 and Table 6). This is due to the western stock status being at or above the target biomass level for a high proportion of the years in the evaluation period and not influencing (reducing) the level of catch assigned to the Chatham Rise fishery.

Table 5: Performance indicators for the eastern stock biomass based metrics. Performance indicators that do not meet the specific criteria are italicised. The * denote additional HCR scenarios with the *PropE* variable set to 1.0 (rather than 0.7).

HCR	Performance indicator										
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
38	0.480	0.000	0.006	0.022	0.065	0.147	0.428	0.428	3.0	4.1	6.8
39	0.533	0.000	0.003	0.011	0.032	0.081	0.588	*0.588*	1.8	3.0	4.6
40	0.434	0.000	0.013	0.048	*0.129*	*0.251*	0.291	0.291	4.5	*5.3*	9.9
41	0.592	0.000	0.001	0.005	0.015	0.036	0.743	*0.743*	0.9	1.8	2.4
42	0.475	0.000	0.006	0.024	0.075	0.165	0.415	0.415	3.2	4.4	7.5
43	0.528	0.000	0.002	0.010	0.032	0.082	0.575	*0.575*	1.9	2.9	4.5
44	0.426	0.000	0.012	0.051	*0.134*	*0.270*	0.273	0.273	4.8	*5.6*	10.1
45	0.587	0.000	0.001	0.005	0.016	0.040	0.735	*0.735*	1.0	2.2	2.8
46	0.486	0.001	0.005	0.019	0.061	0.141	0.442	0.442	3.0	4.0	6.4
47	0.537	0.000	0.002	0.010	0.031	0.076	0.600	*0.600*	1.7	3.0	4.5
48	0.440	0.000	0.011	0.043	*0.115*	0.237	0.304	0.304	4.5	*5.0*	9.1
49	0.593	0.000	0.001	0.004	0.014	0.035	0.749	*0.749*	0.9	1.9	2.4
38*	0.473	0.000	0.006	0.025	0.068	0.157	0.405	0.405	3.3	4.5	7.3
46*	0.471	0.000	0.005	0.025	0.075	0.168	0.397	0.397	3.4	4.5	7.4

Table 6: Performance indicators for the western stock biomass based metrics. Performance indicators that do not meet the specific criteria are italicised. The * denote additional HCR scenarios with the *PropE* variable set to 1.0 (rather than 0.7).

HCR	Performance indicator										
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
38	0.493	0.006	0.012	0.023	0.057	0.120	0.457	0.457	2.3	4.6	6.8
39	0.506	0.006	0.012	0.022	0.054	0.110	0.499	0.499	2.2	4.3	6.5
40	0.483	0.006	0.011	0.023	0.059	0.133	0.424	0.424	2.5	4.6	7.1
41	0.514	0.007	0.012	0.021	0.049	0.100	0.537	*0.537*	1.9	4.4	6.1
42	0.536	0.006	0.011	0.020	0.041	0.082	0.599	*0.599*	1.7	4.0	5.3
43	0.547	0.005	0.010	0.017	0.037	0.076	0.638	*0.638*	1.5	4.1	4.9
44	0.525	0.007	0.013	0.021	0.043	0.088	0.571	*0.571*	1.8	4.1	5.7
45	0.558	0.006	0.011	0.019	0.036	0.071	0.665	*0.665*	1.5	3.8	4.9
46	0.455	0.004	0.011	0.030	0.080	0.180	0.331	0.331	3.2	*5.1*	8.6
47	0.464	0.005	0.012	0.028	0.075	0.164	0.359	0.359	3.0	*5.0*	7.9
48	0.445	0.005	0.014	0.032	0.090	0.200	0.295	0.295	3.4	*5.6*	9.2
49	0.475	0.006	0.013	0.027	0.070	0.150	0.397	0.397	2.7	*5.0*	7.9
38*	0.492	0.004	0.010	0.022	0.056	0.121	0.458	0.458	2.3	4.5	6.4
46*	0.451	0.006	0.013	0.032	0.087	0.187	0.314	0.314	3.1	*5.4*	8.7

Table 7: Performance indicators for the average catches (C1-5) and standard deviation of catches (C6-12) from the main hoki fisheries. The * denote additional HCR scenarios with the *PropE* variable set to 1.0 (rather than 0.7).

HCR	Performance indicator											
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
38	**47.7**	**14.8**	**9.2**	**40.3**	**111.9**	**9.8**	**2.9**	**1.8**	**7.7**	**18.9**	**0.400**	**0.397**
39	40.7	15.8	9.2	40.4	106.1	7.8	2.9	1.8	7.7	17.1	0.403	0.237
40	53.4	13.8	9.1	39.8	116.1	12.4	3.1	1.7	7.6	21.0	0.400	0.522
41	32.8	16.9	9.3	41.0	100.0	6.2	3.1	1.8	7.8	15.7	0.407	0.102
42	48.5	14.7	7.7	34.0	104.9	10.0	2.9	1.4	6.2	17.6	0.208	0.423
43	41.5	15.7	7.8	34.3	99.3	8.0	2.9	1.4	6.3	15.9	0.212	0.243
44	54.2	13.7	7.6	33.4	109.0	12.6	3.1	1.4	6.2	19.9	0.208	0.539
45	33.4	16.8	7.9	34.7	92.7	6.3	3.1	1.5	6.5	14.8	0.213	0.108
46	46.8	14.8	10.5	46.0	118.1	9.7	2.9	2.2	9.7	20.9	0.438	0.377
47	40.1	15.9	10.6	46.4	113.0	7.8	2.9	2.2	9.6	19.1	0.447	0.227
48	52.6	14.0	10.3	45.3	122.2	11.9	3.0	2.2	9.6	22.8	0.444	0.510
49	32.3	17.0	10.6	46.6	106.4	6.3	3.1	2.2	9.5	17.6	0.445	0.100
38*	48.4	14.6	9.1	40.2	112.4	9.8	2.9	1.7	7.7	18.2	0.396	0.354
46*	48.5	14.6	10.4	45.8	119.3	9.6	2.9	2.2	9.6	19.7	0.450	0.355

Table 8: Performance indicators for the average fish weights (W1-4) and vulnerable biomass (VB1-2) of the main hoki fisheries. The * denote additional HCR scenarios with the *PropE* variable set to 1.0 (rather than 0.7).

HCR	Performance indicator					
	W1	W2	W3	W4	VB1	VB2
38	0.95	1.17	1.48	1.55	1.08	1.93
39	0.97	1.20	1.49	1.56	1.17	1.99
40	0.89	1.13	1.45	1.55	1.01	1.89
41	0.99	1.24	1.49	1.56	1.27	2.04
42	0.94	1.16	1.52	1.59	1.08	2.20
43	0.97	1.20	1.53	1.60	1.17	2.24
44	0.92	1.13	1.52	1.59	1.00	2.15
45	0.99	1.23	1.53	1.60	1.26	2.31
46	0.95	1.17	1.45	1.52	1.09	1.69
47	0.92	1.20	1.46	1.52	1.17	1.79
48	0.93	1.14	1.45	1.51	1.02	1.68
49	0.99	1.24	1.46	1.53	1.25	1.83
38*	0.94	1.16	1.47	1.59	1.08	1.95
46*	0.94	1.16	1.44	1.51	1.08	1.68

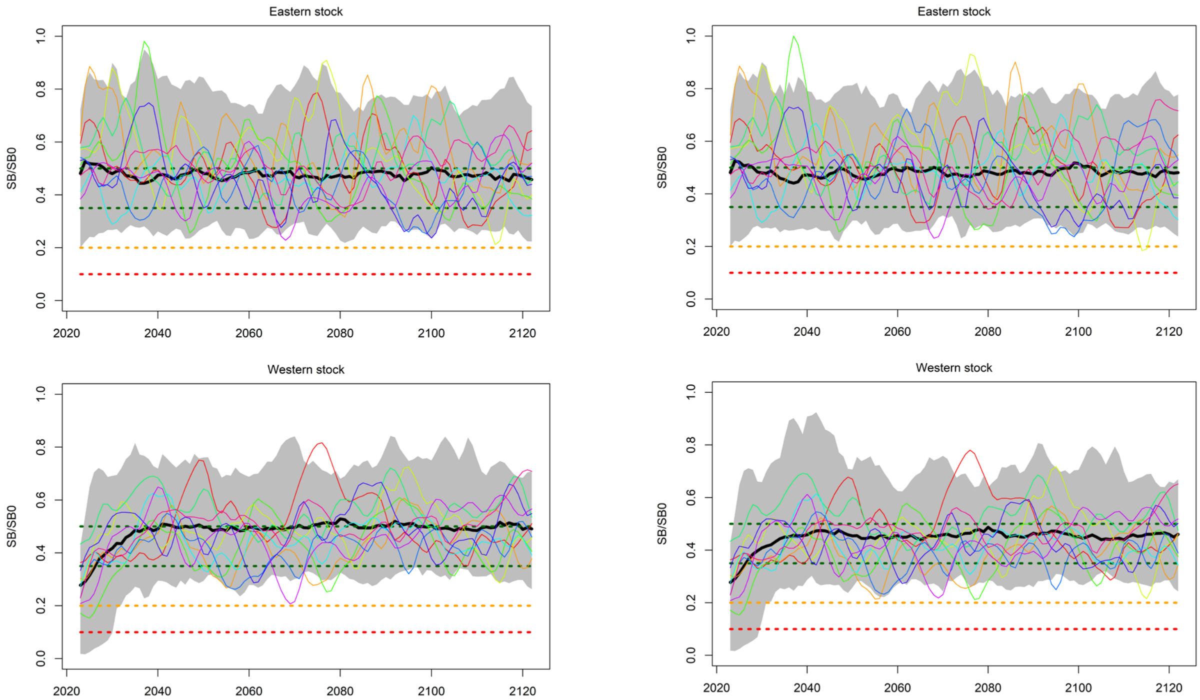

Figure 3: Simulated trends in eastern and western stock biomass (relative to B_0) projected for 100 years under HCRs #38 (left panels) and #46 (right panels). The black line represents the average annual biomass and the grey area represents the 95% interval. The green lines represent the target biomass range (35–50%) and the orange and red lines represent the soft (20%) and hard (10%) limits, respectively. The coloured lines represent a subset of 10 individual simulations (from the 100 simulations).

For each simulation, annual catches by fishery area vary considerably during the evaluation period (Figure 4 and Table 7). The lowest base levels of catch for the WCSI and Sub-Antarctic (HCRs #42–45) and Chatham Rise (HCRs #41, #45, #59) resulted in fewer substantial changes (greater than 5 kt increase or decrease) in annual catches (P11 and P12, respectively) (Table 7).

HCR #38 achieved an average annual total catch of 112 kt. There were substantial changes (greater than 5 kt increase or decrease) in the WCSI catch in 40% of years with annual WCSI catches generally ranging from 30 to 48 kt. Chatham Rise catches fluctuated between 36 and 58 kt with appreciable changes in the Chatham Rise catch in 40% of the years (Figure 4 and Figure 5).

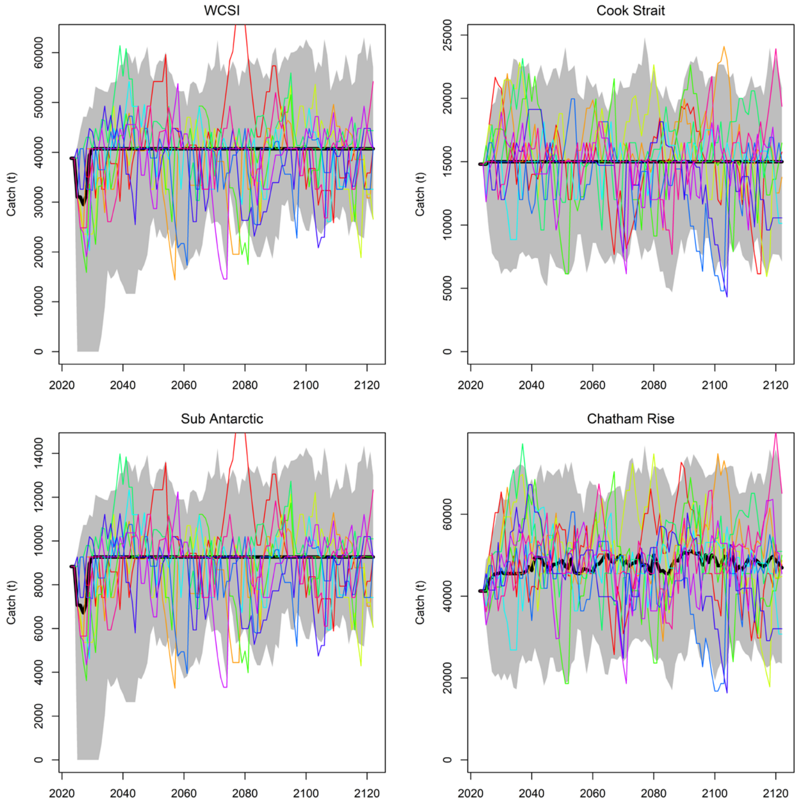

Figure 4: Annual catches from each of the main fishery areas from the evaluation period for HCR #38. The black line represents the average of the annual catch and the grey area represents the 95% interval. The coloured lines represent a subset of 10 individual simulations (from the 100 simulations).

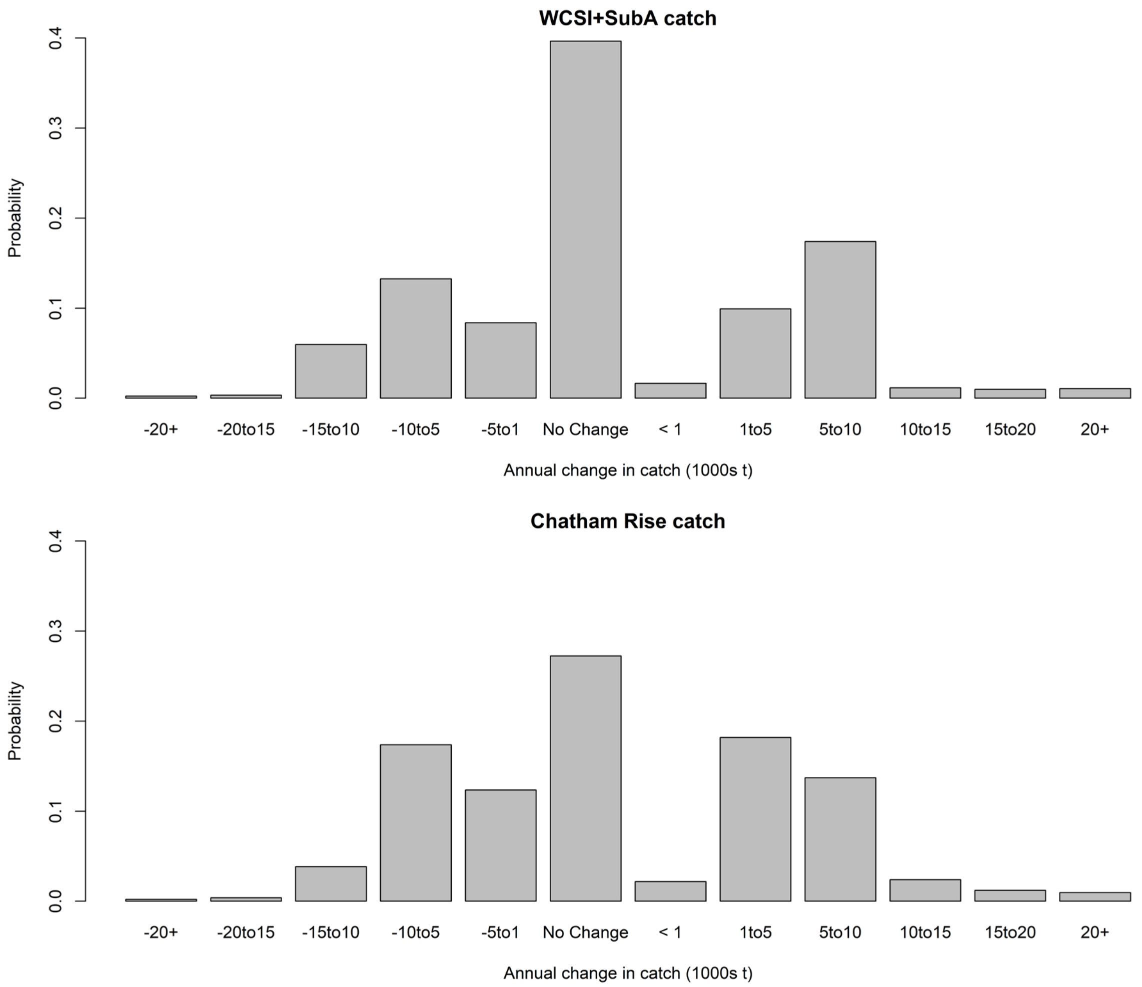

Figure 5: Distributions of the changes in annual catches from the west coast South Island and Sub-Antarctic (top) and Chatham Rise (bottom) fishery area from the evaluation period for HCR #38 (all simulations combined).

For comparative purposes, two HCRs (#38 & #46) were applied to the estimates of current status of the eastern (51% B_0) and western (28% B_0) stocks from the 2022 hoki stock assessment to determine the corresponding fishery catches that would have been set for the 2022/23 fishing year. The results were compared for two different values of *PropE*. (0.7 and 1.0).

HCR #38 determines a lower WCSI and Sub-Antarctic catch than HCR #46 due to the lower base level of catch for the two scenarios (50 kt and 60 kt, respectively) (Table 9). The catches are mediated by the western stock status being below the lower bound of the target biomass. Cook Strait catches are slightly higher than the base catch level (15 kt) due to the eastern stock status being slightly higher than the upper bound of the target biomass (Table 9).

The Chatham Rise catch levels are dependent on the relative influence of the eastern and western stock status. The scenarios with *PropE* set at 1.0 are entirely driven by the eastern stock status yielding a catch of 50.1 kt, slightly higher than the base level of Chatham Rise catch (50 kt). The level of catch was reduced to 43.1 kt for the scenarios that incorporate the western stock status (*PropE* 0.7) in the determination of the Chatham Rise catch, reflecting the western stock status being below the target biomass level (Table 9).

The initial rebuild rates for the western stock were equivalent for the two *PropE* values, reaching the lower bound of the target biomass range in 4 years (for HCR #38), indicating that there was no appreciable effect of moderating the Chatham Rise catch on the rebuild of the western stock.

Table 9: A comparison of the annual catch levels (kt = 1000s of tonnes) for each main fishery area determined from applying the HCRs to the results of the 2022 stock assessment. The results are compared for different *PropE* values incorporated in the HCR. The 2022 model catch is included for comparison.

HCR				Fishery area	Total
	Chatham Rise	Cook Strait	WCSI	Sub-Ant	
#38 *PropE* 0.7	43.1 kt	15.2 kt	21.3 kt	4.7 kt	84.2 kt
#46 *PropE* 0.7	43.1 kt	15.2 kt	25.5 kt	5.6 kt	89.4 kt
#38 *PropE* 1.0	50.1 kt	15.2 kt	21.3 kt	4.7 kt	91.6 kt
#46 *PropE* 1.0	50.1 kt	15.2 kt	25.5 kt	5.6 kt	96.8 kt
2022 catch	41.3 kt	14.8 kt	38.8 kt	8.6 kt	103.7 kt

The proposed HCR catches of 50.1 kt for the Chatham Rise are higher than the recent (2022) level catch, while HCR catches for WCSI and Sub-Antarctic are considerably lower than the 2022 catches (Table 9). TACC decisions following the 2022 assessment retained the HOK1 TACC of 110 000 t for the 2022/23 fishing year, partitioning 45 000 t to western (WCSI and Sub-Antarctic) and 65 000 t eastern (Chatham Rise and Cook Strait) fisheries.

4. DISCUSSION

The MSE was based on the structure of the recent (2022) hoki stock assessment (McGregor et al. 2023). The robustness of the MSE results, including selection of specific HCRs, is dependent on the fundamental stock structure assumptions of the assessment model, particularly the assumption of separate eastern and western stocks with a common nursery ground (natal fidelity). The 2023 stock assessment assumed an equivalent model structure to the 2022 assessment (McGregor et al. in prep). Alternative stock assumptions may influence estimates of recruitment, at different spatial scales, and the potential yields from the associated fisheries. Further testing of stock assumptions will be undertaken for the 2024 stock assessment, including refinement of the movement dynamics of hoki from the nursery area, the potential for density dependent movement processes, and the linkage between the Cook Strait and east coast South Island spawning grounds. Any appreciable differences in the key stock assessment results may require an extension of the current MSE simulation testing to incorporate alterative operating models.

Further, the scope of the MSE work should be expanded to incorporate uncertainty in key biological parameters that are assumed to be known in the current base assessment model (especially natural mortality, growth, and steepness). More generally, there is also potential to extend the MSE approach to simulate the monitoring and assessment processes of the hoki management cycle, enabling a more thorough evaluation of the current HCRs and an extension of the analysis to evaluate the frequency of surveys and assessments under alternative sets of HCRs.

Regardless, the MSE results should be routinely revisited, typically every 5–7 years, as the hoki stock assessments continue to be updated and refined. The HCR(s) should also be reviewed if there is a large-scale shift in the operation of the hoki fishery, such as a large (greater than 15–20 kt) changes in the distribution of catch between areas and/or appreciable change in the size/age of hoki caught. Other extenuating circumstances would include a major change in annual recruitments; for example, a persistent period of 3–4 years of exceptionally low recruitment or large increase in recruitment (as indexed by the Chatham Rise trawl survey). These "break out rules" should be clearly defined in the adoption of a specific HCR. Further consideration of the operationalisation of the HCR(s) should be undertaken during the development of management advice following the 2023 stock assessment process.

Overall, the MSE process indicates that, given the variation in annual recruitments, more active management of the hoki fishery is required to maintain the stock within the target biomass range and maintain fleet CPUE, particularly for the western stock/fisheries. In hindsight, the magnitude of the catches from the WCSI during 2013/14–2016/17 (~ 65–75 kt) and additional catch from the Sub-Antarctic (~15 kt) were too high to sustain the western fishery through the subsequent years which included several years of lower recruitment to the western stock. By comparison, the candidate HCRs would have limited the combined WCSI and Sub-Antarctic catches to about 50 kt during those years.

The results differ from the previous (2009 and 2012) MSE work that estimated higher total yields of about 130 kt (Langley 2009a unpublished) compared with 112–118 kt from the current study. The previous study had the flexibility to take larger catches from the Cook Strait fishery (25 kt), while the current operational constraints have limited catches to about 15 kt for the current study. There has also been an apparent shift in the productivity of the western stock from the late 1990s, with considerably lower recruitment than during the proceeding period. This has reduced the estimates of the overall productivity of the western stock resulting in lower average yields from the combined WCSI and Sub-Antarctic fisheries (about 50–55 kt compared with 65 kt from the 2012 study). The current study also estimated comparable potential yields from the eastern stock compared with the 2012 analysis (Chatham Rise ~48 kt, Cook Strait ~15 kt, and combined ~62 kt compared with 42 kt, 18 kt, and 60 kt from 2012).

The 2022 stock assessment estimated that average recruitments for the western stock for 1997–2020 were 45% of the level of recruitment from the proceeding period (1977–1996). Despite the lower recruitment from the late 1990s, estimates of stock status (relative to B_0) for the western stock are derived from the long-term average level of recruitment (R_0), ensuring the MSE performance indicators were consistent with the results of the current stock assessment and management framework. Further evaluation of the estimates of recruitment, particularly for the western stock, will be undertaken during the 2024 hoki stock assessment. Changes in long-term recruitment attributable to a persistent environmental change ("regime shift") may initiate a recalibration of the reference biomass level (B_0).

The 2023 Plenary did not adopt a HCR for the management of the hoki fishery. Instead, the results of the MSE are considered useful to inform managers regarding the likely level of yields available from the hoki fishery and the scale of management response required to maintain the stock at the optimal target biomass levels. The adoption of a specific HCR would require wider consultation to fully evaluate the relative trade-offs between stock outcomes (informed by key performance indicators). Implementation of a specific set of HCRs would also require the specification of a set of break out rules for managing the stock beyond the scope of the current operating model, e.g., in response to a sustained period of low recruitments.

5. ACKNOWLEDGEMENTS

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