Fisheries New Zealand

Tini a Tangaroa

An update of the assessment of the eastern stock of tarakihi for 2019

New Zealand Fisheries Assessment Report 2019/41

A.D. Langley

ISSN 1179-5352 (online)
ISBN 978-1-99-000827-6 (online)

September 2019

New Zealand Government

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries websites at:
http://www.mpi.govt.nz/news-and-resources/publications
http://fs.fish.govt.nz go to Document library/Research reports

TABLE OF CONTENTS

EXECUTIVE SUMMARY **1**

1. INTRODUCTION **2**

2. STOCK ASSESSMENT INPUTS **2**
- 2.1 Fishery catches 2
- 2.2 CPUE indices 4
- 2.3 ECSI *Kaharoa* trawl survey 7

3. STOCK ASSESSMENT MODEL **7**
- 3.1 Model structure 7
- 3.2 Model diagnostics 7
- 3.3 Stock status 10
- 3.4 Forward projections 12

4. DISCUSSION **15**

5. MANAGEMENT IMPLICATIONS **15**

6. ACKNOWLEDGMENTS **15**

7. REFERENCES **15**

APPENDIX 1 MODEL CATCH HISTORY **17**

APPENDIX 2 CPUE INDICES **18**

APPENDIX 3 FORWARD PROJECTIONS **19**

APPENDIX 4 PRELIMINARY EVALUATION OF POTENTIAL REFERENCE POINTS **22**

EXECUTIVE SUMMARY

Langley, A.D. (2019). An update of the assessment of the eastern stock of tarakihi for 2019.

***New Zealand Fisheries Assessment Report 2019/41.* 29 p.**

Tarakihi (*Nemadactylus macropterus*) off the east coast of the North and South Island are considered to represent a single biological stock. The domain of the stock encompasses the TAR 3 and TAR 2 Fishstocks, the eastern portion of the TAR 1 Fishstock and a small area of the TAR 7 Fishstock in eastern Cook Strait. The first assessment of the eastern tarakihi stock was completed in November 2017. The stock assessment was conducted using a statistical, age-structured population model implemented in Stock Synthesis.

The assessment model is structured with a single region and four fisheries and commences in 1975 under exploited, equilibrium conditions. The 2017 assessment model was updated with the additional data available from the 2016/17 and 2017/18 fishing years, specifically two years of annual catch, two additional CPUE indices and the biomass estimate and length composition from the 2017 ECSI *Kaharoa* trawl survey. Annual catches from the most recent two years (2017 and 2018) were generally comparable to the three previous years (2014–2016), with the exception of the TAR 3 trawl fishery. Catches from that fishery increased by 45% from 2014 to 2017 and then dropped by 33% in 2018.

Five sets of CPUE indices were updated based on the previous CPUE analyses. For the TAR 3 trawl fishery, the CPUE indices increased during 2013/14–2016/17 and then dropped in 2017/18, following the trend in catch from the fishery. The CPUE indices from the TAR 3 set net fishery increased during 2014/15–2017/18. Annual combined CPUE indices from the TAR 2 trawl fishery increased by 51% from 2013/14 to 2016/17 and then dropped by 14% in 2017/18. The CPUE indices from the Bay of Plenty trawl fishery were at the lowest level of the time series during 2013/14–2015/16, increased by 37% in 2016/17 and remained at a similar level in 2017/18. The CPUE indices from the east Northland trawl fishery declined by 60% during 2009/10–2017/18 with a 33% drop in 2017/18.

The updated model provided a very good fit to the recent CPUE indices from the TAR2/Bay of Plenty trawl fishery and the Kaikoura set net fishery. However, there were a number of discrepancies in the fits to the other recent observations, especially the CPUE indices from the East Northland and TAR 3 trawl fisheries and the recent ECSI trawl survey biomass estimates.

The updated assessment model indicates that there was no appreciable change in stock status from 2016 (2015/16) to 2018 (2017/18). Current (2018) stock status was estimated to be at 0.159 SB_0 (C.I. 0.113–0.205). There is a very high probability (96%) that the stock was below the soft limit and a negligible probability (< 1%) that the stock was below the 10% SB_0 hard limit.

Forward projections of the updated assessment model were conducted at fractions (50%, 60%, 70%, 80%, 90% and 100%) of the base level of the model fishery catches (total 3560 t) for the years 2020 to 2048. For each catch scenario, the median spawning biomass increased from the current (2018) level, although the rate of increase varied depending on the magnitude of the projected catch. There is a corresponding increase in the probability of the stock increasing above the 20% SB_0 soft limit with the different levels of catch. The projections were also evaluated relative to two potential levels of target biomass for the stock (35% and 40% SB_0).

A simulation analysis was conducted to investigate the performance of alternative target biomass levels for the stock. Target biomass levels were evaluated within the framework of a set of Harvest Control Rules (HCR) and the associated Management Procedures. The results are intended to assist managers in the formulation of an appropriate level of target biomass for the eastern tarakihi stock. The current study indicates that a target biomass level of about 35% SB_0 is sufficiently high to minimise the risk of breaching the soft and hard limits, while maintaining catches at a relatively high level. This is somewhat lower than the current default target biomass level of 40% SB_0. These results are predicated on the presumptions related to the management procedures and HCRs adopted for the simulations.

1. INTRODUCTION

Tarakihi (*Nemadactylus macropterus*) off the east coast of the North and South Island are considered to represent a single biological stock (Langley 2018). The domain of the stock encompasses the TAR 3 and TAR 2 Fishstocks, the eastern area of the TAR 1 Fishstock and a small area of the TAR 7 Fishstock in eastern Cook Strait.

The first assessment of the eastern tarakihi stock was completed in November 2017. The stock assessment was conducted using a statistical, age-structured population model implemented in Stock Synthesis (Methot & Wetzell 2013). The assessment incorporated the available catch, CPUE indices, trawl survey biomass estimates and age/length frequency distributions, and recent commercial age compositions. The model data sets were structured into three areas: east coast South Island (including eastern Cook Strait), central east coast North Island and the Bay of Plenty combined (BPLE-TAR2), and East Northland. The east coast South Island area included three commercial fisheries: the Canterbury Bight/Pegasus Bay trawl fishery, Kaikoura set net fishery and the eastern Cook Strait trawl fishery. The other two areas included a commercial trawl fishery and a relatively small non-commercial fishery. For each area, a corresponding time-series (or multiple series) of CPUE indices was available (Langley 2017).

Spawning biomass was estimated to have been reduced to 22% SB_0 by the mid 1970s, following a period of relatively high catches (5000–7000 t) during the 1950s and early 1960s. For the base case assessment model, current (2015/16) spawning biomass was estimated to be at 17% of the unfished, equilibrium biomass level (SB_{2016}/SB_0 = 0.170), which is below the soft limit of 20% SB_0 (Langley 2018).

The stock assessment model was updated in early 2018 with the inclusion of catches and CPUE indices from the 2016/17 fishing year. The assessment update was funded by the commercial stakeholder groups Fisheries Inshore New Zealand (FINZ) and Southern Inshore Fisheries Management Company (SIFMC) and reported to the Southern Inshore Stock Assessment Working Group on 4 April 2018. The updated base case model yielded results that were consistent with the previous assessment and estimated the 2016/17 spawning biomass to be at 17% of the unfished, equilibrium biomass level ($SB_{2017}/SB0$ = 0.173). There was a high probability (87%) that the spawning biomass was below the soft limit (20% SB_0) but a very low probability (less than 1%) of being below the hard limit of 10% SB_0.

The updated stock assessment model was applied to conduct a range of stock projections with different multiples of fishery catch. These projections were utilised in the formulation of management advice to implement a rebuild strategy for the stock. The management advice lead to reductions in the TACCs for TAR 1 (a 24% reduction), TAR 2 (16%), TAR 3 (26%) and TAR 7 (4%) for the 2018/19 fishing year. A range of voluntary measures were also introduced in 2018/19, including measures to ensure that the reductions in the TAR 1 and TAR 7 TACCs were applied to the east coast portions of those Fishstocks.

The commercial stakeholder groups FINZ and SIFMC funded a further update of the stock assessment model in 2019, incorporating catch, CPUE and trawl survey data from the 2017/18 fishing year. The updated assessment model was applied to conduct an additional set of stock projections for consideration in the development of management advice for the 2019/20 fishing year. In addition, the stock assessment model was used in a preliminary evaluation of potential target biomass reference points for the eastern tarakihi stock.

2. STOCK ASSESSMENT INPUTS

The recent updates of the 2017 stock assessment have retained the equivalent model structure and data configuration. The most recent (2019) update of the assessment model incorporated two additional years of fishery catch data and CPUE indices and an additional set of data from the time series of winter east coast South Island (ECSI) *Kaharoa* trawl surveys (April–June 2018).

2.1 Fishery catches

The stock assessment model incorporates six commercial fisheries: a set net fishery off Kaikoura (TAR3-SN) and trawl fisheries in Canterbury Bight/Pegasus Bay (TAR3-BT), eastern Cook Strait

(Cook-BT), east coast North Island (TAR2-BT), Bay of Plenty (BPLE-BT) and east Northland (ENLD-BT). The configuration of these fisheries is detailed in Langley (2018). Annual catches were compiled by fishing year; years in the assessment model are denoted by the calendar year at 1 January (e.g. the 2018 model year represents the 2017/18 fishing year).

Annual catches from the commercial fisheries for 2016/17 and 2017/18 fishing years were compiled from an extract of recent catch and effort data provided by Fisheries New Zealand (Data Extract 12270). These data were processed following the methodology described in Langley (2017). The fishery catches also included an additional allowance for unreported catches, assumed to represent 10% of the reported landings.

Annual catches from the most recent two years (2017 and 2018) were generally comparable to the three previous years (2014–2016), with the exception of the TAR3-BT fishery (Figure 1) which increased by 45% from 2014 to 2017 and then dropped by 33% in 2018.

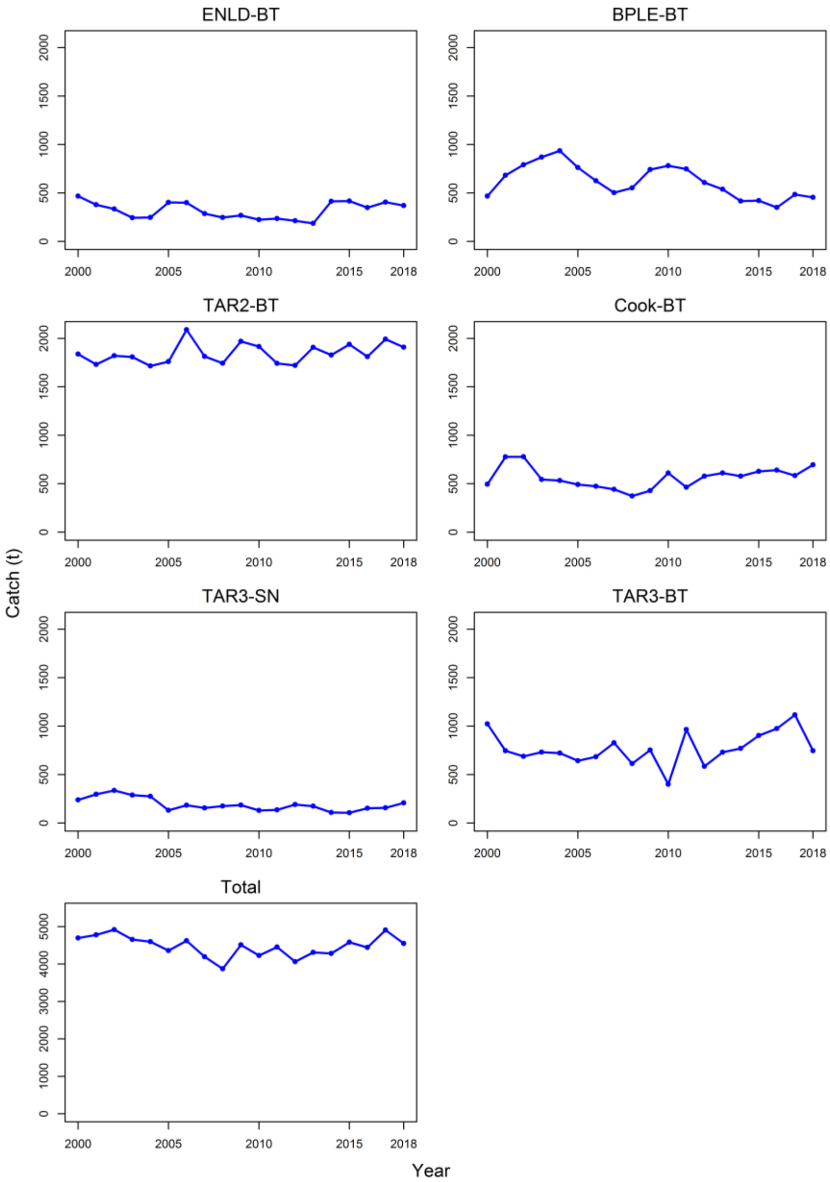

Figure 1: Recent annual catches of tarakihi by commercial fishery and total (including recreational catch). Annual catches include allowances for unreported catch. Model years are configured by fishing year (denoted by the calendar year at 1 January).

The time series of annual fishery catches included in the assessment model is tabulated in Appendix 1. Catches from the recreational fisheries in 2017 and 2018 were assumed to be equivalent to those in the preceding years.

2.2 CPUE indices

For the 2017 stock assessment, standardised CPUE indices were derived for five tarakihi fisheries: TAR 3 trawl, TAR 3 set net, TAR 2 trawl, the Bay of Plenty trawl and east Northland trawl (Langley 2017). These sets of CPUE indices were updated in 2019 with the addition of two years of catch and effort data (2016/17 and 2017/18). The configuration of the individual CPUE data sets is described in Langley (2017).

The individual CPUE models were simply refitted with the equivalent set of explanatory variables included in the original analyses (Langley 2017). The updated CPUE models all yielded indices that were virtually identical to the corresponding annual indices from the original models.

For the TAR 3 trawl fishery, the combined (delta-lognormal) CPUE indices generally increased during 2013/14–2016/17 and then dropped in 2017/18, following the trend in catch from the fishery (Figure 2). The lognormal CPUE indices from the TAR 3 set net fishery increased during 2014/15–2017/18 (Figure 3). Annual combined CPUE indices from the TAR 2 trawl fishery increased by 51% from 2013/14 to 2016/17 and then dropped by 14% in 2017/18 (Figure 4).

The combined (delta-Weibull) CPUE indices from the Bay of Plenty trawl fishery were at the lowest level of the time series during 2013/14–2015/16 (Figure 5). The indices increased by 37% in 2016/17 and remained at a similar level in 2017/18. The combined (delta-Weibull) CPUE indices from the east Northland trawl fishery declined by 60% during 2009/10–2017/18 with a 33% drop in the CPUE index in 2017/18 (Figure 6).

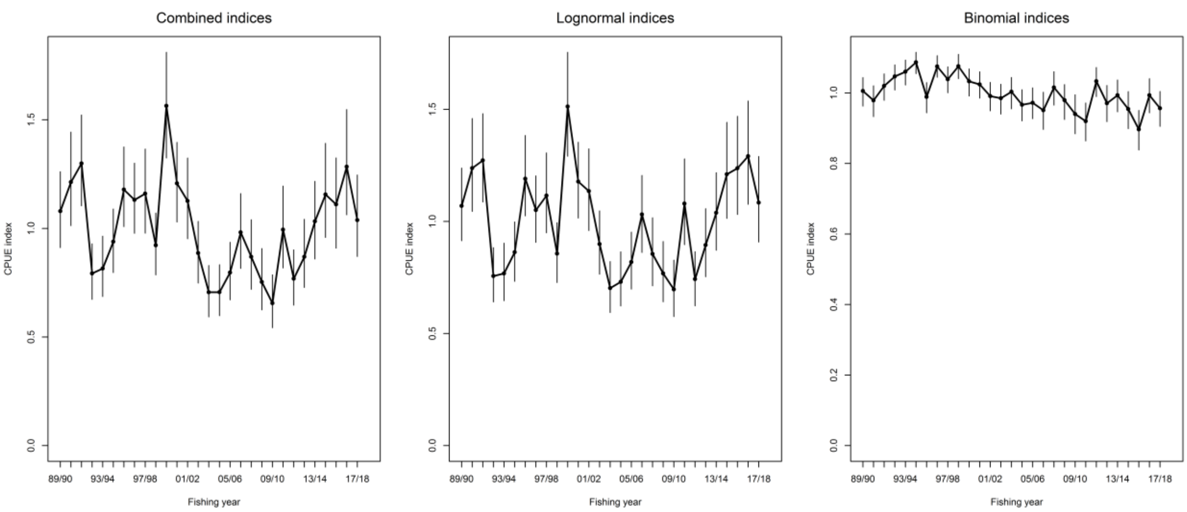

Figure 2: Standardised CPUE indices from the lognormal, binomial and combined (delta-lognormal) CPUE models for the TAR 3 trawl fishery (the vertical lines represent the 95% confidence intervals).

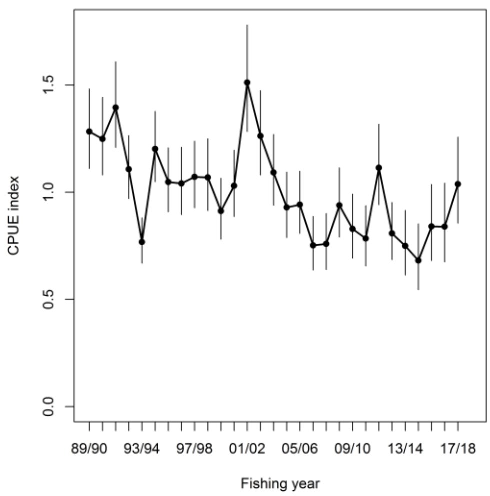

Figure 3: Standardised CPUE indices from the lognormal CPUE model for the TAR 3 set net fishery (the vertical lines represent the 95% confidence intervals).

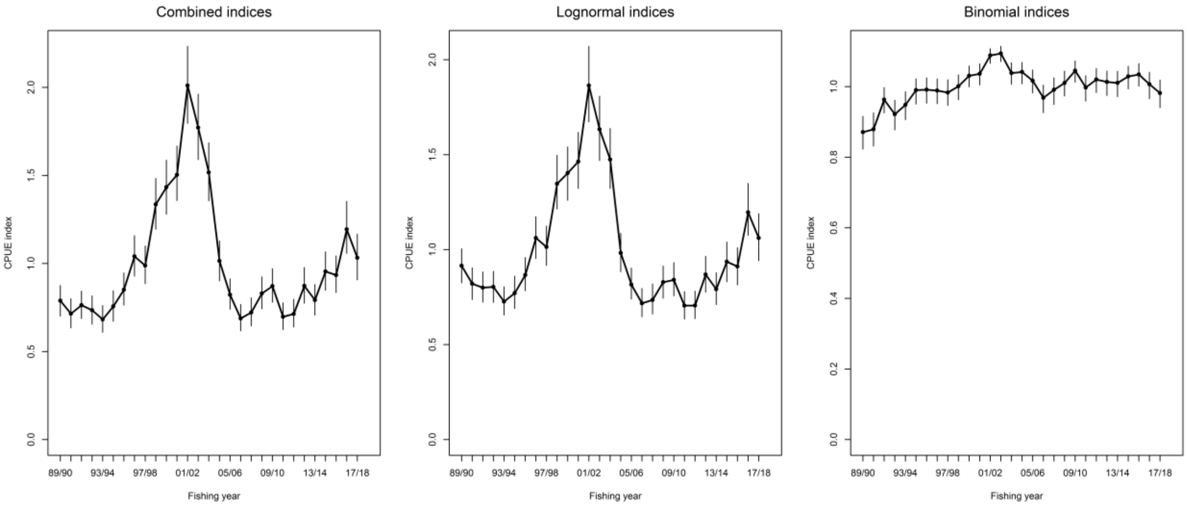

Figure 4: Standardised CPUE indices from the lognormal, binomial and combined (delta-lognormal) CPUE models for the TAR 2 trawl fishery (the vertical lines represent the 95% confidence intervals).

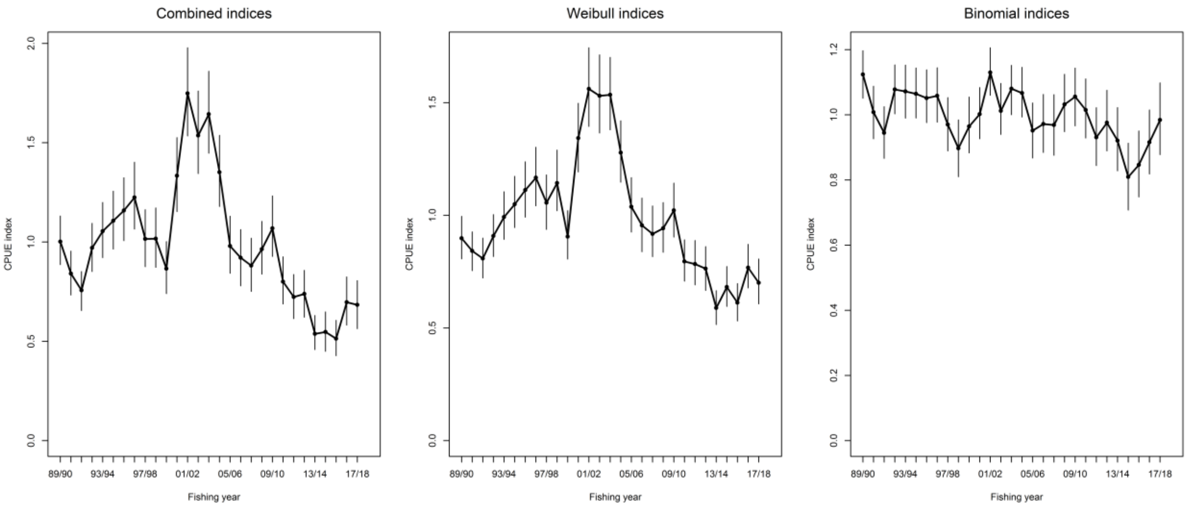

Figure 5: Standardised CPUE indices from the Weibull, binomial and combined (delta-Weibull) CPUE models for the Bay of Plenty (TAR 1) trawl fishery (the vertical lines represent the 95% confidence intervals).

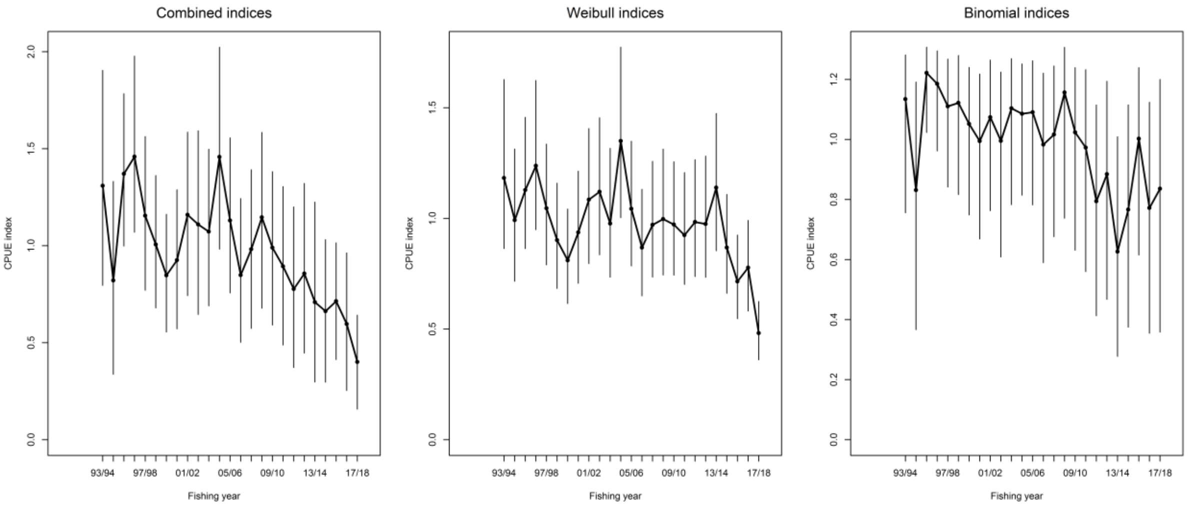

Figure 6: Standardised CPUE indices from the Weibull, binomial and combined (delta-Weibull) CPUE models for the East Northland (TAR 1) trawl fishery (the vertical lines represent the 95% confidence intervals).

For inclusion in the stock assessment model, the separate sets of CPUE indices from the TAR 2 trawl and Bay of Plenty trawl fisheries were combined (*TAR2BPLE-BT*), weighted by the annual catches from each fishery. The final sets of CPUE indices included in the updated stock assessment model are presented in Appendix 2. The four sets of CPUE indices were each assigned a coefficient of variation (CV) of 20% in the assessment model (Langley 2018).

The 2017 stock assessment model did not include standardised CPUE indices from the Cook Strait trawl fishery, primarily due to the relatively limited amount of catch and effort data available from the fishery and limited age composition data available to reliably estimate the selectivity of the fishery. However, during the update of the CPUE indices in 2018 the catch and effort data from the fishery (to 2016/17) were reanalysed and the resulting time-series of CPUE indices was accepted by the SINS WG.

The trends in the CPUE indices from the Cook Strait fishery (Figure 7) are generally consistent with the trends in the CPUE indices from the TAR 3 trawl and set net fisheries (Figure 2 and Figure 3) once the differences in the age composition of the catches between the three fisheries are taken into account (Langley 2018). These additional CPUE indices have not been incorporated in the subsequent updates of the stock assessment model.

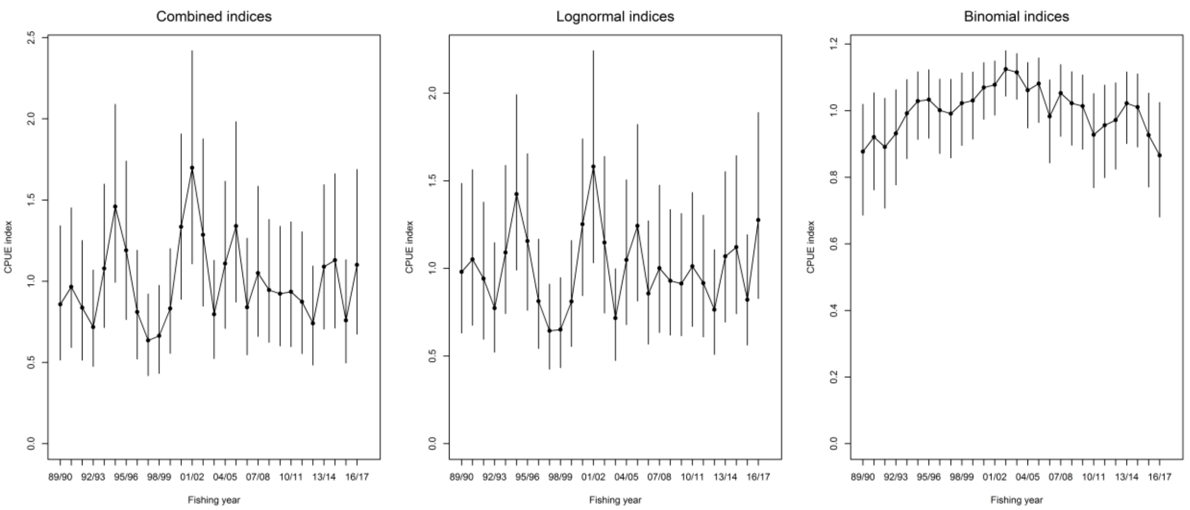

Figure 7: Standardised CPUE indices from the lognormal, binomial and combined (delta-lognormal) CPUE models for the Cook Strait trawl fishery (the vertical lines represent the 95% confidence intervals).

2.3 ECSI *Kaharoa* trawl survey

The stock assessment model includes the time-series of biomass estimates and length or age compositions from the ECSI *Kaharoa* trawl surveys. Since the completion of the stock assessment in 2017, there was an additional trawl survey conducted in April–June 2018 (MacGibbon et al. 2019). The tarakihi biomass estimate from the core area of the trawl survey was 1407 t (CV 0.25) which is lower than the geometric mean of the biomass estimates from the series of winter trawl surveys (1730 t). The trawl survey biomass is primarily composed of fish in the 1–5 year age classes (Langley 2018).

Since 2007, age composition data have been available from each of the ECSI *Kaharoa* trawl surveys. However, the tarakihi otoliths that were collected during the 2018 trawl survey (MacGibbon et al. 2019) are yet to be aged and, in the interim, the 2018 survey length composition was included in the assessment model. The next iteration of the assessment model will instead incorporate the age composition from the latest survey.

3. STOCK ASSESSMENT MODEL

3.1 Model structure

The structure of the updated assessment model was essentially equivalent to the base-case stock assessment model completed in 2017 (Langley 2018). The model is structured with a single region and four fisheries with the age structure initialised in 1975 assuming exploited, equilibrium conditions. The updated model extended the model period from 2016 to 2018 and estimates current stock status in 2018 (2017/18 fishing year). The additional trawl survey observations (biomass and length composition) enable the time-series of recruitment deviates to be extended from 2015 to 2017.

The model was implemented in Stock Synthesis version 3.24Z which was the same version of the software used in the original assessment. The model objective function included contributions from the fishery catches, initial equilibrium catches, indices of abundance (CPUE and survey), age-compositions (commercial and survey), length-compositions, (survey) recruitment, and priors and penalties (see Methot & Wetzell 2013). The weighting applied to the individual data observations was equivalent to the original assessment model.

The estimation procedure minimises the negative log-likelihood of the objective function to determine the mode of the joint posterior distribution (MPD). Model uncertainty was determined using Markov chain Monte Carlo (MCMC) implemented using the Metropolis-Hastings algorithm; 1000 MCMC samples were drawn at 1000 intervals from a chain of 1.1 million following an initial burn-in of 100 000.

3.2 Model diagnostics

The model fit to the individual data sets was very similar to the fit to the comparative data sets in the 2017 stock assessment model. For the MPDs, the combined age composition likelihoods were very similar for the two models (33.84 compared to 33.23 from the 2017 assessment) and the models provide a good fit to the individual age compositions from the trawl surveys and fisheries (Langley 2018). The key parameter estimates were also very similar.

As with the original model, the updated assessment provides a good fit to the general trend in four sets of CPUE indices, although there is some divergence from each of the sets of CPUE indices over the time-series (Figure 8). For the most recent two years, the updated model provides a good fit to the *TAR2BPLE-BT* and *TAR3-SN* CPUE indices. However, the model does not fit the large drop in the *ENLD-BT* CPUE index in 2018 and underestimates the *TAR3-BT* CPUE indices in 2017 and 2018 (Figure 8).

The recent *TAR3-BT* CPUE indices appear to conflict with the biomass estimates from the two most recent ECSI trawl surveys; the model underestimates the CPUE indices but overestimates the trawl survey vulnerable biomass in both 2016 and 2018 (Figure 9). As in the original assessment, the model fits to the length compositions from the ECSI trawl survey are generally quite poor and do not adequately fit the modal structure of the individual cohorts (Figure 10). This observation also pertains to the length composition from the most recent (2018) trawl survey.

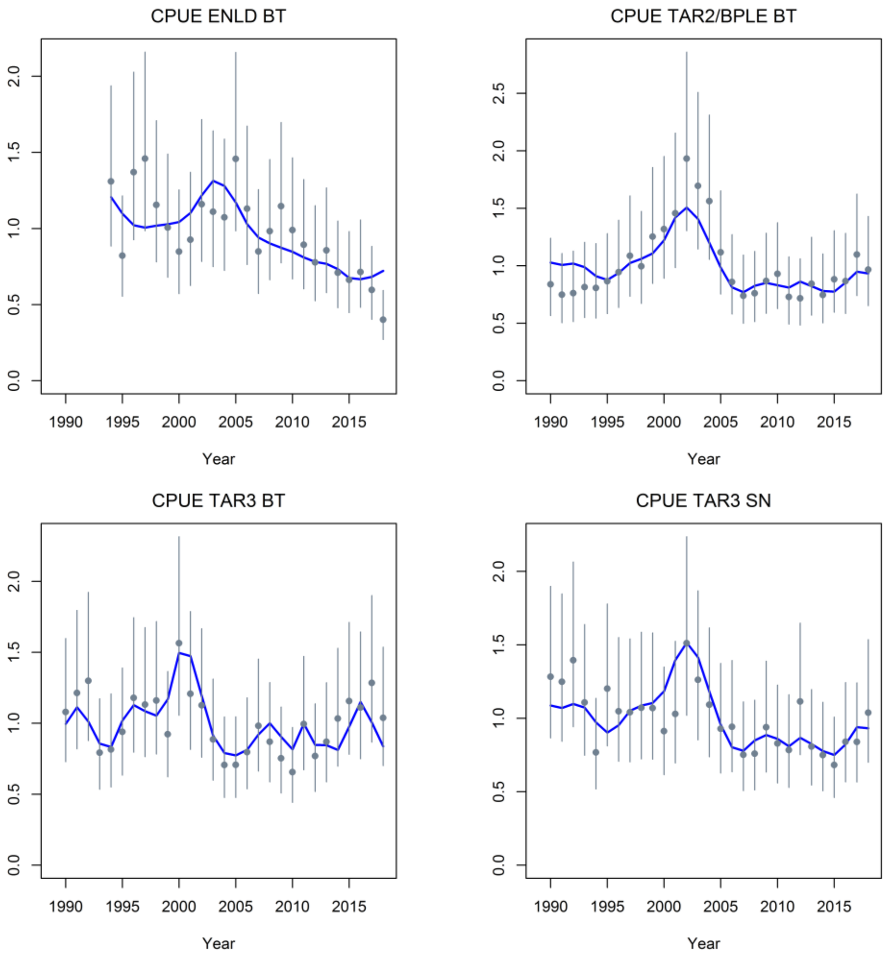

Figure 8: Fits to the four sets of CPUE indices included in the updated assessment model.

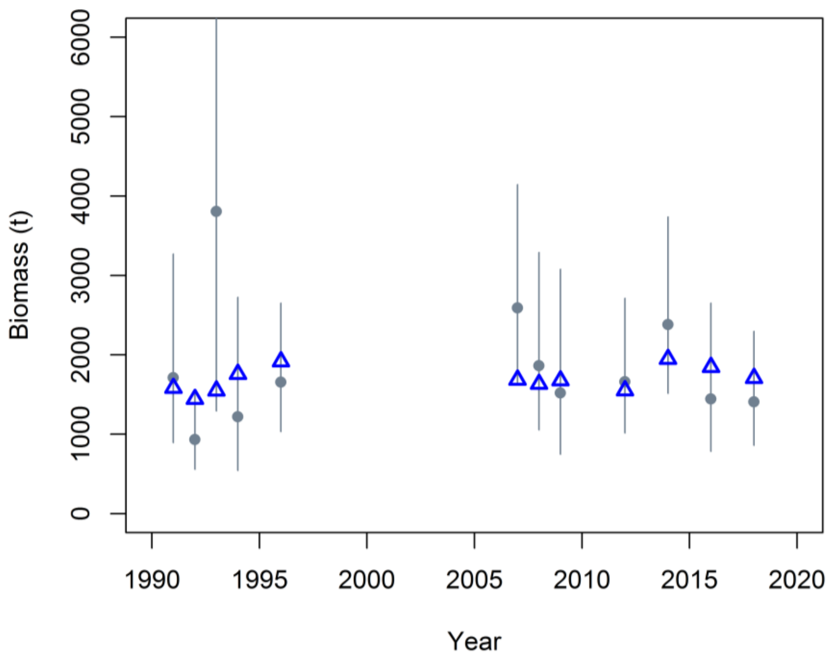

Figure 9: Observed (grey points) and predicted (blue triangles) winter ECSI trawl survey biomass from the updated assessment model.

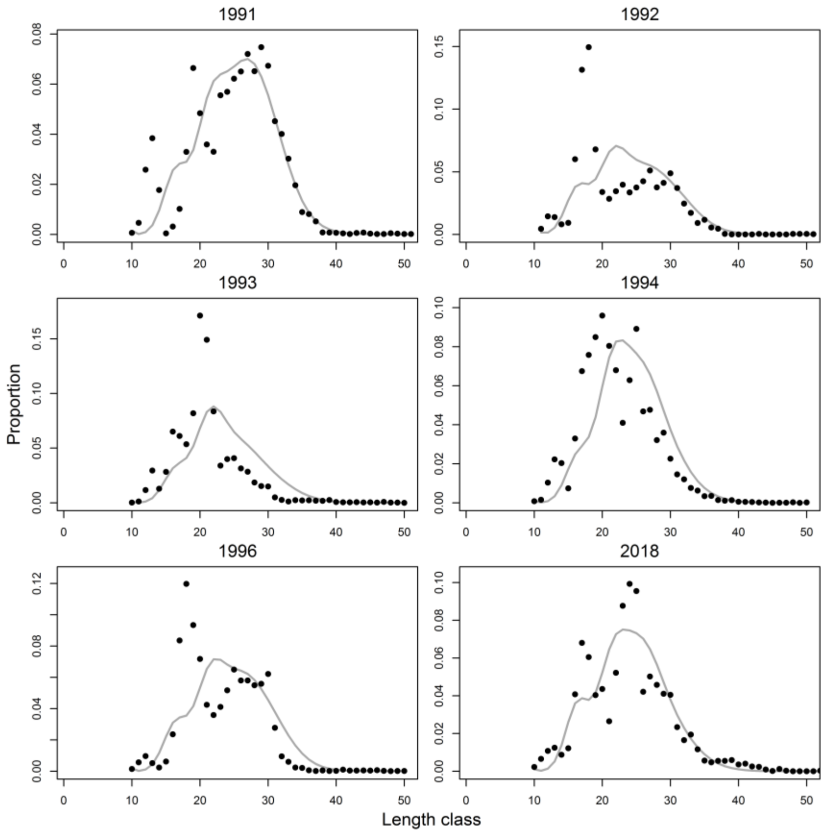

Figure 10: Comparison of observed (points) and predicted (lines) individual length compositions (both sexes combined) from the winter ECSI *Kaharoa* trawl surveys (including the most recent survey) from the updated assessment model.

The updated model estimated annual recruitments that were very similar in magnitude to the original assessment (Figure 11). There was a small reduction in the level of recruitment estimated during the early 1980s and recruitment estimates from the terminal years of the original model (2013–2015) were less variable. Recent recruitments are characterised by relatively strong year classes in 2011 and 2012 and lower recruitment in 2013 and 2014. Recruitments in 2015–2017 were poorly estimated by the updated assessment model (Figure 11), reflecting the limited information from the recent ECSI trawl survey data.

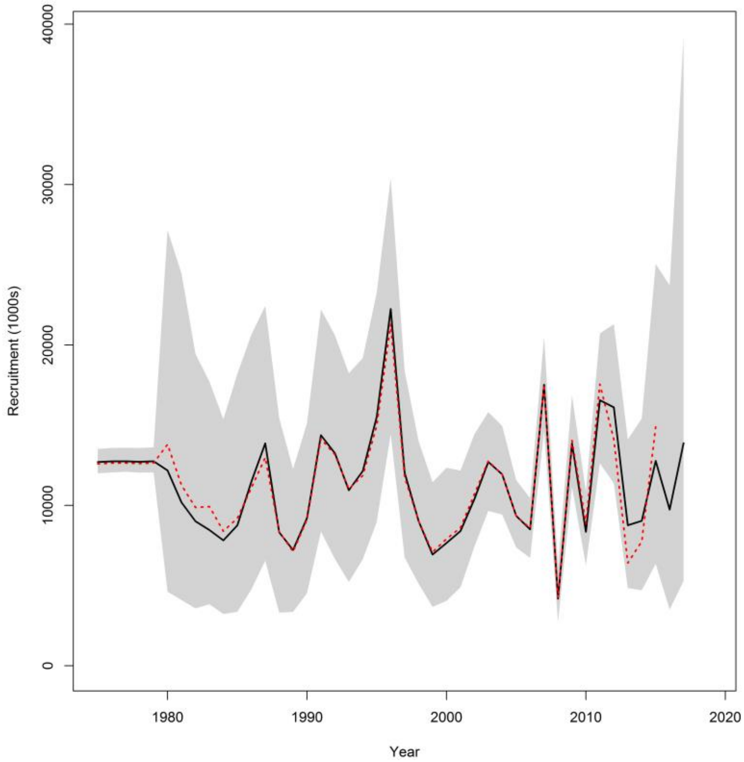

Figure 11: A comparison of the estimates of annual recruitment from the 2017 assessment (red dashed line) and the updated assessment (black line and associated 95% confidence intervals). The lines represent the median values of the MCMC distributions.

3.3 Stock status

The updated assessment model yielded stock trajectories that were very similar to the original assessment model, in terms of absolute spawning biomass (Figure 12) and spawning biomass relative to equilibrium unexploited biomass (Figure 13). There was some divergence in the stock trajectories in the 1980s and early 1990s corresponding to the lower level of recruitment estimated by the updated assessment model (Figure 11). The estimate of stock status in 2016, the terminal year of the original assessment, was also slightly lower from the updated model (SB_{2016}/SB_0 0.161 compared to 0.170 from the previous assessment) with a corresponding lower probability of being above the soft limit of 20% SB_0 (Table 1).

The updated assessment model indicates that there was no appreciable change in stock status from 2016 (2015/16) to 2018 (2017/18) (Table 1 and Table 2). Current (2018) stock status was estimated to be at 0.159 SB_0 (C.I. 0.113–0.205). There was a very high probability (96%) that the stock was below the soft limit and a negligible probability (< 1%) that the stock was below the 10% SB_0 hard limit (Table 2). The estimates of current stock status were consistent with the results of stock projections conducted with the original assessment model (based on an assumption of constant catches equivalent to the 2016 catch levels) (Table 2).

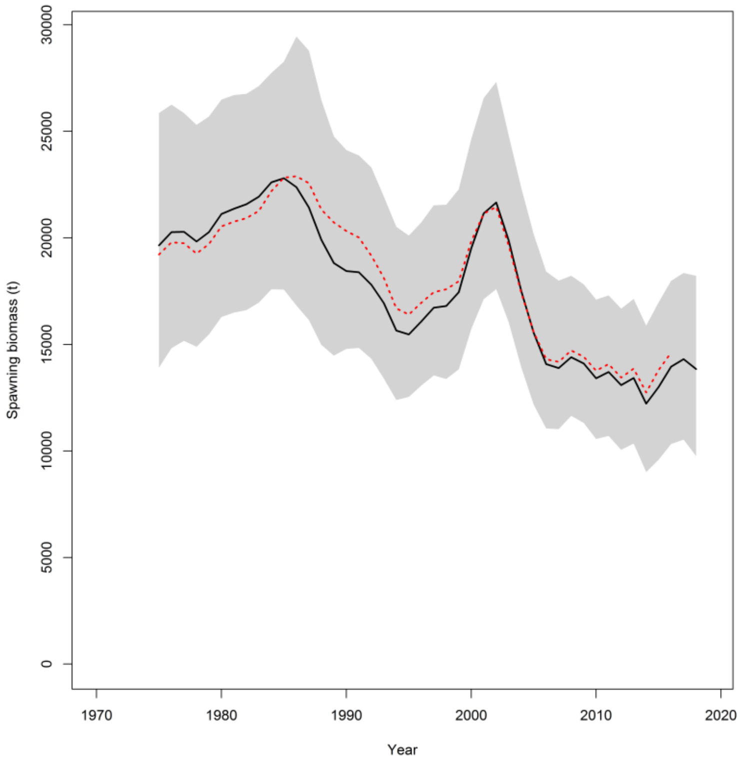

Figure 12: A comparison of spawning biomass from the 2017 assessment (red dashed line) and the updated assessment (black line and associated 95% confidence intervals). The lines represent the median values of the MCMC distributions.

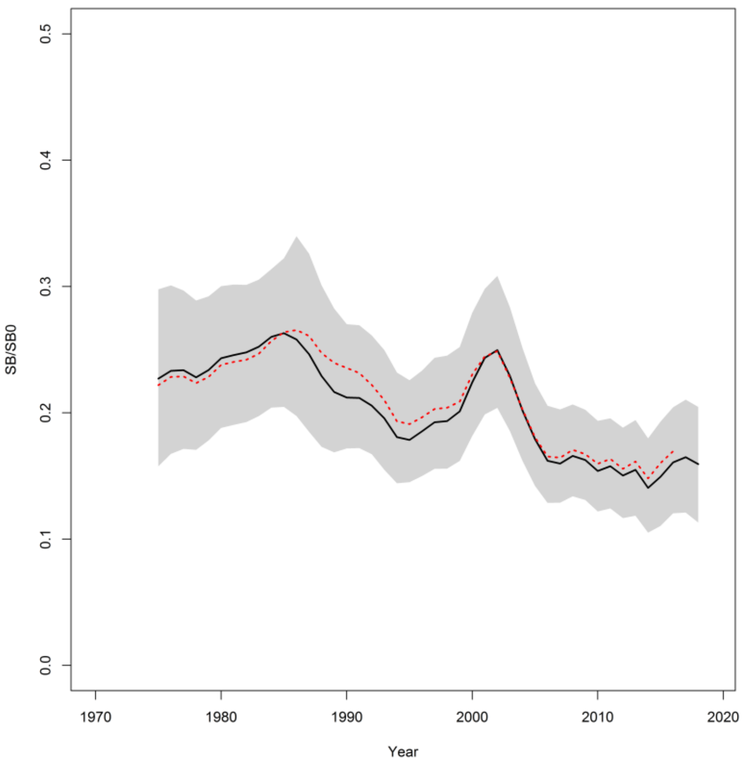

Figure 13: A comparison of spawning biomass relative to virgin biomass (*SB_0*) from the 2017 assessment (red dashed line) and the updated assessment (black line and associated 95% confidence intervals). The lines represent the median values of the MCMC distributions.

Table 1: Stock status in 2016 (2015/16 fishing year) from the original assessment (Base 2017) and the updated assessment model.

Model option	***SB_0***	***SB_{2018}***	***SB_{2018}/SB_0***	**Pr (SB_{2018} > $X\%SB_0$)**		
				40%	**20%**	**10%**
Base 2017	86 321 (81 977–91 907)	14 620 (10 685–19 413)	0.170 (0.126–0.219)	0.00	0.112	0.997
Update 2019	86 972 (82 432–92 164)	13 955 (10 330–17 985)	0.161 (0.120–0.204)	0.00	0.036	0.998

Table 2: Stock status in 2018 (2017/18 fishing year) from the original assessment (Base 2017) and the updated assessment model. The stock status from the original assessment is based on a constant catch projection, assuming projected catches were equivalent to 2016 catches. Projection results are presented in grey italics.

Model option	***SB_0***	***SB_{2018}***	***SB_{2018}/SB_0***	**Pr (SB_{2018} > $X\%SB_0$)**		
				40%	**20%**	**10%**
Base 2017	86 321 (81 977–91 907)	*13 671* *(8 002–19 900)*	*0.158* *(0.098–0.222)*	*0.00*	*0.148*	*0.998*
Update 2019	86 972 (82 432–92 164)	13 844 (9 762–18 220)	0.159 (0.113–0.205)	0.00	0.042	0.996

3.4 Forward projections

The updated assessment model was applied to conduct forward projections to evaluate a range of different catch scenarios, specifically related to the rebuilding of the stock. Forward projections were conducted for a 30 year period from 2019 to 2048. For all scenarios, annual catches in the first year (2019 = 2018/19) were equivalent at the base level of catches corresponding to the new TACCs introduced in 2018/19 and the associated proportion allocated to the eastern stock (for TAR 1 and TAR 7) (Table 3).

The 2018/19 catches for each Fishstock/QMA were then apportioned between model fisheries based on the catch proportions from 2017/18 (Table 3). The Cook Strait trawl fishery operates within TAR 7 and the northern area of TAR 3 (Statistical Area 018), and hence the Cook-BT fishery catch is composed of a proportion of the TACC of both Fishstocks. The projected commercial catches also included an additional 10% unreported catch (Table 3). Recreational catches were held constant throughout the projection period at the 2016 level (71 t and 97 t from Bay of Plenty and QMA 2, respectively).

Forward projections were conducted at fractions of the base level of the model fishery catches (total 3560 t) for the years 2020 to 2048. The projections were conducted for 50%, 60%, 70%, 80%, 90% and 100% of the base levels of fishery catch.

Table 3: Derivation of the base level of fishery catches included in the forward projections.

Fishstock	2018/19 TACC	Proportion East	2018/19 Catch	Model fishery (% 2018/19 catch)	Catch (t)	Including 10% unreporting
TAR 1	1 097	0.472	518	ENLD-BT (45%)	233	256
				BPLE-BT (55%)	285	313
TAR 2	1 500	1.0	1 500	TAR2-BT (100%)	1 500	1 650
TAR 3	1 040	1.0	1 040	TAR3-BT (66%)	688	757
				TAR3-SN (10%)	106	116
				Cook-BT (24%)	246	467
TAR 7	1 042	0.17	179	Cook-BT (100%)	179	
Total					3 237	3 560

Forward projections were conducted using MCMC with 1000 samples drawn at 1000 intervals from a chain of 1.1 million draws (with an initial burn-in of 100 000). Annual recruitments were derived from the Beverton-Holt spawner-recruit relationship with recruitment deviates resampled from the assumed distribution (*sigmaR* 0.6).

The results of the individual projections were collated to determine the median biomass level (SB_{year}/SB_0) and the probability of the biomass being above the hard limit (10% SB_0), the soft limit (20% SB_0) and two potential levels of target biomass (35% and 40% SB_0) for each year of the projection. The full range of results from the projections is presented in Appendix 3.

For each catch scenario, median spawning biomass increases from the current (2018) level, although the rate of increase varies depending on the magnitude of the projected catch (Figure 14). For example, under the current (2018/19) level of commercial catch, the median biomass increases from 0.158 to 0.23 SB/SB_0 in 10 years, whereas at 50% of the current catch level the stock reaches 0.40 SB/SB_0 in the same period.

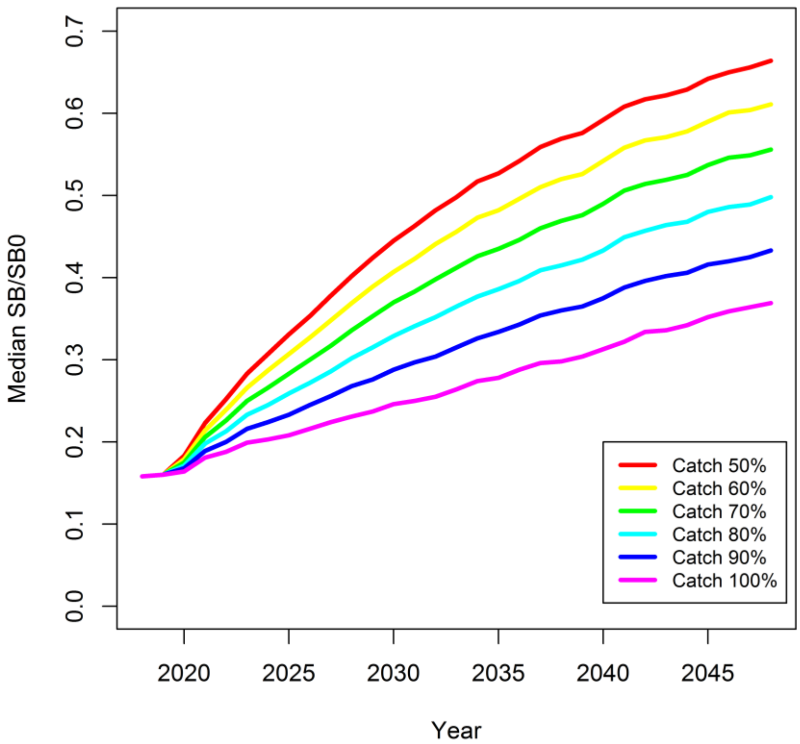

Figure 14: Median annual spawning biomass relative to virgin spawning biomass (SB_0) for the projection period for each of the catch scenarios (percentages of the base level of catch).

There is a corresponding increase in the probability of the stock increasing above the 20% SB_0 soft limit with the different levels of catch. The current (100%) catch projections indicate that there is a 62% probability that the stock will be above the soft limit in 10 years, whereas there is a 99% probability of being above the soft limit in 10 years with catches at 50% of the base level (Figure 15).

The probability of reaching 35% and 40% SB_0 increases over time for all catch scenarios, although the probability of reaching either threshold during the projection period is higher for the lower catch scenarios (Figure 15).

For all catch scenarios, the projections indicate that the risk of the stock declining below the 10% hard limit is negligible over the next 10 years. The probability remains very low for all catch scenarios throughout the projection period, with the exception of the base catch scenario (100%) which has a 5–10% probability of decreasing below the hard limit throughout the last 20 years of the projection period (Appendix 3).

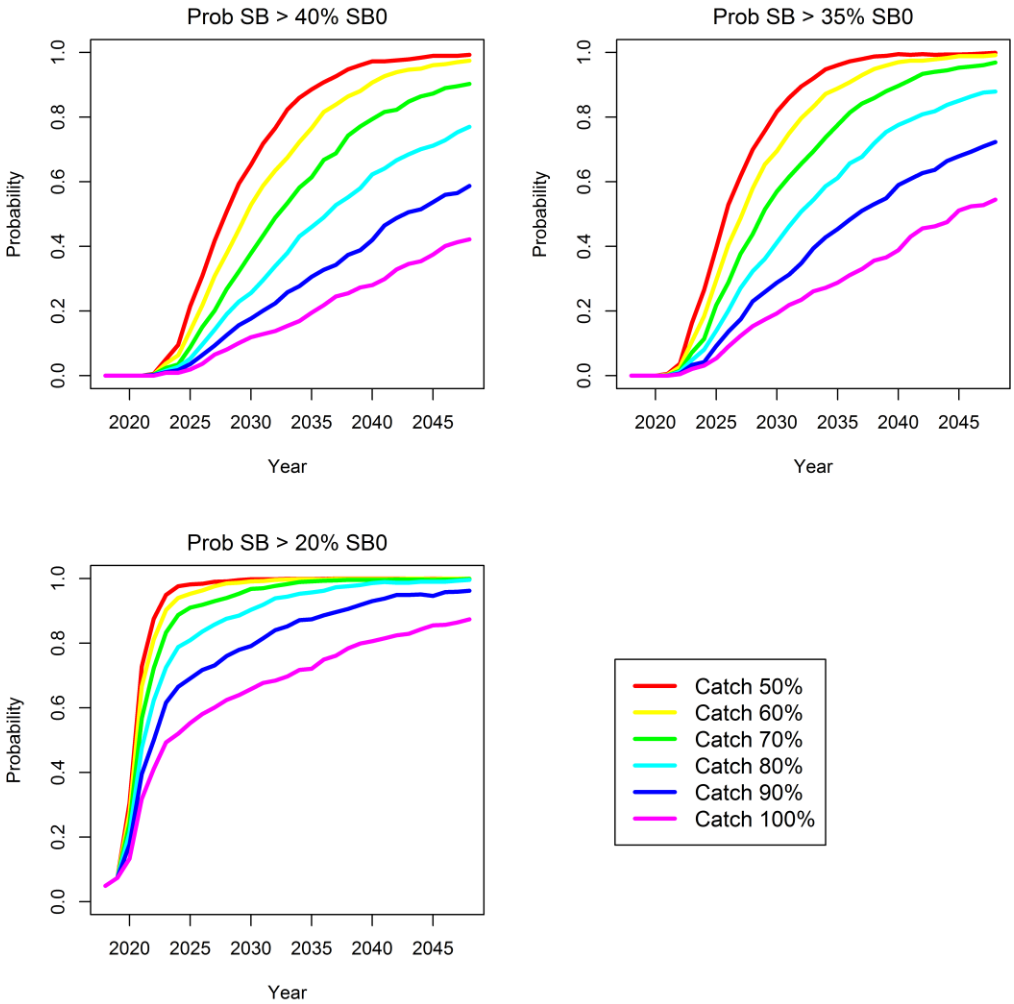

Figure 15: Annual probability of spawning biomass being greater than 20% (bottom left panel), 40% (top left) and 35% (top right) SB_0 for the projection period for each of the catch scenarios (percentages of the base level of catch).

4. DISCUSSION

The 2017 assessment model was updated with the additional data available from 2016/17 and 2017/18 fishing years. The updated model provided a very good fit to the recent CPUE indices from the TAR2/Bay of Plenty trawl fishery and Kaikoura set net fishery. However, there are a number of discrepancies noted in the fits to the other recent observations, especially the CPUE indices from the East Northland and Canterbury Bight/Pegasus Bay trawl fisheries and the recent ECSI trawl survey biomass estimates. The deterioration in the fit to these data may indicate regional differences in recent trends in stock abundance due to differential levels of exploitation and/or differences in recent patterns in recruitment. A national catch sampling programme has been implemented to collect age composition data from the main tarakihi fisheries during the 2018/19 and 2019/20 fishing years, and these data will be available for incorporation into the next full stock assessment of eastern tarakihi, planned for 2021. Age composition data will also be available from the 2018 and 2020 ECSI trawl survey. The age composition data are likely to increase our understanding of the regional scale stock dynamics and assist in elucidating recent trends in stock biomass.

The relatively poor fit to the most recent abundance indices indicates that further evaluation of the reliability of the CPUE indices from the main fisheries is required. The recent changes in the management of the tarakihi fishery (i.e. the reductions in TACCs and the partitioning of catches within the TAR 1 Fishstock) are likely to influence the operation of the trawl fisheries which may influence the reliability of the CPUE indices, especially in the coming years.

The relatively poor fit to some of the most recent abundance indices introduces additional uncertainty into the estimates of current stock status, although the overall assessment model was relatively insensitive to the inclusion of these data. Therefore, it is considered that the updated assessment model is sufficiently robust for the purposes of conducting forward projections. The current set of forward projections yielded results that are entirely consistent with projections conducted with an earlier (2018) iteration of the model.

5. MANAGEMENT IMPLICATIONS

The results of the forward projections have been provided to Fisheries New Zealand and commercial stakeholder groups (FINZ and SIFMC) for the formulation of management proposals for consideration in the 2019 Sustainability Round.

The next full stock assessment for eastern tarakihi is scheduled for 2021 and will incorporate the age compositions of the catch derived from sampling during 2018/19 and 2019/20 and from the 2018 and 2020 ECSI trawl surveys. It is anticipated that the updated stock assessment will improve estimates of current stock status and enable the initial period of the rebuilding of the stock to be evaluated (to 2020/21).

6. ACKNOWLEDGMENTS

The project was funded by the FINZ and SIFMC commercial stakeholder groups and coordinated by Oliver Wilson (FINZ). The results were reviewed by the Stock Assessment Methods Working Group and the Southern Inshore Stock Assessment Working Group. Members of both Working Groups provided advice on technical details of the analyses. Pamela Mace and Marc Griffiths (Fisheries New Zealand) provided comments on the manuscript of the report.

7. REFERENCES

Caddy, J.F.; Mahon, R. (1995). Reference points for fisheries management. *FAO Fisheries Technical Paper.* No. 347. Rome, FAO. 83 p.

Francis, R.I.C.C; Mace, P.M. (2005). An evaluation of some alternative harvest strategies. *New Zealand Fisheries Assessment Report* 2005/60. 30 p.

Geromont, H.F.; Butterworth, D.S. (2015). A review of the assessment methods and the development of management procedures for data-poor fisheries. FAO Report. The Marine Resource

Assessment and Management Group (MARAM). University of Cape Town, South Africa. 219 p.
Haist, V. (2014). Target reference points for fisheries management. (Draft manuscript held by Fisheries New Zealand, Wellington.)
Hoggarth, D.D.; Abeyasekera, S.; Arthur, R.I.; Beddington, J.R.; Burn, R.W.; Halls, A.S.; Kirkwood, G.P.; McAllister, M.; Medley, P.; Mees, C.C.; Parkes, G.B.; Pilling, G.M.; Wakeford, R.C.; Welcomme, R.L. (2006). Stock assessment for fishery management – A framework guide to the stock assessment tools of the Fisheries Management Science Programme (FMSP). *FAO Fisheries Technical Paper.* No. 487. Rome, FAO. 2006. 261 p.
Langley, A.D. (2017). Fishery characterisation and Catch-Per-Unit-Effort indices for tarakihi in TAR 1, TAR 2 and TAR 3. *New Zealand Fisheries Assessment Report 2017/44.* 122 p.
Langley, A.D. (2018). Stock assessment of tarakihi off the east coast of mainland New Zealand. *New Zealand Fisheries Assessment Report 2018/05*. 85 p.
MacGibbon, D.J.; Beentjes, M.P.; Lyon, W.L.; Ladroit, Y. (2019). Inshore trawl survey of Canterbury Bight and Pegasus Bay, April–June 2018 (KAH1803). *New Zealand Fisheries Assessment Report 2019/03*. 136 p.
Methot, R.D.; Wetzel, C.R. (2013). Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. *Fisheries Research 142:* 86–99.
Ministry of Fisheries (2008). Harvest Strategy Standard for New Zealand Fisheries. October 2008. http://fs.fish.govt.nz/Doc/16543/harveststrategyfinal.pdf.ashx.
Ministry of Fisheries (2011). Operational Guidelines for New Zealand's Harvest Strategy Standard, Revision 1. June 2011. https://fs.fish.govt.nz/Doc/22847/Operational_Guidelines_for_HSS_rev_1_Jun_2011.pdf.ashx.

APPENDIX 1 MODEL CATCH HISTORY

Table A1: Annual tarakihi catch (t) by fishery and total included in the stock assessment model.

Year	Fishery								Total
	TAR3-BT	TAR3-SN	Cook-BT	TAR2-BT	TAR2-Rec	BPLE-BT	BPLE-Rec	ENLD-BT	
1975	2 296	0	498	1 769	0	426	0	231	5 220
1976	1 327	0	449	1 643	0	260	0	327	4 006
1977	2 312	0	590	1 384	0	385	0	231	4 902
1978	1 978	0	744	1 649	0	600	0	205	5 176
1979	448	0	559	1 502	0	797	0	347	3 653
1980	816	43	500	1 150	0	735	0	503	3 746
1981	1 186	132	504	1 164	71	805	97	603	4 561
1982	1 266	223	394	1 213	71	594	97	553	4 411
1983	915	229	216	1 316	71	743	97	433	4 020
1984	866	216	362	979	71	730	97	554	3 877
1985	1 232	308	384	971	71	615	97	448	4 125
1986	1 101	275	486	1 096	71	670	97	406	4 202
1987	771	225	416	1 514	71	507	97	373	3 974
1988	853	246	416	1 519	71	607	97	446	4 256
1989	598	182	416	1 550	71	522	97	384	3 821
1990	770	237	322	1 400	71	416	97	379	3 692
1991	625	339	384	1 804	71	627	97	368	4 315
1992	714	378	452	1 675	71	803	97	475	4 667
1993	356	337	445	1 713	71	855	97	349	4 224
1994	462	223	355	1 651	71	821	97	424	4 103
1995	376	275	581	1 612	71	715	97	395	4 122
1996	660	342	531	1 590	71	682	97	394	4 368
1997	786	263	449	1 727	71	574	97	489	4 455
1998	746	272	406	1 776	71	613	97	500	4 481
1999	843	216	519	1 674	71	586	97	429	4 434
2000	1 022	238	495	1 839	71	467	97	467	4 696
2001	745	297	777	1 731	71	682	97	379	4 779
2002	688	336	779	1 821	71	791	97	335	4 918
2003	732	288	545	1 809	71	870	97	244	4 656
2004	722	275	533	1 716	71	935	97	247	4 596
2005	642	131	492	1 760	71	763	97	402	4 358
2006	683	183	473	2 090	71	626	97	399	4 621
2007	827	155	443	1 814	71	502	97	286	4 195
2008	613	175	374	1 743	71	552	97	247	3 872
2009	752	185	429	1 970	71	742	97	268	4 514
2010	399	129	611	1 916	71	781	97	224	4 228
2011	964	135	464	1 742	71	747	97	236	4 455
2012	585	190	578	1 721	71	607	97	213	4 062
2013	730	173	611	1 907	71	538	97	186	4 314
2014	770	108	578	1 829	71	416	97	414	4 284
2015	903	106	628	1 939	71	421	97	417	4 583
2016	975	152	641	1 811	71	350	97	348	4 445
2017	1 116	157	584	1 993	71	484	97	405	4 907
2018	745	208	695	1 909	71	454	97	370	4 549

APPENDIX 2 CPUE INDICES

Table A2: Standardised CPUE indices included in the stock assessment model.

Year	TAR3-BT	TAR3-SN	TAR2BPLE-BT	ENLD-BT
1990	1.080	1.283	0.838	
1991	1.213	1.248	0.747	
1992	1.299	1.394	0.761	
1993	0.793	1.107	0.813	
1994	0.815	0.767	0.806	1.309
1995	0.939	1.202	0.864	0.821
1996	1.179	1.047	0.944	1.370
1997	1.131	1.041	1.086	1.459
1998	1.160	1.072	0.995	1.155
1999	0.922	1.069	1.253	1.006
2000	1.564	0.912	1.318	0.848
2001	1.208	1.030	1.455	0.926
2002	1.126	1.511	1.931	1.160
2003	0.886	1.262	1.695	1.110
2004	0.706	1.092	1.562	1.073
2005	0.707	0.929	1.116	1.458
2006	0.797	0.942	0.858	1.130
2007	0.982	0.752	0.739	0.849
2008	0.869	0.759	0.760	0.982
2009	0.753	0.939	0.867	1.147
2010	0.656	0.829	0.929	0.990
2011	0.994	0.784	0.728	0.893
2012	0.768	1.114	0.716	0.777
2013	0.869	0.808	0.843	0.856
2014	1.033	0.749	0.745	0.709
2015	1.156	0.682	0.882	0.663
2016	1.110	0.840	0.866	0.714
2017	1.284	0.839	1.097	0.596
2018	1.038	1.037	0.966	0.401

APPENDIX 3 FORWARD PROJECTIONS

Table A3a: Summary of the results of the forward projections. Part 1.

Model year	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Projection year		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Total catch (model)																				
catch 50%	4 549	3 727	1 949	1 949	1 949	1 949	1 949	1 949	1 949	1 949	1 949	1 949	1 949	1 949	1 949	1 949	1 949	1 949	1 949	1 949
catch 60%	4 549	3 727	2 304	2 304	2 304	2 304	2 304	2 304	2 304	2 304	2 304	2 304	2 304	2 304	2 304	2 304	2 304	2 304	2 304	2 304
catch 70%	4 549	3 727	2 659	2 659	2 659	2 659	2 659	2 659	2 659	2 659	2 659	2 659	2 659	2 659	2 659	2 659	2 659	2 659	2 659	2 659
catch 80%	4 549	3 727	3 017	3 017	3 017	3 017	3 017	3 017	3 017	3 017	3 017	3 017	3 017	3 017	3 017	3 017	3 017	3 017	3 017	3 017
catch 90%	4 549	3 727	3 373	3 373	3 373	3 373	3 373	3 373	3 373	3 373	3 373	3 373	3 373	3 373	3 373	3 373	3 373	3 373	3 373	3 373
catch 100%	4 549	3 727	3 727	3 727	3 727	3 727	3 727	3 727	3 727	3 727	3 727	3 727	3 727	3 727	3 727	3 727	3 727	3 727	3 727	3 727
Pr(SByr > 40% SB_0)																				
catch 50%	0.000	0.000	0.000	0.000	0.006	0.051	0.095	0.215	0.309	0.417	0.507	0.594	0.653	0.718	0.766	0.824	0.860	0.886	0.908	0.926
catch 60%	0.000	0.000	0.000	0.000	0.004	0.038	0.063	0.139	0.218	0.308	0.378	0.452	0.529	0.588	0.635	0.675	0.723	0.766	0.816	0.839
catch 70%	0.000	0.000	0.000	0.000	0.004	0.024	0.035	0.088	0.151	0.201	0.268	0.322	0.379	0.433	0.489	0.534	0.582	0.614	0.668	0.688
catch 80%	0.000	0.000	0.000	0.000	0.002	0.015	0.027	0.053	0.097	0.142	0.190	0.229	0.256	0.296	0.339	0.380	0.431	0.460	0.490	0.528
catch 90%	0.000	0.000	0.000	0.000	0.002	0.011	0.017	0.036	0.064	0.093	0.125	0.156	0.177	0.201	0.224	0.258	0.277	0.306	0.328	0.343
catch 100%	0.000	0.000	0.000	0.000	0.000	0.009	0.009	0.019	0.037	0.065	0.081	0.101	0.119	0.129	0.138	0.154	0.169	0.195	0.218	0.245
Pr(SByr > 35% SB_0)																				
catch 50%	0.000	0.000	0.000	0.006	0.037	0.163	0.265	0.396	0.529	0.617	0.700	0.758	0.817	0.860	0.895	0.920	0.948	0.961	0.973	0.980
catch 60%	0.000	0.000	0.000	0.003	0.027	0.106	0.184	0.296	0.405	0.487	0.580	0.654	0.695	0.750	0.797	0.832	0.872	0.889	0.908	0.930
catch 70%	0.000	0.000	0.000	0.001	0.015	0.072	0.114	0.219	0.288	0.377	0.438	0.515	0.570	0.615	0.656	0.694	0.737	0.776	0.814	0.842
catch 80%	0.000	0.000	0.000	0.000	0.012	0.048	0.081	0.139	0.201	0.271	0.323	0.362	0.412	0.462	0.508	0.544	0.586	0.612	0.657	0.677
catch 90%	0.000	0.000	0.000	0.000	0.007	0.033	0.042	0.092	0.136	0.174	0.230	0.259	0.288	0.313	0.348	0.394	0.428	0.454	0.483	0.510
catch 100%	0.000	0.000	0.000	0.000	0.005	0.021	0.031	0.054	0.090	0.123	0.153	0.174	0.193	0.219	0.235	0.261	0.272	0.288	0.311	0.330
Pr(SByr > 20% SB_0)																				
catch 50%	0.049	0.074	0.307	0.728	0.876	0.949	0.976	0.982	0.984	0.990	0.991	0.995	0.998	0.998	0.998	0.999	0.999	0.999	0.999	1.000
catch 60%	0.049	0.074	0.275	0.666	0.812	0.902	0.940	0.953	0.963	0.976	0.985	0.987	0.991	0.992	0.996	0.997	0.998	0.998	0.997	0.999
catch 70%	0.049	0.074	0.243	0.567	0.723	0.833	0.887	0.910	0.919	0.930	0.940	0.953	0.968	0.970	0.977	0.983	0.989	0.991	0.993	0.994
catch 80%	0.049	0.074	0.213	0.476	0.623	0.725	0.788	0.809	0.836	0.858	0.876	0.885	0.903	0.919	0.939	0.944	0.953	0.957	0.962	0.973
catch 90%	0.049	0.074	0.177	0.395	0.500	0.616	0.665	0.691	0.717	0.731	0.760	0.779	0.791	0.815	0.840	0.852	0.871	0.874	0.886	0.896
catch 100%	0.049	0.074	0.133	0.318	0.411	0.493	0.520	0.553	0.581	0.601	0.624	0.639	0.658	0.677	0.684	0.697	0.717	0.721	0.749	0.761

Model year	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Projection year		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Pr(SByr > 10% SB_0)																				
catch 50%	0.991	0.983	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
catch 60%	0.991	0.983	0.994	0.999	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
catch 70%	0.991	0.983	0.990	0.998	0.999	0.999	0.999	0.999	0.998	0.999	0.999	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.999	0.999
catch 80%	0.991	0.983	0.988	0.998	0.997	0.997	0.997	0.994	0.995	0.993	0.991	0.992	0.992	0.995	0.996	0.996	0.997	0.998	0.997	0.997
catch 90%	0.991	0.983	0.983	0.996	0.996	0.995	0.990	0.982	0.976	0.977	0.978	0.979	0.982	0.978	0.979	0.977	0.979	0.981	0.983	0.984
catch 100%	0.991	0.983	0.978	0.991	0.987	0.980	0.969	0.952	0.948	0.937	0.931	0.933	0.928	0.927	0.929	0.925	0.924	0.923	0.924	0.925
Median SByr/SB_0																				
catch 50%	0.158	0.160	0.183	0.223	0.252	0.283	0.307	0.331	0.353	0.378	0.402	0.424	0.445	0.463	0.482	0.498	0.517	0.527	0.542	0.559
catch 60%	0.158	0.160	0.179	0.214	0.239	0.266	0.287	0.307	0.327	0.348	0.369	0.389	0.407	0.423	0.441	0.456	0.473	0.482	0.496	0.510
catch 70%	0.158	0.160	0.175	0.206	0.226	0.250	0.266	0.283	0.300	0.317	0.336	0.353	0.370	0.383	0.398	0.412	0.426	0.435	0.446	0.460
catch 80%	0.158	0.160	0.171	0.198	0.213	0.233	0.245	0.259	0.272	0.286	0.302	0.315	0.329	0.341	0.352	0.365	0.377	0.386	0.396	0.409
catch 90%	0.158	0.160	0.168	0.189	0.200	0.216	0.224	0.233	0.245	0.256	0.268	0.276	0.288	0.297	0.304	0.315	0.326	0.334	0.343	0.354
catch 100%	0.158	0.160	0.164	0.181	0.188	0.199	0.203	0.208	0.216	0.224	0.231	0.237	0.246	0.250	0.255	0.264	0.274	0.278	0.288	0.296

Table A3a: Summary of the results of the forward projections. Part 2.

Model year	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048
Projection year	20	21	22	23	24	25	26	27	28	29	30
Total catch (model)											
catch 50%	1 949	1 949	1 949	1 949	1 949	1 949	1 949	1 949	1 949	1 949	1 949
catch 60%	2 304	2 304	2 304	2 304	2 304	2 304	2 304	2 304	2 304	2 304	2 304
catch 70%	2 659	2 659	2 659	2 659	2 659	2 659	2 659	2 659	2 659	2 659	2 659
catch 80%	3 017	3 017	3 017	3 017	3 017	3 017	3 017	3 017	3 017	3 017	3 017
catch 90%	3 373	3 373	3 373	3 373	3 373	3 373	3 373	3 373	3 373	3 373	3 373
catch 100%	3 727	3 727	3 727	3 727	3 727	3 727	3 727	3 727	3 727	3 727	3 727
Pr(SByr > 40% SB_0)											
catch 50%	0.948	0.961	0.973	0.973	0.976	0.979	0.984	0.990	0.990	0.990	0.993
catch 60%	0.864	0.881	0.907	0.927	0.939	0.947	0.950	0.961	0.964	0.970	0.975
catch 70%	0.743	0.771	0.794	0.816	0.823	0.848	0.864	0.873	0.890	0.896	0.903
catch 80%	0.552	0.580	0.623	0.641	0.667	0.685	0.701	0.712	0.729	0.753	0.770
catch 90%	0.374	0.388	0.420	0.465	0.488	0.506	0.515	0.537	0.560	0.565	0.587
catch 100%	0.255	0.273	0.280	0.299	0.329	0.346	0.354	0.375	0.401	0.413	0.422
Pr(SByr > 35% SB_0)											
catch 50%	0.988	0.990	0.995	0.993	0.995	0.993	0.994	0.994	0.995	0.997	0.999
catch 60%	0.949	0.960	0.970	0.975	0.975	0.979	0.983	0.989	0.989	0.989	0.992
catch 70%	0.859	0.880	0.897	0.915	0.934	0.940	0.945	0.953	0.957	0.961	0.969
catch 80%	0.719	0.754	0.776	0.792	0.809	0.818	0.838	0.851	0.864	0.876	0.879
catch 90%	0.531	0.549	0.590	0.609	0.627	0.637	0.664	0.679	0.693	0.709	0.723
catch 100%	0.356	0.366	0.388	0.430	0.456	0.462	0.475	0.511	0.524	0.528	0.545
Pr(SByr > 20% SB_0)											
catch 50%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
catch 60%	0.999	0.999	0.999	0.999	0.999	1.000	1.000	0.999	1.000	1.000	1.000
catch 70%	0.996	0.996	0.996	0.996	0.997	0.997	0.997	0.996	0.997	0.997	0.999
catch 80%	0.976	0.980	0.986	0.989	0.987	0.987	0.990	0.990	0.990	0.993	0.996
catch 90%	0.906	0.918	0.930	0.938	0.949	0.949	0.951	0.946	0.958	0.959	0.962
catch 100%	0.784	0.799	0.806	0.815	0.824	0.829	0.843	0.855	0.857	0.864	0.874
Pr(SByr > 10% SB_0)											
catch 50%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
catch 60%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
catch 70%	0.999	0.999	0.999	0.999	0.999	0.999	1.000	1.000	1.000	1.000	1.000
catch 80%	0.997	0.997	0.995	0.997	0.998	0.997	0.998	0.997	0.998	0.999	1.000
catch 90%	0.987	0.990	0.987	0.986	0.988	0.989	0.989	0.988	0.988	0.990	0.990
catch 100%	0.935	0.943	0.945	0.947	0.948	0.949	0.953	0.956	0.961	0.958	0.957
Median SByr/SB_0											
catch 50%	0.569	0.576	0.592	0.608	0.617	0.622	0.629	0.642	0.650	0.656	0.664
catch 60%	0.520	0.526	0.542	0.558	0.567	0.571	0.578	0.590	0.601	0.604	0.611
catch 70%	0.469	0.476	0.490	0.506	0.514	0.519	0.525	0.537	0.546	0.549	0.556
catch 80%	0.415	0.422	0.433	0.449	0.457	0.464	0.468	0.480	0.486	0.489	0.498
catch 90%	0.360	0.365	0.375	0.388	0.396	0.402	0.406	0.416	0.420	0.425	0.433
catch 100%	0.298	0.304	0.313	0.322	0.334	0.336	0.342	0.352	0.359	0.364	0.369

APPENDIX 4 PRELIMINARY EVALUATION OF POTENTIAL REFERENCE POINTS

The Fisheries New Zealand Harvest Strategy Standard (HSS) specifies a default target biomass level for Fishstocks based on the productivity of the species (Ministry of Fisheries 2008 and 2011). Within the HSS framework, tarakihi is defined as a low productivity stock and the corresponding default target biomass level is 40% of unexploited spawning biomass (SB_0). A key criterion for defining an appropriate target biomass level is to minimise the risk of the stock declining below a threshold level that may affect the productivity of the stock, by default this threshold level has been established as the "soft limit" of 20% SB_0 (Caddy & Mahon 1995, Ministry of Fisheries 2008 and 2011).

A simulation analysis was conducted to investigate the performance of alternative target biomass levels for the eastern tarakihi stock, following a similar approach used by Francis & Mace (2005) and Haist (2014). The target biomass was evaluated within the configuration of a Harvest Control Rule (HCR) and the associated Management Procedures (MP) (Hoggarth et al. 2006, Geromont & Butterworth 2015).

Simulation framework

The simulation analysis was implemented in the *R* software environment. The stock dynamics of the base Stock Synthesis assessment model (updated in 2018) were replicated in the customised *R* code. The simulator was initialised with the population age structure (numbers-at-age) from the terminal year of the stock assessment model (end of 2017) and conducted a forward projection of the population, incorporating the key parameters from the assessment model (primarily selectivity parameters) to extract fishery specific catches. Each iteration of the simulator utilised the outputs (numbers-at-age and parameter estimates) from an individual MCMC draw from the assessment model. For each MP scenario evaluated, 1000 iterations of the forward projection were conducted (corresponding to the 1000 MCMC samples).

Annual recruitments in the projection period were modelled using three different approaches: 1) individual recruitment deviates were resampled from the last 20 years of the assessment model and applied to the SRR (steepness h = 0.9 and R_0 parameter values); 2) individual recruitment deviates were sampled from the assumed distribution of recruitment deviates in the assessment model (*sigmaR* = 0.6) and applied to the SRR; or 3) numbers of recruits were resampled from the last 20 years of the assessment model.

A preliminary set of simulations was also conducted that included autocorrelation in recruitment, as well as simulations incorporating uncertainty in both the natural mortality and SRR steepness parameters.

The forward projections were conducted for a 200 year period. The long evaluation period enabled sufficient time for the model biomass to stabilise at a level that corresponded to the specific HCR being evaluated. Annual catches in the projection period were based on the fishery specific catches that were included in the assessment model for 2017 (termed *CatchBase*, representing a total catch of 4442 t). The annual catches in the first year of the projection (2018) were set at the *CatchBase* level. Annual catches in the five subsequent years (2019–2022) were held constant at 75% of *CatchBase* to replicate the level of catches required to initiate the rebuilding of the stock (from 0.16% SB_0 in 2017).

Catches during the remainder of the projection period were determined based on the specific Harvest Control Rule (HCR) included in the Management Procedure (MP). The set of HCRs that were evaluated all had the same generic structure, with the total annual catch determined based on the status of the stock relative to the target biomass level (expressed as a proportion of SB_0) (Figure A1). The general structure of the HCR maintains catches at a constant (specified) level when the stock is close to the specified target biomass level (target biomass ± 0.05 threshold) and reduces catches when the stock is below the target biomass range. Annual catches are set to zero when the biomass is below the hard limit (10% SB_0). When the biomass is above the upper threshold of the target biomass (target biomass + 0.05), the HCR increases catches above the specified base level in a linear manner (Figure A1).

The set of HCRs evaluated included seven base levels of catch that were multiples of the *CatchBase* (catch scalars of 70%, 80%, 90%, 100%, 110%, 120% and 130%) at three alternate levels of target biomass (30%, 35% and 40% SB_0) (Figure A1). The base level of catch for each HCR was the catch taken when the stock was at the respective target.

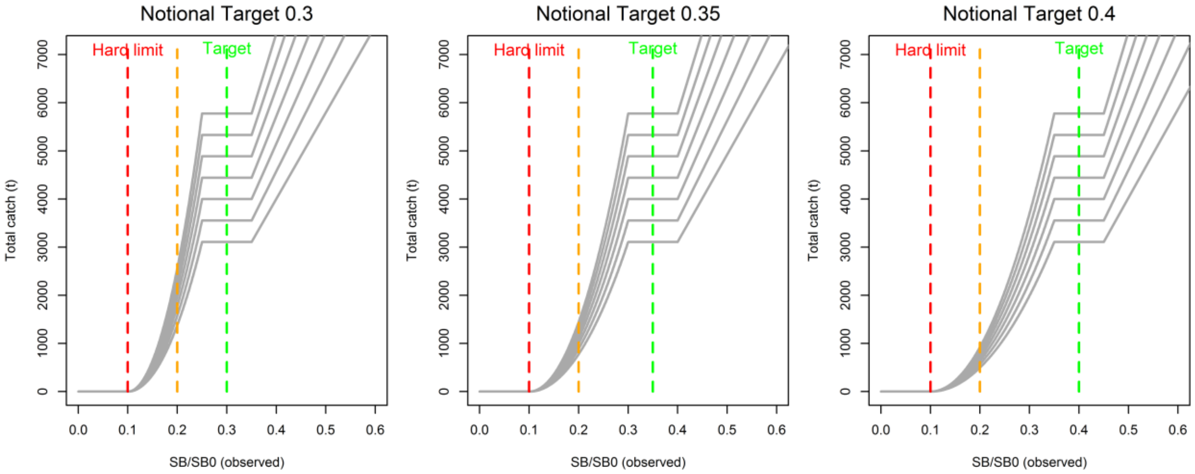

Figure A1. The range of harvest control rules included in the management procedure evaluation. The grey lines represent the total level of catch associated with multiples of the base level of catch (catch scalars of 70%, 80%, 90%, 100%, 110%, 120% and 130%) for three alternate levels of notional target biomass (30%, 35% and 40% SB_0).

For each projection, the status of the stock was determined at 5-year intervals, approximating the current time frame for conducting full stock assessments of the eastern tarakihi stock. Stock status ($SBratio_{year}$) was simply determined as $SB_{year}/SB_0 + Error$. The *Error* component was assumed to be normally distributed with a coefficient of variation of 20%. The magnitude of the error was based on the precision of the estimate of the stock status in the terminal year of the stock assessment (CV 15%).

The $SBratio_{year}$ was applied to the specific HCR to determine the corresponding level of catch ($CatchMP_{year}$). This was the basis for determining the level of annual catches in the subsequent 5-year period (until the next assessment). However, if the difference in the resultant level of catch ($CatchMP_{year}$) was less than 10% of the current level of catch ($Catch_{year}$) there was no change in the annual catches implemented for the subsequent period. Further, the maximum change in catch that was implemented (for the next 5 years) was limited to ± 20% of the current level of catch.

Each HCR was evaluated using the set of 1000 MCMC samples. Performance metrics were determined for the projection period, following the exclusion of the first 25 years which included the initial rebuild period. The primary performance metrics were:

i. The proportion of years the biomass is below the 20% SB_0 soft limit (all years, all simulations combined) (*RiskSB20*).
ii. The proportion of years the biomass is below the 10% SB_0 soft limit (all years, all simulations combined) (*RiskSB10*).
iii. The median spawning biomass (% SB_0) during the projection period.
iv. The average annual catch during the projection period.
v. The standard deviation of the annual catches during the projection period.

The performance of individual HCRs was assessed based on the risk criteria specified in the HSS (Ministry of Fisheries 2008). The risk criteria are defined as *"the probability of breaching the soft limit (20% SB_0) does not exceed 10% and the probability of breaching the hard limit (10% SB_0) does not exceed 2%*" (criterion 1) ***or*** *"no more than a 5% probability of breaching the soft limit"* (criterion 2) (Ministry of Fisheries 2008).

Standardised CPUE indices from four main fisheries represent a key input in the eastern tarakihi stock assessment. These are primarily derived from target fisheries and there is potential for the CPUE indices to deviate from the assumed proportional relationship with stock abundance. A set of simulations were conducted that assumed a degree of hyperstability in the estimates of stock status, representing a proxy for the CPUE indices. This was implemented by including the power term (X) in the determination of the current stock status; i.e. $SBratio_{year} = (SB_{year}/SB_0)^X + Error$ where X = 0.9. This introduced a 10–15% positive bias in the estimate of stock status at 25–40% SB_0.

Additional simulations were conducted that incorporated an additional source of assessment bias that was auto correlated with periodic shifts in the magnitude of the bias. This was implemented following Haist (2014).

Results

Initial simulations revealed that there was no appreciable difference in the performance of the MPs for the three different formulations of recruitment during the projection period. The final set of simulations used the first recruitment option; i.e. SRR with resampled recruitment deviates from the last 20 years of the assessment.

The base set of simulations revealed that the overall level of biomass during the projection period was more strongly influenced by the catch scalar (and hence magnitude of the catch) than the notional target biomass. For example, for the HCR scenarios with a notional target biomass of 35% SB_0, the median level of biomass ranged from 41.5% SB_0 for a 70% catch scalar to 28.5% SB_0 for a 130% catch scalar (Table A4 and Figure A2) . The scenario that realised a level of biomass equivalent to the notional target of 35% SB_0 was the HCR with the 90% catch scalar (35.2% SB_0). This scenario produced the level of catch that corresponded to the level of equilibrium yield at the specific target biomass (Table A4).

The range of catch based HCRs were adopted in this study as they more explicitly represent the TACC based management regime. The mismatches between the notional target biomass and the realised level of biomass for individual HCR scenarios is not an indication of a failure of the HCR per se. Rather, it is a consequence of using a catch based HCR which will be less flexible than a fishing mortality based HCR. However, it does indicate that the catch-based HCRs do need to be “tuned” if they are required to achieve the notional target biomass level.

For the sets of HCRs with the notional target of 35% SB_0, the HCRs with catch scalars of 70–100% met both risk criteria, while a catch scalar of 110% violated risk criterion 1 ($Risk20$ < 10 % and $Risk10$ < 2%) but not risk criterion 2 ($Risk20$ > 5%) (Table A4 and Figure A2). Catch scalars of 120% and 130% failed to meet either one or both of the risk criteria. The realised level of average annual catch was very similar for the 90–130% range of catch scalars, although annual catches were considerably more variable at the upper range. Somewhat less variable and lower average annual catches were achieved for 70% and 80% catch scalars (Table A4 and Figure A2).

The sets of HCRs with the lower notional target of 30% SB_0 had a higher probability of breaching the risk criteria compared to the HCRs with the notional target of 35% SB_0 and the corresponding catch scalar scenarios and, while the overall levels of average catch were similar, the catches were more variable (for 30% SB_0). Conversely, the sets of HCRs with the higher notional target of 40% SB_0 had a lower probability of breaching the risk criteria compared to the corresponding catch scalar scenarios for the notional target of 35% SB_0, while overall levels of average catch were slightly lower and less variable (Table A4 and Figure A2).

For the overall set of HCRs, four scenarios met the risk criteria and yielded higher average annual catches (of about 3850 t), specifically: notional target biomass 30% SB_0 and catch scalar 80%, notional target biomass 35% SB_0 and catch scalars of 90% or 100%, and notional target biomass 40% SB_0 and catch scalar 110%. Each of these scenarios realised a median biomass level of about 35% SB_0 suggesting that maintaining the stock at that level of biomass (i.e. 35% SB_0) represents a reasonable trade-off between yield and risk. Of these four scenarios, annual catches were the least variable for the HCR with a notional target biomass 35% SB_0 and a catch scalar of 90% (Table A4 and Figure A2).

Table A4. Performance metrics from the 1000 iterations of each Management Procedure evaluated in the base set of simulations. The individual HCRs are characterised by the Notional Target % SB_0 and the catch scalar. The performance metrics include the median biomass level (SB/SB_0 %), the probability of being below 20% SB_0 (*Risk20*) and 10% SB_0 (*Risk10*) and the average annual catch and associated standard deviation. MPs that breach risk criterion 1 are highlighted in red, MPs that breach risk criterion 2 are highlighted in orange.

MP criteria		Performance metrics				
Notional target	Catch scalar (%)	SB/SB_0	*Risk20*	*Risk10*	Catch (t)	
					Mean	St.dev
30%	70%	38.1%	0.7%	0.0%	3 699	695
30%	80%	34.4%	2.3%	0.4%	3 840	759
30%	90%	31.4%	5.7%	0.7%	3 932	837
30%	100%	28.8%	**12.4%**	1.6%	3 976	1 021
30%	110%	26.6%	**21.2%**	**4.6%**	3 921	1 337
30%	120%	24.9%	**29.5%**	**8.2%**	3 820	1 654
30%	130%	23.0%	**38.4%**	**14.9%**	3 614	2 020
35%	70%	41.5%	0.3%	0.1%	3 533	677
35%	80%	38.1%	0.6%	0.0%	3 699	694
35%	90%	35.2%	1.7%	0.1%	3 814	758
35%	100%	32.8%	4.3%	0.4%	3 889	870
35%	110%	31.1%	8.0%	0.8%	3 934	987
35%	120%	29.8%	**13.0%**	1.9%	3 933	1 172
35%	130%	28.5%	**18.1%**	**4.2%**	3 882	1 389
40%	70%	44.7%	0.0%	0.0%	3 368	647
40%	80%	41.4%	0.2%	0.0%	3 537	680
40%	90%	38.7%	0.4%	0.0%	3 666	734
40%	100%	36.7%	1.3%	0.2%	3 751	821
40%	110%	35.0%	3.0%	0.3%	3 813	902
40%	120%	33.8%	5.3%	0.5%	3 853	991
40%	130%	32.7%	8.1%	1.2%	3 857	1 112

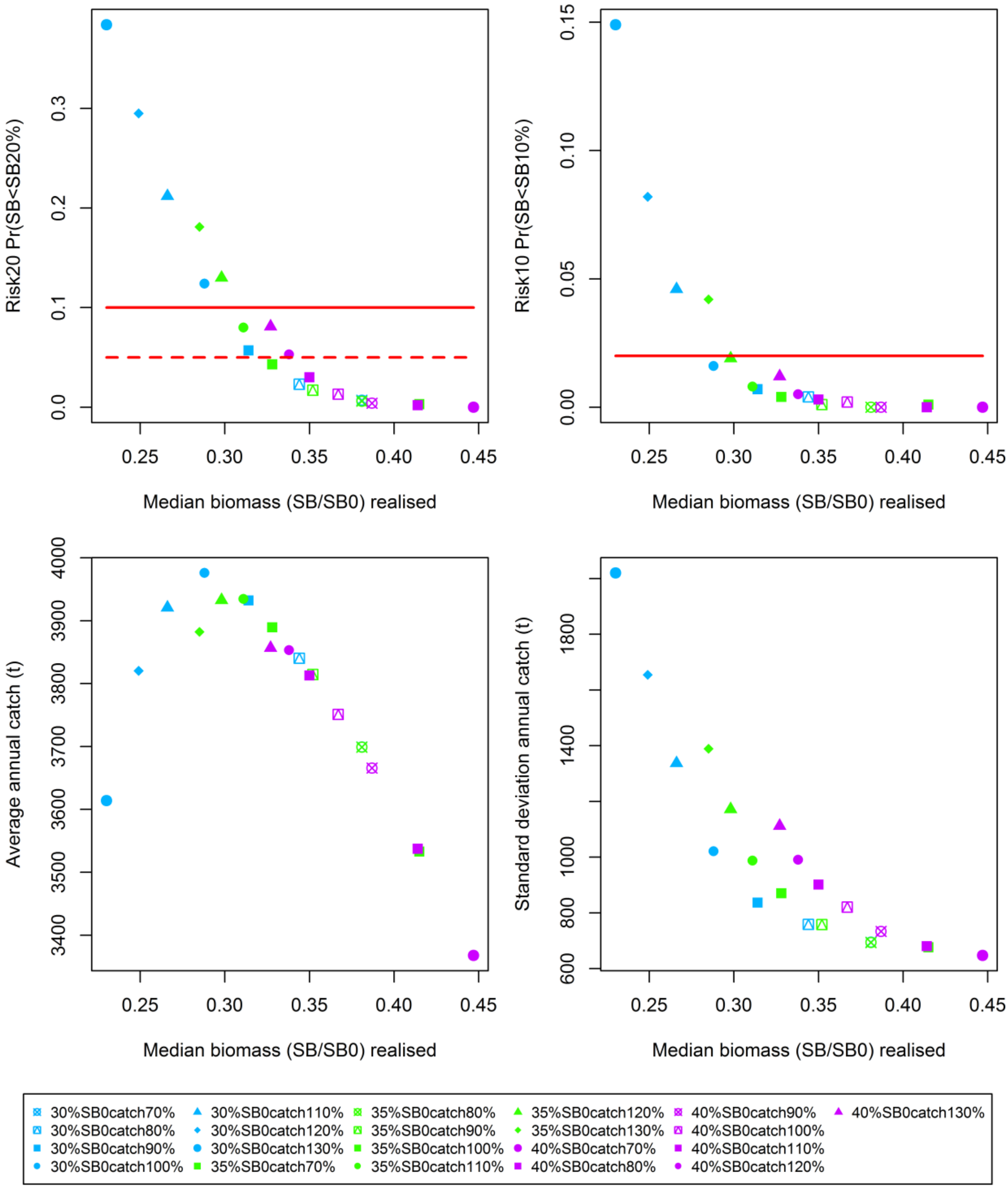

Figure A2: Performance metrics relative to the realised level of biomass (*SB/SB₀*) from the 1000 iterations of each Management Procedure evaluated in the base set of simulations. The individual HCRs are characterised by the Notional Target % *SB₀* (colours) and the catch scalar (symbols). The risk criteria associated with the probability of breaching the soft limit (top left panel) and hard limit (top right panel) are specified by the horizontal red lines.

Additional simulations were conducted with additional autocorrelation in assessment bias (Table A5) and hyperstability in the CPUE proxy for the assessment (Table A6). Including autocorrelation in assessment bias resulted in a marginal increase in the risk metrics, without appreciably changing the overall risk profile of the range of HCRs evaluated (relative to the base simulations). However, there was an increase in the variability of the annual catches, while the average levels of catch remained similar to the levels from the base simulations (Table A5).

The introduction of hyperstability in the CPUE proxy also increased the level of risk relative to the base simulations (Table A6). The impact was most pronounced for the set of HCRs with the 30% SB_0 notional target biomass level and extended the risk profile to include a lower tier of catch scalars. The variation in annual catches also tended to increase for the lower target biomass options due to the increase in the frequency of the hard limit being breached (resulting in catches being set to zero).

An additional set of simulations was conducted that incorporated autocorrelation (*Rho* = 0.60) in the recruitment deviates. This option resulted in a small increase in *Risk20* for HCRs scenarios with lower levels of target biomass (30% and 35% SB_0) and higher catch levels (110%, 120% and 130% scalars). However, there was no evidence of strong autocorrelation in the estimated recruitment deviates from the stock assessment model ($Recdev_{year+1} = 0.045 * Recdev_{year}$) and, hence, autocorrelation was not incorporated in the final set of simulations.

In addition, incorporating uncertainty in the natural mortality Normal(mean = 0.1, sd=0.025) and SRR steepness h Uniform(0.75, 1.00) parameters in the assessment model did not appreciably change the risk profile of the range of HCRs evaluated.

Summary

The simulator incorporates the generalised population dynamics and fishery dynamics of the assessment model and provides the platform to evaluate a range of alternative management options. The HCRs and associated management procedures are an attempt to codify the management response at different levels of stock biomass relative to the target biomass level. The basic structure of the HCRs is considered to be appropriate from a technical perspective for the purpose of evaluating alternative target biomass levels. The results of the evaluation of alternative HCRs are intended to assist managers in the formulation of an appropriate level of target biomass for the eastern tarakihi stock.

The current study indicates that a target biomass level of about 35% SB_0 is sufficiently high to minimise the risk of breaching the soft and hard limits, while maintaining catches at a relatively high level. This is somewhat lower than the current default target biomass level of 40% SB_0. These results are predicated on the presumptions regarding the management procedures and the HCRs adopted for the simulations.

The actual management procedure and HCR have not been prescribed for the eastern tarakihi stock. The management strategy for the stock needs to be developed within the framework of a management plan, formulated by fisheries managers in conjunction with the commercial, recreational and customary fishing sectors. The magnitude of the appropriate target biomass will be dependent on key elements of the management strategy, including the proportional distribution of catch amongst fisheries, the frequency of stock assessment process, the accuracy of the assessment and the nature of the management response. To date, there has been limited input from managers into the formulation of the range of HCRs that might be considered appropriate for the management of the tarakihi fishery.

Table A5: Performance metrics from the 1000 iterations of each Management Procedure evaluated in the set of simulations that included autocorrelation in the assessment error. The individual HCRs are characterised by the Notional Target % SB_0 and the catch scalar. The performance metrics include the median biomass level (SB/SB_0 %), the probability of being below 20% SB_0 (*Risk20*) and 10% SB_0 (*Risk10*) and the average annual catch and associated standard deviation. MPs that breach risk criterion 1 are highlighted in red, MPs that breach risk criterion 2 are highlighted in orange.

MP criteria		Performance metrics				
Notional target	Catch scalar (%)	SB/SB_0	Risk20	Risk10	Catch (t)	
					Mean	St.dev
30%	70%	38.1%	1.1%	0.3%	3 682	766
30%	80%	34.6%	3.1%	0.4%	3 825	802
30%	90%	31.6%	7.7%	1.7%	3 887	977
30%	100%	29.0%	**14.2%**	**2.8%**	3 905	1 190
30%	110%	26.9%	**22.6%**	**5.9%**	3 845	1 470
30%	120%	24.6%	**33.5%**	**13.8%**	3 590	1 913
30%	130%	22.4%	**41.9%**	**20.2%**	3 380	2 203
35%	70%	41.6%	0.5%	0.1%	3 522	723
35%	80%	38.2%	1.2%	0.2%	3 683	761
35%	90%	35.4%	2.8%	0.5%	3 780	851
35%	100%	33.2%	5.6%	0.8%	3 851	961
35%	110%	31.3%	**10.1%**	1.8%	3 872	1,134
35%	120%	29.9%	**15.2%**	**3.8%**	3 840	1,338
35%	130%	28.6%	**21.1%**	**7.2%**	3 738	1,600
40%	70%	44.9%	0.2%	0.0%	3 361	698
40%	80%	41.8%	0.5%	0.1%	3 514	738
40%	90%	39.1%	0.0%	0.2%	3 636	807
40%	100%	37.1%	2.1%	0.2%	3 727	870
40%	110%	35.4%	4.3%	0.7%	3 770	992
40%	120%	33.9%	7.0%	1.4%	3 794	1 122
40%	130%	33.0%	**10.4%**	**2.8%**	3 758	1 281

Table A6: Performance metrics from the 1000 iterations of each Management Procedure evaluated in the set of simulations that <u>included hyperstability in the CPUE proxy</u>. The individual HCRs are characterised by the Notional Target % SB_0 and the catch scalar. The performance metrics include the median biomass level (SB/SB_0 %), the probability of being below 20% SB_0 (*Risk20*) and 10% SB_0 (*Risk10*) and the average annual catch and associated standard deviation. MPs that breach risk criterion 1 are highlighted in red, MPs that breach risk criterion 2 are highlighted in orange.

MP criteria		Performance metrics				
Notional target	Catch scalar (%)	SB/SB_0	Risk20	Risk10	Catch (t)	
					Mean	St.dev
30%	70%	35.3%	1.7%	0.1%	3 809	717
30%	80%	31.6%	5.4%	0.6%	3 941	766
30%	90%	28.2%	**12.3%**	1.0%	4 023	848
30%	100%	25.6%	**23.4%**	**2.8%**	4 026	1 057
30%	110%	23.1%	**35.8%**	**8.3%**	3 882	1 448
30%	120%	20.7%	**47.2%**	**17.0%**	3 628	1 876
30%	130%	17.0%	**59.8%**	**32.2%**	3 064	2 310
35%	70%	38.9%	0.5%	0.0%	3 659	675
35%	80%	35.3%	1.7%	0.1%	3 813	703
35%	90%	32.2%	4.2%	0.2%	3 929	745
35%	100%	29.6%	9.5%	0.6%	3 994	849
35%	110%	27.6%	**17.0%**	**2.2%**	3 991	1 053
35%	120%	25.9%	**25.1%**	**5.4%**	3 926	1 315
35%	130%	24.1%	**33.7%**	**11.0%**	3 764	1 643
40%	70%	42.2%	0.1%	0.0%	3 498	654
40%	80%	38.7%	0.4%	0.0%	3 669	671
40%	90%	35.8%	0.0%	0.2%	3 790	737
40%	100%	33.6%	3.3%	0.2%	3 874	809
40%	110%	31.7%	6.4%	0.3%	3 936	886
40%	120%	30.1%	**11.3%**	1.5%	3 946	1 032
40%	130%	29.1%	**16.0%**	**3.0%**	3 931	1 186