Fisheries New Zealand

Tini a Tangaroa

Stock assessment for ling off the west coast South Island (LIN 7WC) to the 2018–19 fishing year

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EXECUTIVE SUMMARY

Kienzle, M. (2021). Stock assessment for ling off the west coast South Island (LIN 7WC) to the 2018–19 fishing year.

***New Zealand Fisheries Assessment Report 2021/18.* 22 p.**

This report details the 2020 update of the status of the ling stock off the west coast of the South Island (LIN 7WC), using the Bayesian stock assessment method. The Fisheries New Zealand Deepwater Fisheries Assessment Working Group (DWFAWG) chose a base case model to assess the status of this stock that incorporated all relevant biological parameters, commercial catch histories, onboard observer data, market sampling data, and research trawl survey data. Four alternative models were developed to evaluate the sensitivity of the assessment to various hypotheses regarding natural mortality input values and using different indices of abundance.

The stock assessment estimated an unfished biomass (B_0) at 47 000 t (43 700–51 900 t) and the spawning stock biomass (*SSB*) to be above the target reference point (40% B_0) in 2020, at 46% (34–59) of B_0. These results were found to be sensitive to the value of natural mortality used in the model, and not sensitive to using alternative indices of abundance. This assessment showed that the stock biomass had been declining since the beginning of the catch history. This trend was forecasted to continue to 2025 if catches at the level of the Total Allowable Commercial Catch (TACC) in 2020 were taken in the future. Projections assuming a future reduction in catch to 85% or 90% of the 2020 TACC would reduce the decline in *SSB* and keep the median of the projected *SSB* above the target level.

1. INTRODUCTION

The New Zealand ling (*Genypterus blacodes*) is a commercially important species taken mainly in fisheries around the South Island. Ling stocks support a substantial bottom longline target fishery and a largely bycatch trawl fishery (Fisheries New Zealand 2020). Ling were introduced into the New Zealand Quota Management System (QMS) on 1 October 1986. Ling are widely distributed through the middle depths (200–800 m), particularly south of latitude 40° S.

New Zealand ling are managed using eight administrative Quota Management Areas (QMAs), although five of these (LIN 3, 4, 5, 6, and 7) (Figure 1) have produced about 95% of the landings (Fisheries New Zealand 2020). Previous research has supported an assumption of at least five biological stocks of ling in New Zealand waters: the Chatham Rise (LIN 4 and northern part of LIN 3), the Sub-Antarctic including the Stewart-Snares shelf and Puysegur Bank (LIN 5 and western part of LIN 6), the Bounty Plateau (the eastern part of LIN 6), the west coast of the South Island (LIN 7 WC), and Cook Strait (north-eastern section of LIN 7) (Horn 2005).

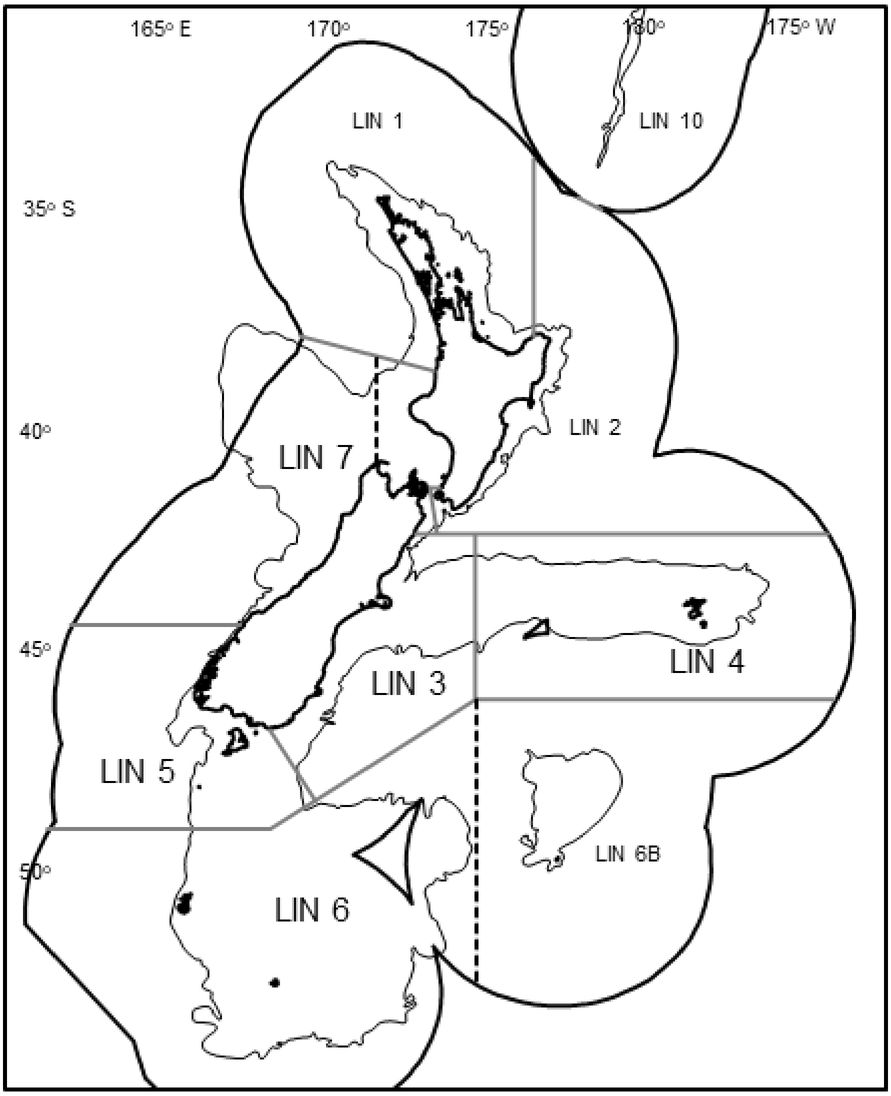

Figure 1: Ling fishstocks and the 1000 m isobath. The boundaries used to separate biological stock LIN 6B from the rest of LIN 6, and the west coast South Island section of LIN 7 from the rest of LIN 7, are shown as broken lines.

The overall history of the ling fishery is described by Fisheries New Zealand (2020). From 1975 to 1980, there was a substantial longline fishery on Chatham Rise (and to a lesser extent in other areas) carried out by Japanese and Korean vessels. Since 1980, ling have been caught by large trawlers, both domestic and foreign owned, and by small domestic longliners and trawlers. In the early 1990s, the domestic fleet was increased by the addition of several relatively large longliner vessels having autoline equipment, resulting in a large increase in the catches off the east and south of South Island (LIN 3, 4, 5, and 6). However, after about 2000 the catches by line vessels declined in most areas, offset, to some extent, by increased trawl landings.

Ling stock assessments for LIN 7WC started in 1993 with researchers estimating ling population parameters: von Bertalanffy growth parameters from length and age data; natural mortality using maximum age in samples (M=0.18 per year) and total mortality (Z) from catch curves (Fisheries New Zealand 2020). Horn (1993b) presented preliminary estimates of virgin biomass (B_0=75 000 t) and Mean Constant Yield (*MCY*=3200 t) applying a stock reduction analysis. This first assessment concluded that the Total Allowable Commercial Catch (TACC) in 1992 (2192 t) was sustainable and could be increased. In 1996, all relevant biological parameters, the commercial catch history, the west coast of the South Island (WCSI) longline Catch Per Unit of Effort (CPUE) series, and three series of catch-at age data were incorporated into a population model using by a Minimised Integrated Average Mean Squared Error Approach to biomass estimation (Horn & Cordue 1996). This method produced not only new estimates of B_0 and *MCY* but also uncertainties around those estimates. Estimates of B_0 (52 300 t, 95% CI 24 500–145 000 t) and *MCY* (2500 t, 1200–6800 t) were comparable to previous ones, and uncertainties were large.

From 2003 onward (Horn & Dunn 2003), the LIN 7WC stock assessment has been implemented using CASAL (Bull et al. 2012). Horn & Dunn (2003) estimated a virgin biomass (B_0) at 42 100 t (36 100–62 400 t), *MCY* at 2270 t, and a spawning stock biomass of 51% B_0 in 2002. They concluded that the size and status of the LIN 7WC stock were poorly known, but there were no sustainability issues with that stock. They cited the lack of fishery independent indices of abundance as a key problem.

Scientific trawl surveys off the WCSI started in 2000 (O'Driscoll & Ballara 2019), and data from these surveys were first included in the assessment in 2013, when two relative abundance estimates were available (Dunn et al. 2013). The 2013 assessment was accepted by the Ministry for Primary Industries Deepwater Fisheries Assessment Working Group (DWFAWG), with reservations, given that the assessment model did not fit well all the observational data. In the 2017 assessment, more survey data were available but problems fitting age composition data persisted, and a solution to adequately fitting apparently bimodal age composition data was suggested by fitting two selectivity ogives, one to each mature and immature component of the stock (Dunn & Ballara 2019). The 2019 stock assessment estimated ling in LIN 7WC to be above 40% B_0 with very high probability (over 90%). Biomass was estimated to have been declining in recent years, but the stock age composition was broad, indicating a low exploitation rate. There was a lack of contrast in the biomass indices to strongly inform the estimate of B_0 (Dunn & Ballara 2019).

Historically the index of abundance for ling in LIN 7WC came from standardising CPUE data from the commercial trawl fishery, where ling were caught predominantly as a bycatch when targeting hoki. The CPUE from the line fishery, which targeted ling, was considered to be low quality and was excluded (Dunn & Ballara 2019). Relative biomass data from the RV *Kaharoa* inshore survey were also not used, because these data were considered to have inadequate spatial coverage of the stock (Dunn & Ballara 2019). As the research trawl survey series increases, and provides more information about the variation of biomass, the stock assessments can shift from using CPUE as the primary index of abundance to replacing them with survey data (e.g., Kienzle et al. 2019). The stock assessment presented in this document follows that trend, whereby the base case model used the scientific surveys as an index of abundance, and the standardised CPUE trend was only used as a sensitivity run.

This document describes the stock assessment of LIN 7WC that took place in 2020 and details the process of model development and sensitivity runs for future reference. It describes the research conducted under all objectives of Fisheries New Zealand Project LIN2019-03. The specific project objective was *to complete a stock assessment of the WCSI ling stock including estimating biomass,* *sustainable yields and status of the stock,* and *projecting biomass and stock status trajectories as required to support management.*

2. METHODS

2.1 Data

2.1.1 Catch history

Ling in LIN 7 have been taken primarily as a bycatch of fisheries targeting other species, particularly the west coast South Island (WCSI) spawning hoki trawl fishery, though some ling target longlining does occur (Horn & Ballara 1999). The estimated catch history (Fisheries New Zealand 2020) shows that catches in both fisheries were lower than 100 t prior to 1975 (Figure 2, Appendix A). Catches up to 1973 were therefore assumed to be zero, although it is likely that small quantities of ling were taken in various areas before then (Dunn & Ballara 2019). Landings peaked briefly in 1975–76 and 1976–77 as a result of longlining by foreign-registered vessels (Horn & Ballara 1999). Ignoring the unusual large catches in fishing years 1974–75 to 1976–77, catches increased steadily until the late 1980s, when they persistently exceeded the TACC, and remained above the TACC for almost all of the 1990s and 2000s. Catches started declining in 2000–01, and reached levels at or below the TACC in 2007–08 and 2008–09. Afterwards, the TACC was increased three times, and the catches increased.

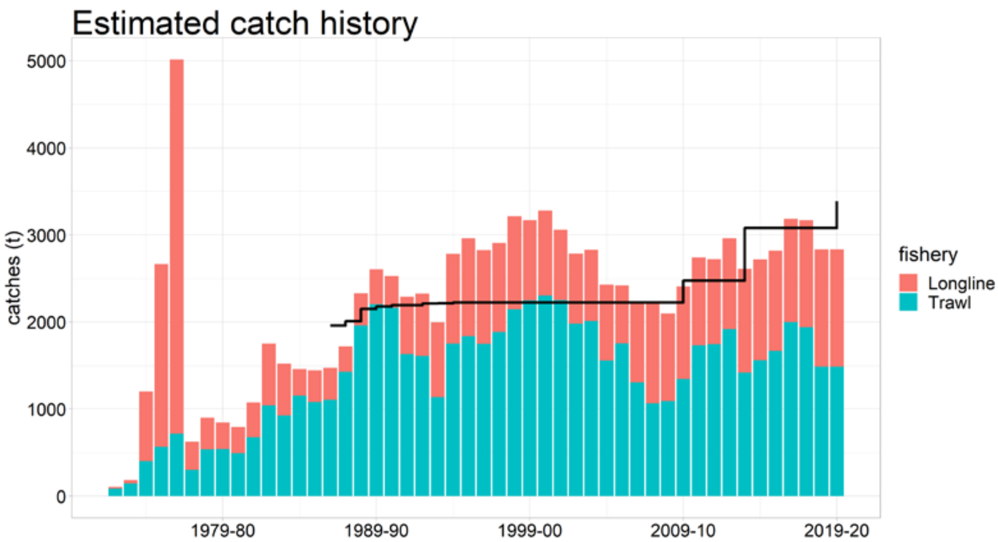

Figure 2: Time series of ling catches in LIN 7WC by fishery. The black line indicates the TACC.

It was noticed after the DWFAWG meetings in 2020 that the time series of catches used in the models presented during the meetings that year did not correspond to estimated catch history described by Fisheries New Zealand (2020), but to a sensitivity requested by Fisheries New Zealand described at the end of Dunn & Ballara (2019). This error was corrected in the models described in this report, and all analyses were updated with the correct data. The resulting conclusions have not changed, and the results differ by negligible quantities because the discrepancies between the two time series of catches occur in the 1970s, affecting cohorts that have long disappeared from the population.

2.1.2 Indices of abundance

The relative abundance of ling in LIN 7WC was estimated using (a) a scientific trawl survey of part of the habitat of ling on the west coast (O'Driscoll & Ballara 2019) and (b) standardised commercial catch per unit of effort from the trawl fishery (Dutilloy 2021). The indices of abundance were used by the model as relative indices, scaled to the estimate of biomass by the catchability (q).

Scientific survey

A series of deepwater research trawl surveys by RV *Tangaroa* covering the known ling depth range are available for LIN 7WC (O'Driscoll et al., 2019) (Table 1). Biomass estimates were used for the core survey area, with associated CVs estimated from the survey analysis. Including deeper strata made negligible difference to the biomass estimate or trend, therefore only the core strata biomass index was used into the stock assessment. This also provided the longest time series available for this survey, because the deeper strata were added in more recent surveys. Biomass estimates show an increase from the beginning of the time series to 2012 and 2013, followed by a decline.

Table 1: Series of relative biomass indices (t) from RV *Tangaroa* (TAN) trawl surveys of the LIN 7WC fish stock. with estimated coefficients of variation (CV).

			Core (300–650 m)	
Area	Trip code	Year	Biomass (t)	CV (%)
WCSI	TAN0007	2000	1 861	17.3
	TAN1210	2012	2 169	14.8
	TAN1308	2013	2 000	18.4
	TAN1609	2016	1 635	12.7
	TAN1807	2018	1 682	18.3

Standardised CPUE

Data from the commercial trawl fishery were used to estimate an index of abundance by standardising catch per unit effort using Generalised Linear Models (Dutilloy 2021). The delta log-normal model was chosen by the DWFAWG to be used in the stock assessment. The CPUE index showed that though abundance might have been variable from 1986–87 until 1999–00, it might have declined for the next ten years and increased in the decade since 2009–10 (Figure 3). The CPUE index was used as an addition and/or replacement of the survey index of abundance.

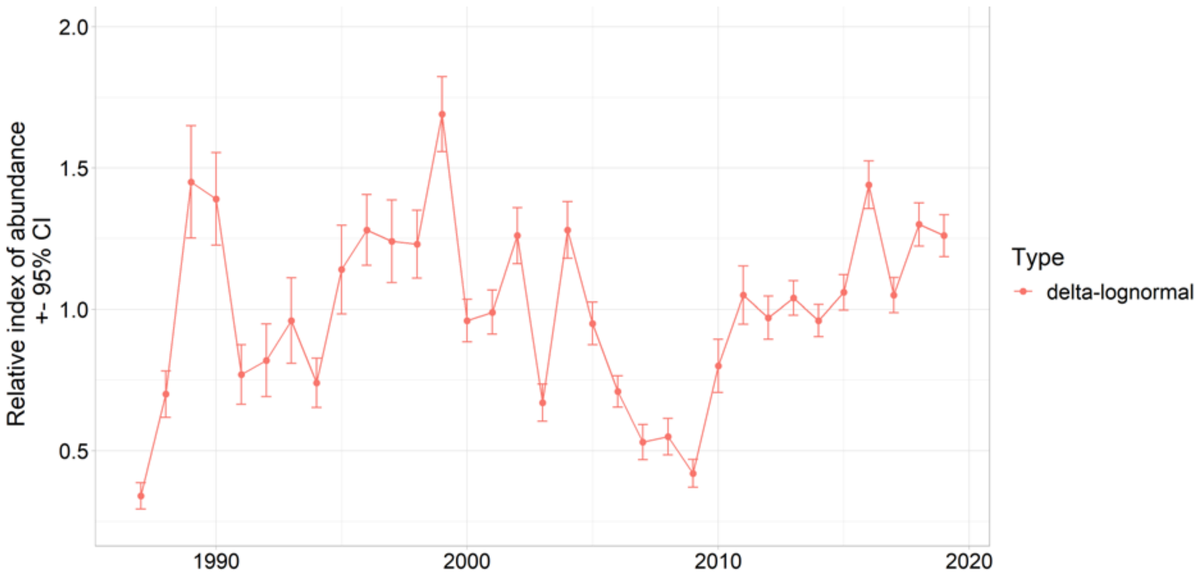

Figure 3: The CPUE index of abundance obtained by standardising the commercial trawl fishery catch and effort data (x-axis labelled as fishing year-ending).

2.1.3 Age compositions

Data describing the age composition of the catch came from three sources: (1) the trawl fishery; (2) the longline fishery, and (3) the scientific surveys.

Trawl fishery

The age of ling caught by the trawl fishery ranged from 3 to over 21 years old (Table 2). The age at which ling were first captured appeared to increase around 1998 to 1999, but this might equally be the result of a relatively large cohort (or group of cohorts) originating around 1990 and dominating the age composition at the time. The potential large year class from 1990 (age 5 in 1995), and perhaps around 2001 (age 5 in 2006), did not appear to track that clearly across the catch-at-age composition, which may reflect ageing error. The estimate of the 1991 year class (following the potentially large 1990 year class) seemed relatively erratic, again suggestive of ageing error. Ageing error for the observed proportions-at-age data was previously assumed to have a discrete normal distribution with a CV of 5% (Dunn & Ballara 2019); examination of the catch-at-age data suggested a CV any lower than this would not be plausible.

Longline fishery

The dataset of proportions at age in the longline fishery catches was sparser and only five years of data were available (Table 3). Older ling were caught in this fishery, with ages ranging from 5 to over 28 years. The age composition of adjacent years (2006, 2007) was so different that it did not seem plausible that the samples were drawn from the same population. Such variability could not be accounted by ageing error alone and suggested unrepresentative sampling.

Scientific survey

Ling catch composition at age was obtained from otolith samples taken during each survey (Horn & Sutton 2017). The number of otoliths used to derive the age frequency distributions for 2000, 2012, 2013, 2016, and 2018 were, respectively, 560, 603, 519, 453, and 487. The age composition from the research trawl survey appeared to be persistently bimodal, with a ‘gap’ in abundance at around age six or seven, which was close to the mean age at first maturity (Table 4). This was first observed in the 2017 assessment (Dunn & Ballara 2019), because in earlier assessments only data from relatively distant years 2000 and 2012 were available and the pattern was interpreted as indicative of year class strength (not selectivity) (Dunn et al. 2013).

Table 2: Proportions of ling at age (4–21+ y) by fishing year (labelled as year-ending) in the commercial trawl fishery. Higher values have darker shading.

Year	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
1991	0.00	0.01	0.01	0.02	0.06	0.05	0.09	0.08	0.15	0.19	0.07	0.05	0.09	0.06	0.04	0.01	0.02	0.00
1994	0.01	0.02	0.04	0.07	0.10	0.11	0.11	0.12	0.08	0.08	0.08	0.09	0.02	0.02	0.02	0.01	0.01	0.00
1995	0.02	0.06	0.06	0.11	0.15	0.14	0.08	0.09	0.07	0.06	0.06	0.04	0.03	0.02	0.01	0.01	0.00	0.00
1996	0.00	0.02	0.08	0.07	0.11	0.15	0.10	0.10	0.09	0.10	0.06	0.04	0.03	0.01	0.01	0.01	0.01	0.00
1997	0.00	0.01	0.05	0.06	0.07	0.11	0.11	0.11	0.13	0.11	0.07	0.05	0.03	0.02	0.02	0.02	0.01	0.00
1998	0.00	0.02	0.03	0.04	0.10	0.20	0.14	0.13	0.12	0.07	0.06	0.02	0.01	0.02	0.01	0.02	0.01	0.00
1999	0.01	0.03	0.04	0.05	0.13	0.16	0.15	0.14	0.10	0.06	0.05	0.02	0.02	0.01	0.02	0.01	0.00	0.01
2000	0.01	0.02	0.03	0.05	0.15	0.06	0.22	0.10	0.10	0.11	0.03	0.04	0.02	0.02	0.01	0.01	0.01	0.01
2001	0.01	0.06	0.05	0.04	0.07	0.11	0.13	0.14	0.11	0.08	0.08	0.04	0.04	0.01	0.01	0.01	0.01	0.01
2002	0.02	0.04	0.06	0.04	0.12	0.10	0.10	0.13	0.12	0.10	0.07	0.04	0.02	0.02	0.01	0.01	0.00	0.01
2003	0.03	0.09	0.07	0.06	0.09	0.08	0.10	0.10	0.12	0.09	0.06	0.04	0.02	0.02	0.01	0.02	0.00	0.00
2004	0.03	0.06	0.08	0.07	0.09	0.08	0.07	0.10	0.13	0.10	0.08	0.05	0.03	0.02	0.01	0.01	0.00	0.00
2005	0.07	0.07	0.06	0.05	0.07	0.08	0.09	0.09	0.08	0.07	0.06	0.07	0.05	0.04	0.02	0.01	0.01	0.00
2006	0.05	0.12	0.08	0.06	0.07	0.07	0.09	0.09	0.09	0.07	0.05	0.05	0.05	0.04	0.02	0.01	0.00	0.00
2007	0.02	0.06	0.06	0.12	0.07	0.10	0.06	0.08	0.08	0.10	0.06	0.05	0.07	0.04	0.02	0.01	0.01	0.00
2008	0.04	0.12	0.05	0.09	0.09	0.06	0.07	0.07	0.08	0.09	0.05	0.05	0.04	0.03	0.04	0.02	0.00	0.00
2012	0.02	0.02	0.03	0.06	0.10	0.13	0.14	0.13	0.08	0.06	0.05	0.04	0.03	0.02	0.03	0.02	0.02	0.01
2013	0.08	0.06	0.04	0.04	0.11	0.14	0.14	0.10	0.10	0.07	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.01
2014	0.03	0.06	0.06	0.06	0.07	0.13	0.16	0.10	0.11	0.07	0.03	0.05	0.01	0.02	0.01	0.02	0.00	0.01
2015	0.07	0.11	0.04	0.05	0.06	0.10	0.10	0.08	0.10	0.08	0.06	0.07	0.03	0.01	0.02	0.00	0.01	0.01
2016	0.03	0.04	0.02	0.03	0.06	0.08	0.12	0.11	0.14	0.10	0.10	0.05	0.03	0.04	0.02	0.01	0.00	0.01
2017	0.07	0.08	0.04	0.03	0.08	0.05	0.10	0.08	0.08	0.09	0.10	0.08	0.04	0.03	0.03	0.01	0.01	0.01
2018	0.03	0.05	0.04	0.05	0.07	0.06	0.07	0.10	0.13	0.08	0.10	0.08	0.04	0.02	0.03	0.01	0.01	0.02
2019	0.05	0.04	0.03	0.04	0.09	0.09	0.12	0.11	0.11	0.09	0.07	0.06	0.03	0.02	0.01	0.01	0.01	0.01

Table 3: Proportions of ling at age (5–28+ y) by fishing year (labelled as year-ending) in the commercial longline fishery. Higher values have darker shading.

Year	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28+
2003	0.00	0.00	0.02	0.03	0.04	0.06	0.10	0.13	0.11	0.09	0.07	0.06	0.07	0.05	0.03	0.02	0.01	0.01	0.05	0.02	0.02	0.01	0.00	0.00
2006	0.01	0.03	0.07	0.10	0.11	0.11	0.14	0.09	0.05	0.06	0.06	0.06	0.04	0.02	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2007	0.01	0.02	0.05	0.03	0.08	0.06	0.07	0.06	0.06	0.05	0.04	0.13	0.02	0.10	0.01	0.01	0.05	0.06	0.02	0.00	0.00	0.05	0.01	0.00
2012	0.00	0.00	0.01	0.02	0.04	0.06	0.07	0.08	0.07	0.08	0.07	0.10	0.06	0.07	0.08	0.05	0.06	0.03	0.01	0.02	0.01	0.00	0.01	0.00
2015	0.00	0.00	0.01	0.04	0.10	0.12	0.16	0.19	0.13	0.09	0.04	0.03	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4: Proportions of ling at age (3–23 y) by fishing year (labelled as year-ending) in the scientific trawl survey. Higher values have darker shading.

Year	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
2000	0.02	0.04	0.05	0.04	0.03	0.10	0.06	0.20	0.09	0.08	0.10	0.03	0.04	0.02	0.02	0.01	0.02	0.01	0.00	0.01	0.01
2012	0.04	0.05	0.04	0.03	0.05	0.06	0.08	0.10	0.09	0.07	0.06	0.05	0.04	0.04	0.02	0.04	0.04	0.03	0.02	0.02	0.03
2013	0.03	0.07	0.05	0.03	0.04	0.08	0.11	0.13	0.08	0.09	0.07	0.05	0.02	0.02	0.01	0.02	0.02	0.02	0.01	0.01	0.02
2016	0.03	0.07	0.06	0.03	0.04	0.06	0.07	0.10	0.09	0.12	0.07	0.07	0.04	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.04
2018	0.05	0.04	0.03	0.04	0.03	0.05	0.04	0.06	0.10	0.12	0.09	0.10	0.09	0.04	0.02	0.04	0.01	0.01	0.00	0.01	0.01

2.1.4 Biological parameters

The maximum age recorded for New Zealand ling is 46 years, although only 0.5% of successfully aged ling have been older than 30 years (Fisheries New Zealand 2020). The natural mortality rate, M, was initially estimated from the equation $M = \log_e 100/A_{max}$, where A_{max} is the age to which 1% of the population survives in an unexploited stock (Sparre & Venema 1998). Horn (1993a, b) estimated A_{max} from five samples as 23–27 years, giving M in the range 0.17 to 0.20 year^{-1} (with mean of 0.18 year^{-1}). Less than 0.2% of aged ling were older than 30 years, and an A_{max} of 30 gives a likely minimum value of M of 0.15 per year. However, a review of M, and results of modelling conducted in 2007, suggested that this parameter may vary between stocks and natural mortality off the west coast of the South Island might be higher than 0.18 (Horn 2008). In 2017, M was estimated to equal 0.23 per year in assessment models developed for LIN 7WC by Dunn & Ballara (2019).

Length-weight relationships were revised most recently by Horn (2006) (Table 5). Von Bertalanffy growth curve parameters were estimated by Dunn & Ballara (2019). Variability in size-at-age was assumed to be normal with a constant CV of 0.15.

The maturity ogive represents the proportion of fish mature at age in the population and was estimated by sex and combined by Horn (2005). In the absence of data, the proportion spawning was assumed to be 1.0 for older age-groups.

Following Dunn & Ballara (2019), a stock-recruitment relationship (Beverton-Holt) was used with assumed steepness parameter (h = 0.84; Shertzer & Conn 2012).

The biological parameters used for stock assessment in 2020 were the same as those in the previous assessment (Dunn & Ballara 2019; Table 5).

Table 5: Biological and other input parameters used in the ling assessments for LIN 7WC (from Fisheries New Zealand 2020).

1. Natural mortality (M)

	Both sexes
FMA	
All stocks	0.18

2. Weight = a (length)^b (Weight in g, length in cm) total length)

	Female		Male		Combined	
FMA	*a*	*b*	*a*	*b*	*a*	*b*
LIN 7WC	0.000934	3.368	0.001146	3.318	0.00104	3.318

3. von Bertalanffy growth parameters

	Female			Male			Combined		
FMA	K	t_0	L_∞	K	t_0	L_∞	K	t_0	L_∞
LIN 7WC	0.078	–0.87	169.3	0.067	–2.37	159.9	0.07	-1.5	168.5

4. Maturity ogives*****

Age (y)	3	4	5	6	7	8	9	10	11	12
LIN 7WC										
Male	0.0	0.015	0.095	0.39	0.77	0.94	1.00	1.00	1.00	1.0
Female	0.0	0.004	0.017	0.06	0.18	0.39	0.65	0.85	0.94	1.0
Combined	0.0	0.010	0.056	0.23	0.48	0.67	0.83	0.93	0.97	1.0

2.2 Stock assessment models

The starting point for this assessment in 2020 was the most recent stock assessment of ling in LIN 7WC described by Dunn & Ballara (2019).

For 2020, five stock assessment models were developed and fitted to the data (Figure 4). The base case model (model 1) was fitted to the data with the assumption that M was equal to 0.18 year^{-1}. Two models were used to assess the sensitivity to the value of M: model 2 used M = 0.22 year^{-1} and model 3 used M = 0.14 year^{-1}, covering the range of values estimated for ling natural mortality. A sensitivity to the indices of abundance used was performed by (a) developing a model that discarded all survey information and replaced the survey index of abundance by the CPUE index (model 4), and (b) adding the CPUE index of abundance to the base case model (model 5). Parameter estimates for all model runs were made from the mode of the joint posterior distribution (MPD), and parameters of model runs 1 and 5 were also estimated using Markov chain Monte Carlo (MCMC).

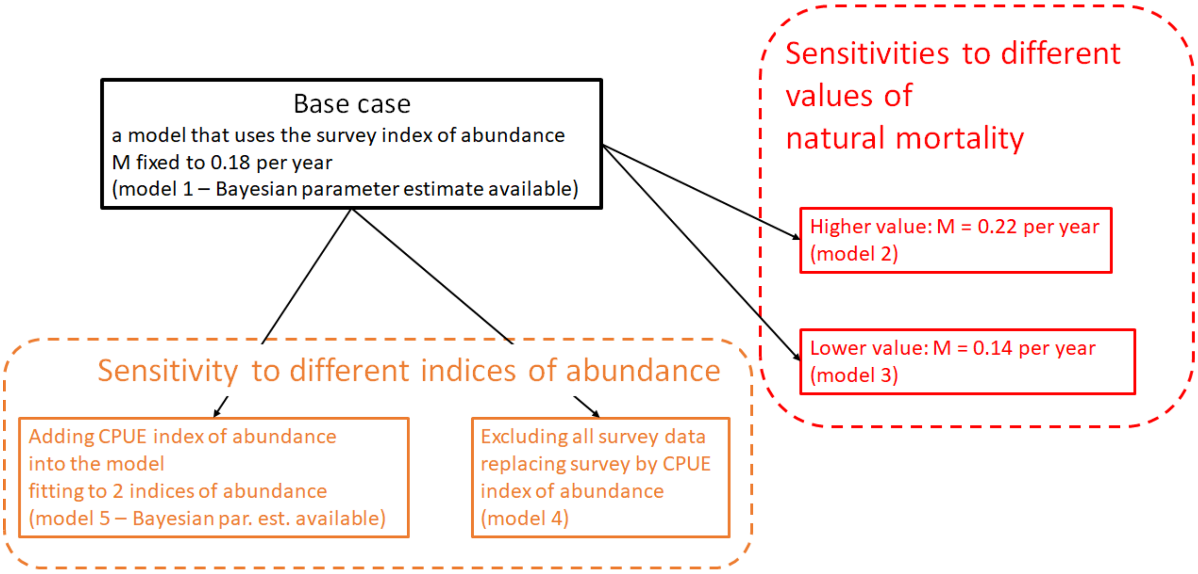

Figure 4: Relationship between the base case model and 4 alternative models. 'Bayesian par.est.' is Bayesian parameter estimate.

2.2.1 Model structure

The ling population in the stock assessment model was structured by age, using 26 one-year wide categories for age groups 3 to 28 years old. The last age group was a plus group (contained all individuals 28 years and older). The stock was assumed to reside in a single area. Two fisheries were implemented representing the trawl and longline fisheries. The model's annual cycle for the stock is described in Table 6.

Female ling grow significantly faster than males (Horn 1993b). Despite known differences in dynamics between the sexes, assessment models incorporating sex had previously provided poor fits to data (Dunn et al. 2013, Dunn & Ballara 2019) and were rejected by DWFAWG. For this assessment, the population was not partitioned by sex, and all observations (age frequencies) and associated parameters (selectivities), and biological parameters (growth, maturity, etc.) were calculated for both sexes combined as in the previous assessment (Dunn & Ballara 2019).

The model partitioned the population into mature and immature individuals, which were allowed to have potentially different selectivities to the trawl survey. This was introduced by Dunn & Ballara (2019) to fit the bimodal distribution of proportion at age observed in the age distributions from the scientific survey.

The annual life cycle was modified from Dunn & Ballara (2019) by adding an additional time step (time step 3) at the end of the annual cycle to increment age. This modification was made to make sure that age increment followed removals from the fisheries in the succession of operations made on the partitions of the model in CASAL. The fraction of age used to calculate growth in the second time step was adjusted to 0.8.

Table 6: Annual cycles of the LIN 7WC stock model, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality occurs within a time step after all other processes, with half of the natural mortality for that time step occurring before and half after the fishing mortality.

					Observations	
Time step	Period	Processes	M^1	Age[2]	Description	$\%Z^3$
1	Oct–May	Maturation Recruitment Fishery (line)	0.75	0.5	Line catch-at-age	0.5
2	Jun–Sep	Spawning Fishery (trawl)	0.25	0.8	Trawl CPUE Trawl catch-at-age *Tangaroa* survey data	0.5
3	End of Sep	Increment ages	0	0		

1. *M* is the proportion of natural mortality that was assumed to have occurred in that time step.
2. Age is the age fraction, used for determining length-at-age, that was assumed to occur in that time step. In time step 1, the mean size of 2-year-old fish is calculated as if they were age 2.5
3. %*Z* is the percentage of the total mortality in the step that was assumed to have taken place at the time each observation was made.

The gear selectivities of both the trawl and the longline fishery were assumed to be logistic. The *Tangaroa* survey selectivity was assumed to be a capped logistic for the immature, and a logistic for the mature. Selectivities were assumed to be constant through time.

The maximum exploitation rate allowed by the model was assumed to be 0.6 (although this was never achieved).

The indices of abundance (scientific survey and CPUE) assumed a lognormal error distribution, with known CVs for each year. An additional error (‘process error’, Bull et al. 2012) of 0.2 was added to the research biomass surveys, and 0.4 to the CPUE indices. The proportions-at-age data from trawl and line fisheries and scientific surveys were assumed to have a multinomial error distribution. Effective sample sizes were estimated using the method TA1.8 described by Francis (2011). An ageing error was also added, which was normal with a CV of 0.1.

Year class strengths were assumed known (and equal to 1) for years before 1975 and after 2013, when inadequate or no catch-at-age data were available. Otherwise, year class strengths were estimated using the Haist parameterisation, under which the YCS deviates must average to one.

Penalty functions were used to constrain the model so that any combination of parameters that did not allow the historical catch to be taken were strongly penalised. A penalty was also applied to the estimates of year class strengths to encourage estimates that averaged to 1 (this penalty has been shown to improve MCMC performance; Bull et al. 2012).

In New Zealand, fishery management decisions are based on stock assessment models in which parameters, and derived quantities, are estimated using a Bayesian approach. Two models, the base case stock assessment model and model 5, had their parameters estimated using Markov chain Monte Carlo, based upon the Metropolis-Hastings algorithm coded in CASAL v2.30 software (Bull et al. 2012).

Parameters were estimated using four independent MCMC chains. Each chain was made of 6 million iterations. The first million iterations were considered as a burn-in period and discarded. Chains were thinned to provide 2000 samples per chain, and all combined to estimate the posterior distribution of the parameters and derived quantities from the model (i.e., from 8000 samples).

Mixing and convergence of the chains was considered acceptable when the chains visually looked "grassy" (Kéry & Schaub 2012) and met expectations of experts in the Deepwater Working Group (see Acknowledgements section), and the estimates of parameters and quantities from the four chains were similar (within a few percent).

Prior distributions of some parameters (survey catchability, B_0) were left unchanged from the previous assessment (Dunn et al. 2019). Priors for most parameters were intended to be relatively uninformative and were specified with wide bounds (Table 7). The prior for the *Tangaroa* trawl survey catchability (q) was informed, and followed the method used to set the prior for the *Tangaroa* trawl surveys of the Chatham Rise and Sub-Antarctic: catchability was assumed to be the product of areal availability (0.5–1.0), vertical availability (0.5–1.0), and vulnerability between the trawl doors (0.03–0.40), and the resulting (approximately lognormal) distribution had mean 0.13 and CV 0.70, with bounds assumed to be 0.02 to 0.30 (Horn et al. 2013). However, the WCSI survey area in the 200–800 m depth range in strata 0004 A–C and 0012 A–C comprised 12 928 km^2, whereas the seabed area in that depth range in the entire LIN 7 biological stock area (excluding the Challenger Plateau) was estimated to be about 24 000 km^2. Because biomass from only 54% of the WCSI potential ling habitat was included in the index, the mean of the prior was modified accordingly (i.e., 0.13 × 0.54 = 0.07).

Table 7: Prior distributions of the parameters used in the stock assessment models.

Parameter	Distribution
Survey catchability	Lognormal; μ=0.07, cv=0.7
B_0	Uniform-log, lower bound=10 000, upper bound=500 000
Survey selectivity	**Immature:** lognormal; μ_1=2.8 μ_2=0.77, μ_3=0.03, cv_1=0.2, cv_2=0.2, cv_3=0.2, lower $bound_1$=1, lower $bound_2$=0.1, lower $bound_1$=0.001 upper $bound_1$=30, upper $bound_2$=30, upper $bound_3$=0.02 **Mature:** lognormal; μ_1=13.6 μ_2=7.2, cv_1=0.2, cv_2=0.2, lower bound=1, upper bound=30
Trawl fishery selectivity	lognormal; μ_1=10.0 μ_2=5.5, cv_1=0.2, cv_2=0.2, lower bound=1, upper bound=30
Longline fishery selectivity	Uniform; lower $bound_1$=1, lower $bound_2$=1 upper $bound_1$=60, upper $bound_1$=200
Year Class Strength	Lognormal; μ=1, cv=0.7 lower bound=0.01, upper bound=100
CPUE catchability	Uniform-log, lower bound=1e^{-8}, upper bound=1e^{-3}

2.2.2 Projections

Trends in Spawning Stock Biomass (*SSB*) were projected into the future to 2025 using (a) future recruitments drawn from either the full series of estimated recruitment (1973–2013) or only the last 10 years of estimated recruitment (2004–2013); and (b) assuming future constant catches fixed at three different levels: 85, 90 and 100% of the 2020 TACC.

3. RESULTS

3.1 Mean of the Posterior Distribution (MPD) fit of the base case model

The Mean of the Posterior Distribution (MPD) fit of the base case model indicated that the virgin spawning stock biomass (B_0) was most likely between 35 000 and 55 000 tonnes (Figure 5). The survey biomass (wcsiTANbio) and the age data from the trawl fishery (wcsiTRLage) provided consistent information regarding the estimate of this parameter (46 700 t), as well as being the most precise source of information to determine this parameter of the model. Other data sources (age data in the longline fishery and in the surveys) suggested that lower values of B_0 were less likely than higher ones.

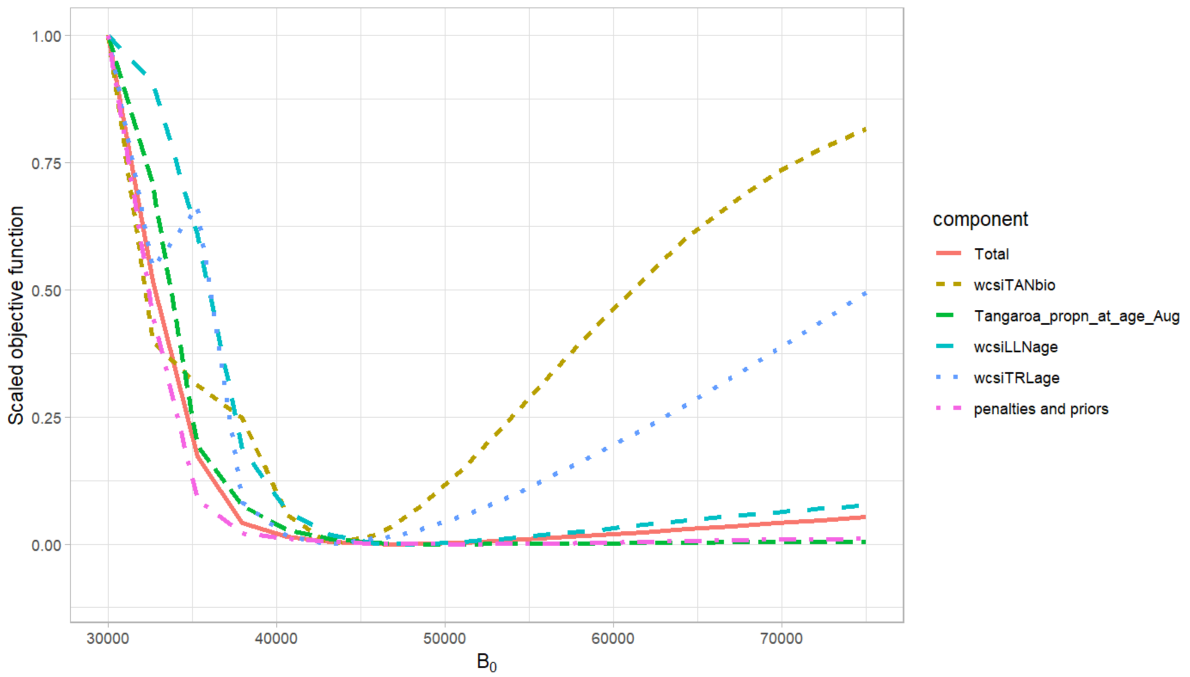

Figure 5: Likelihood profiles of the base case model for the virgin spawning stock biomass parameter (B_0) for each likelihood component: likelihood profile of all the components (Total); survey biomass estimates (wcsiTANbio); survey proportions at age (Tangaroa_propn_at_age_Aug); age distributions in catches by the longline fishery (wcsiLLNage); age distributions in catches by the trawl fishery (wcsiTRLage); and model penalties and priors (penalties and priors).

The base case model fitted the survey and trawl fishery data within two standard deviations of the observations, but it did not fit closely the proportions at age in the longline fishery catches (Figure 6).

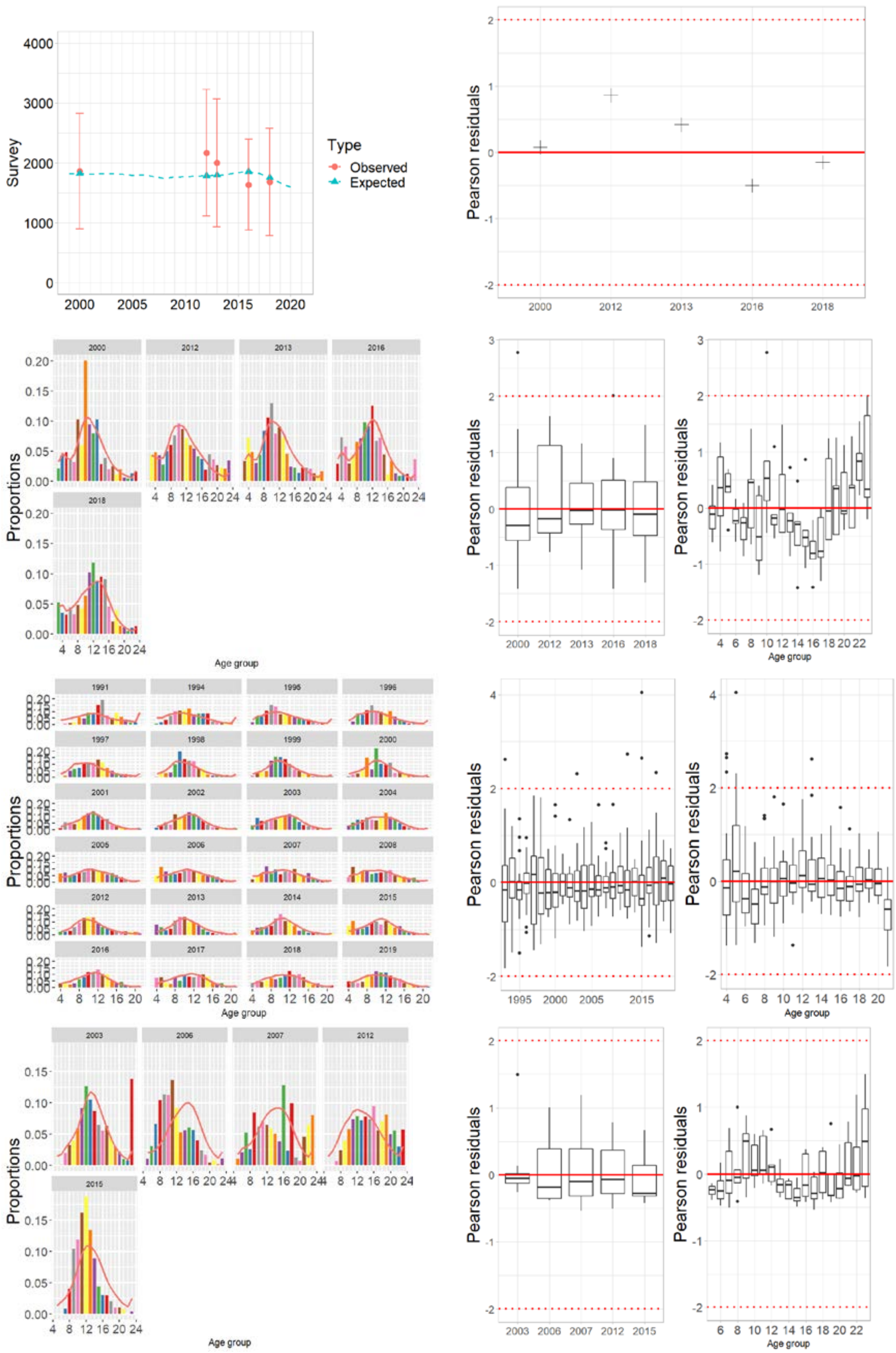

Figure 6: Diagnostics of the fit of the base case model: the left hand side column shows the data overlaid with the model and the right hand side shows the Pearson residuals for each dataset. Row 1 presents the fit to the index of abundance from the scientific surveys; row 2, the fit to the age composition in the scientific surveys; row 3, the fit to the age composition in the trawl fishery catches and row 4, the fit to the age composition in the catch from the long line fishery.

3.2 MPD sensitivity to the value of natural mortality rate

The stock assessment model outputs were sensitive to the value of natural mortality rate used in the model. Higher values of *M* result in higher estimates of absolute and relative *SSB* (Figure 7). The pattern of the time series of *SSB* were similar between the three models, and the estimates of B_0 were almost identical. The differences in *SSB* estimates between the three models increase with time. The larger the assumed value of *M*, the more resilient to exploitation the *SSB* appeared to be. Using the lowest value of *M* would lead to conclude that the stock in 2020 was below the target reference point (40% B_0), whereas the two highest values of *M* lead to the opposite conclusion, although all three models show a declining trend.

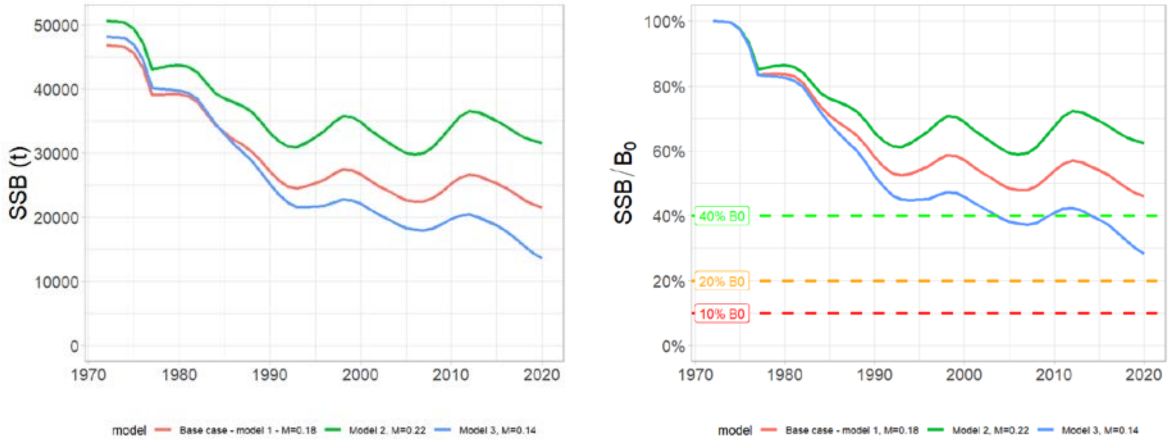

Figure 7: Trends in Spawning Stock Biomass (*SSB*) estimates by the base case model and model 2 and 3: (left hand side) estimates of absolute *SSB*; (right hand side) estimate of *SSB* relative to virgin spawning stock biomass (B_0).

3.3 MPD sensitivity to different indices of abundance

The results of the stock assessment were relatively insensitive to alternative indices of abundance, as model runs with alternative indices of abundance (model 1, 4, and 5) estimated similar trends in, and absolute, *SSB* (Figure 8).

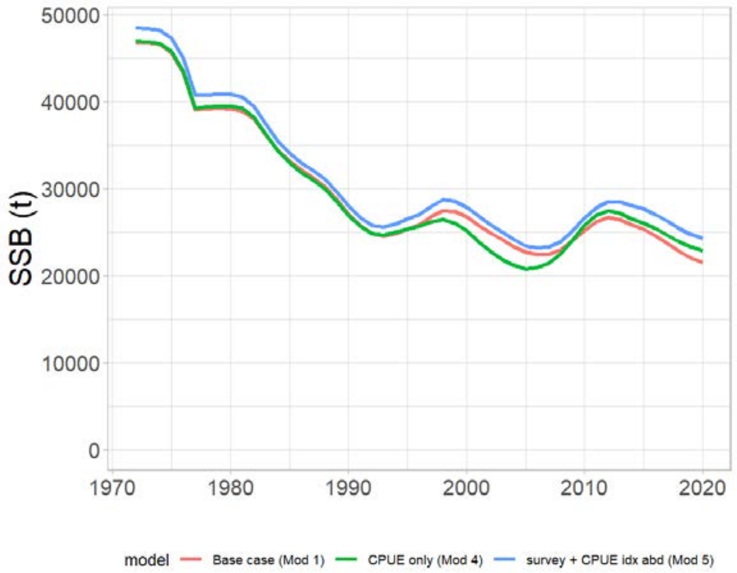

Figure 8: Trends in Spawning Stock Biomass (*SSB*) estimated by 3 models to assess the sensitivity of the stock assessment to using difference indices of abundance.

3.4 MCMC estimates

The MCMC chains used to estimate the posterior distributions of parameters in the base case model and model 5 showed acceptable mixing. The parameters of base case model estimated with the Bayesian approach were, therefore, considered suitable to provide a stock assessment for ling.

The differences between estimates from the base case model and model 5 were small. For example, the median virgin biomass estimate was 3% larger in model 5 compared with the base case model (48 800 t compared with 47 200 t, Figure 9). The median of the survey catchability estimated by model 5 was 9% smaller than that estimated by the base case model (0.21 compared with 0.24). The posterior density function of the survey catchability (Figure 9) showed that the data provided certainty that this parameter was between 0 and 1, updating the prior distribution that it could be between 0 and 4, and most likely equal to 0.7.

The *SSB* was estimated to have declined sharply from the beginning of the time series to the beginning of the 1990s (Figure 10). Subsequently, the *SSB* rebounded and declined further at a slower rate. Both models estimated that it was more probable that the ling *SSB* was above the target reference point (40% B_0) in 2020 than not.

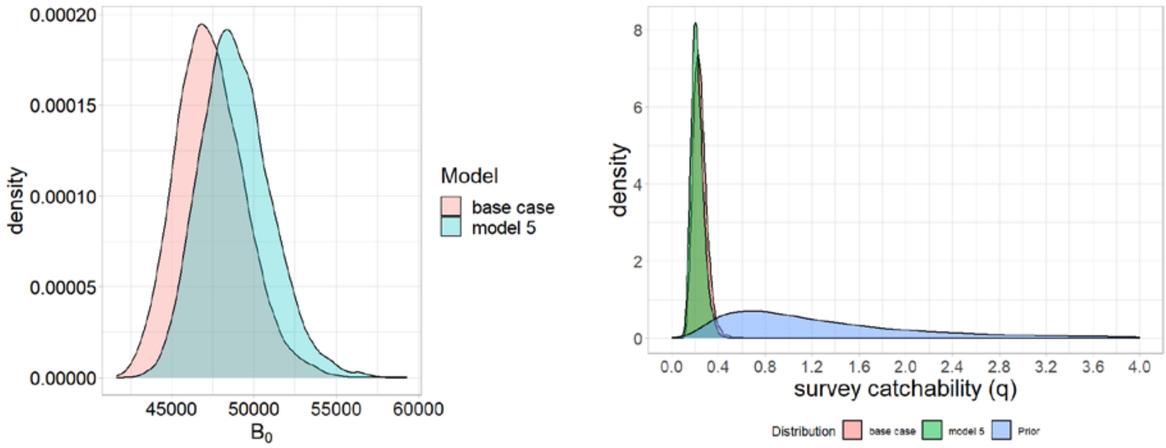

Figure 9: Comparison of the posterior distributions of virgin spawning stock biomass (*B_0*, left hand side) between the base case model and model 5. Comparison of the posterior distribution of survey catchability between the base case and model 5 and its prior distribution.

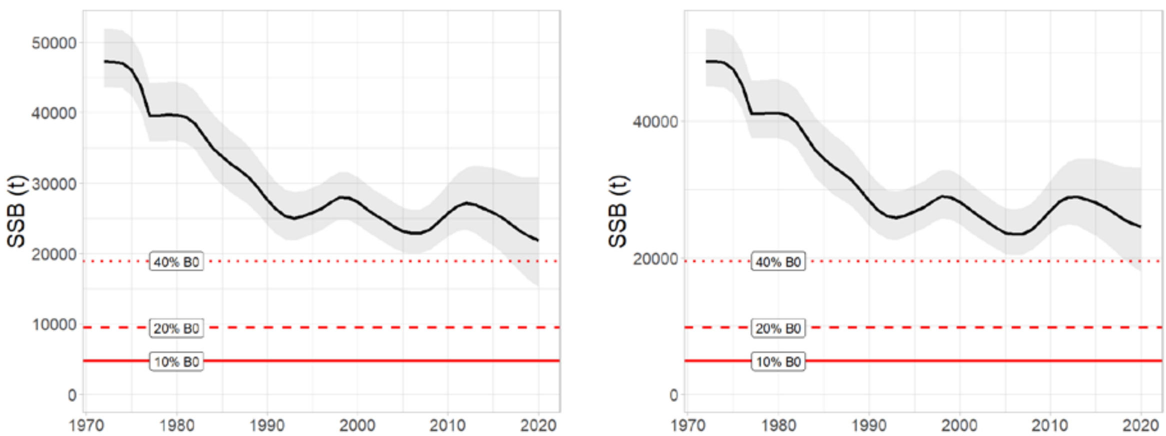

Figure 10: Estimated trends in Spawning Stock Biomass (*SSB*, in tonnes) using the base case model (left hand side) and model 5 (right hand side). The black line shows the median and the grey area the boundaries of the 95% confidence intervals. The horizontal red lines give the management reference points.

Recruitment estimates by model 1 and 5 were almost identical (Figure 11). The models estimated below average recruitment from 1975 to 1985, and two spikes above average recruitment around 1990 and 2003.

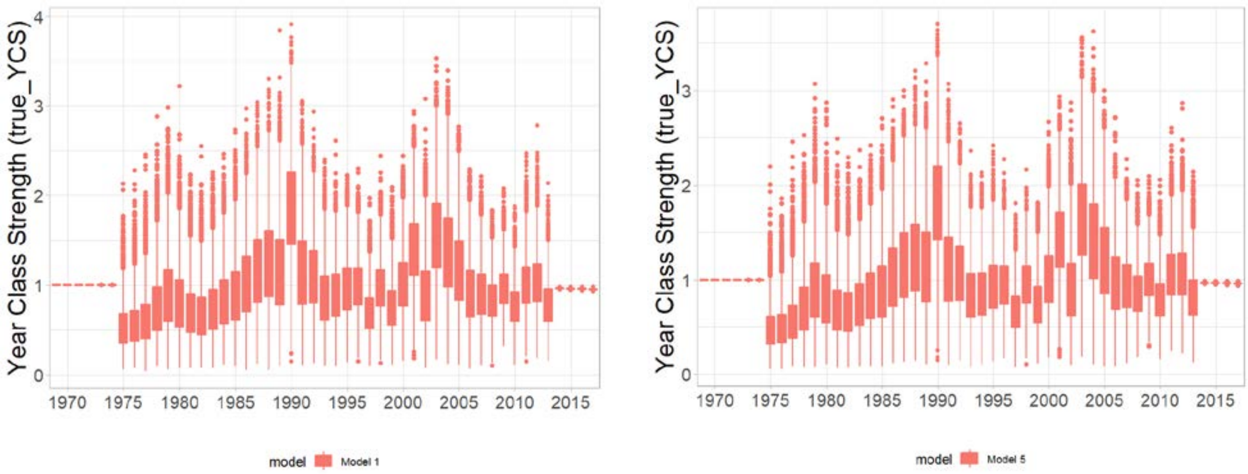

Figure 11: Estimated recruitment trends and variability by model 1 (left hand side) and model 5 (right hand side).

The estimates of gear selectivity are almost identical between model 1 and 5 (Figure 12). The trawl fishery was estimated to select younger fish than those in the survey, with an A_{50} estimated between 8 and 9 years old for model 1, and at 8 years old for model 5. The survey selectivity for mature ling was estimated to be more similar to the longline than the trawl fishery with an A_{50} of 12 years old for the survey (identical from both models) and 13 years old for the longline fishery. Models 1 and 5 estimated slightly different steepness for the logistic selectivity of the survey for mature ling and longline fishery. Both models estimated a constant selectivity of immature ling in the survey of 3%.

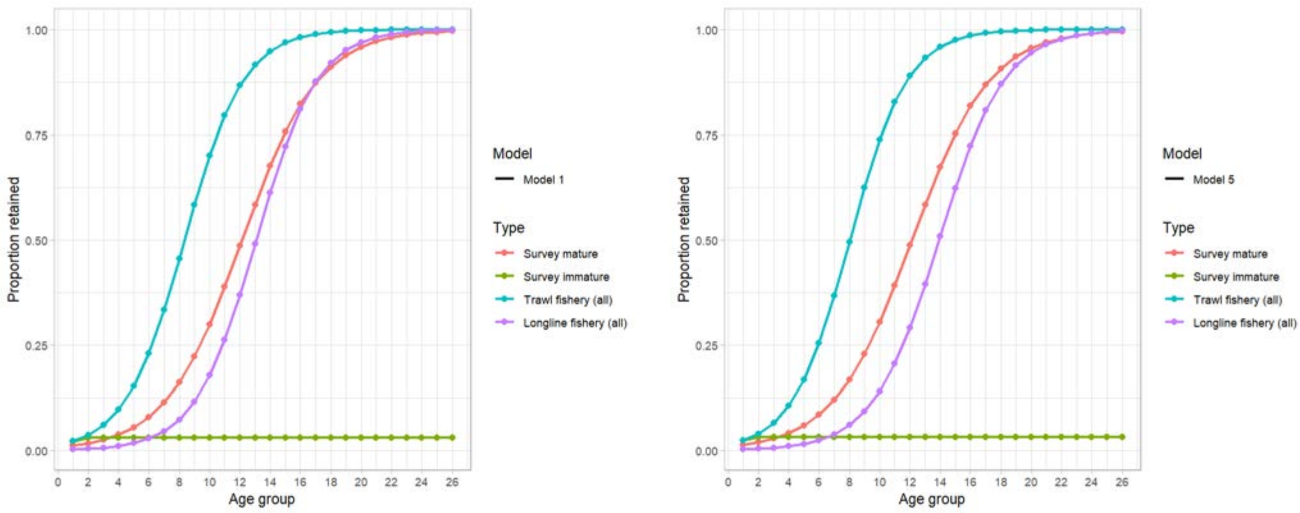

Figure 12: Gear selectivity estimates by model 1 (left hand side) and model 5 (right hand side).

3.5 Projections

Projecting the stock to 2025, under the assumption that the future combined fisheries catch equalled the 2020 TACC, forecasted further decline in ling *SSB* (Figure 13). At that catch, ling *SSB* would be more likely than not to below the target reference point (40% B_0) by 2025. Projections assuming a future reduction in catch to 85% or 90% of the 2020 TACC would reduce the decline in *SSB* and keep the median of the projected *SSB* above the target level (Figure 13, Table 8). The difference between projection results using data from the longer times series of recruitment estimates (1975 to 2013), and the last 10 years, were negligible (Table 8).

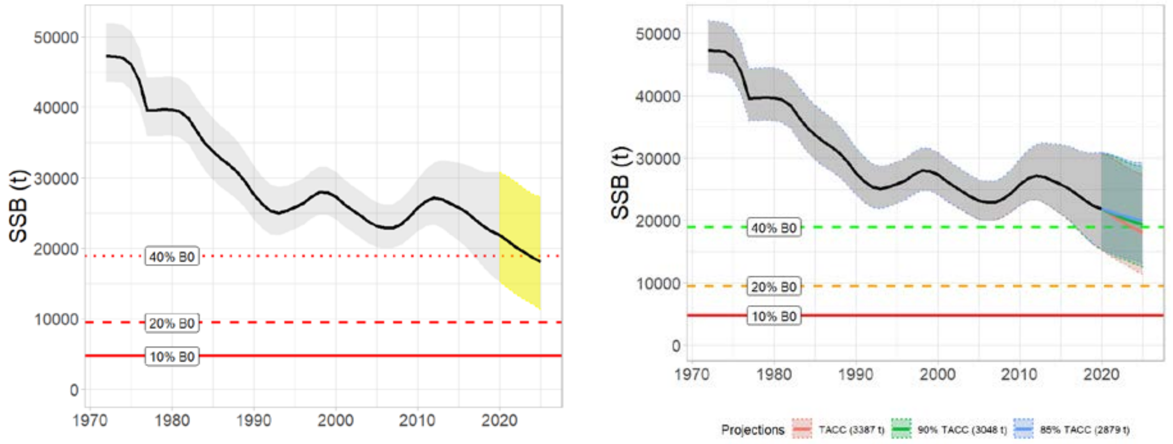

Figure 13: Projected trends in Spawning Stock Biomass (*SSB*, in tonnes) to 2025 using future annual catches equal to the TACC in 2020 and the last 10 years of recruitment estimates (left hand side). The right-hand side compares trajectories of ling *SSB* with future catches set at 85, 90, and 100% of the TACC in 2020.

Table 8: Median projected ratio of *SSB* to B_0 by years to 2025 (in columns) with 95% confidence interval between parentheses according to various scenarios of future constant catch (85, 90, or 100% of TACC in 2020) and recruitment drawn from either the entire time series of estimates (1975–2013) or the last 10 years of estimates (2004–2013).

Scenario	2021	2022	2023	2024	2025
Catch: TACC Recruitment: 1975–2013	0.45 (0.30, 0.64)	0.43 (0.29, 0.62)	0.41 (0.27, 0.60)	0.40 (0.26, 0.58)	0.38 (0.25, 0.57)
Catch: TACC Recruitment: 2004–2013	0.45 (0.30, 0.64)	0.43 (0.29, 0.62)	0.41 (0.27, 0.60)	0.40 (0.26, 0.59)	0.38 (0.24, 0.58)
Catch: 90% TACC Recruitment: 1975–2013	0.45 (0.31, 0.65)	0.44 (0.30, 0.63)	0.43 (0.29, 0.62)	0.42 (0.28, 0.61)	0.41 (0.27, 0.60)
Catch: 90% TACC Recruitment: 2004–2013	0.45 (0.31, 0.65	0.44 (0.30, 0.63)	0.43 (0.29, 0.62)	0.42 (0.28, 0.61)	0.41 (0.26, 0.61)
Catch: 85% TACC Recruitment: 1975–2013	0.45 (0.31, 0.65)	0.44 (0.30, 0.64)	0.44 (0.29, 0.63)	0.43 (0.29, 0.62)	0.42 (0.28, 0.61)
Catch: 85% TACC Recruitment: 2004–2013	0.45 (0.31, 0.65)	0.44 (0.30, 0.64)	0.44 (0.29, 0.63)	0.43 (0.29, 0.62)	0.42 (0.28, 0.62)

4. DISCUSSION

The estimates of virgin biomass (B_0) 47 000 t (43 700–51 900 t) were consistent with Horn & Dunn (2003) and Horn (2001, 2002), who estimated B_0 ranging between 22 000 t and 125 000 t, but lower than Dunn et al. (2013) and Dunn & Ballara (2019) who estimated B_0 greater than about 60 000 t. The projections were indicative of a further decline in biomass into the future, corroborating the conclusions by Horn (2001, 2002), Horn & Dunn (2003), and Horn et al. (2013). Nevertheless, the stock in 2020 was very likely (over 85%) to be above the target reference point (40% B_0).

The results of the sensitivity model runs to the value of natural mortality reiterated the results from Dunn & Ballara (2019), that "this parameter was highly influential in determining stock size and status". The sensitivity of stock assessment models to M is reported extensively in the scientific literature (e.g., Lee et al. 2011). This result emphasises the importance of using the most realistic value for M in the stock assessment, which currently is 0.18 year^{-1} (Horn 1993b). Although newer results were published by Edwards (2017), these were not accepted by the Working Group and therefore they were not included in this model. Sparre & Venema (1998) and Hoenig (1983) mentioned that mortality rates estimated from longevity provide an estimate of natural mortality if fishing is negligible. The data used by Horn (1993b), collected in 1989–1992, cannot be assumed to come from a ling population with negligible fishing mortality because the time series of catches shows that a fishery had been ongoing for more than a decade. Therefore, the Horn (1993b) estimates are estimates of total mortality (Z) and can be seen as an upper limit to natural mortality (M). Nevertheless, this reasoning is itself sensitive to the assumed proportion of 1% of ling surviving to maximum age (A_{max}).

In the 2017 assessment, a solution to adequately fitting the bimodal age composition data was found, but it was not clear how or why the stock might be structured to produce this pattern (Dunn & Ballara 2019). Since the 'gap' between the age modes fell at around the age of first maturity, it is possible that their relative frequency might be determined by the frequency of scientific survey hauls hitting spawning and non-spawning aggregations.

The MCMC chains were assessed to have converged and the Bayesian approach was deemed satisfactory to provide a model to assess the status of ling in LIN 7WC. This was an improvement compared with the lesser performance of the MCMC in the previous assessment (Dunn & Ballara 2019). The improvement was most likely a result of changing the annual cycle and, in particular, replacing double normal selectivity ogives by the more parsimonious logistic function.

5. MANAGEMENT IMPLICATIONS

The assessment was accepted by the Fisheries New Zealand Deepwater Fisheries Assessment Working Group. Ling biomass in LIN 7WC in 2020 was estimated to be at about 46% of B_0, with 85% probability to be above the target reference point (40% B_0). At the current rate of exploitation (catches equal to the TACC in 2020), the stock was projected to decline to 38% of B_0 by 2025, with a 60% probability of being below B_0. The probability of the stock being below the soft (20% B_0) and hard reference points (10% B_0) were both negligible (under 1%). It is necessary to monitor future trends in biomass and review stock status in relation to the target.

6. ACKNOWLEDGMENTS

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APPENDIX 1:

Estimated catch histories (t) for LIN 7WC (Fisheries New Zealand 2020)

Year	LIN 7WC	
	trawl	line
1972	0	0
1973	85	20
1974	144	40
1975	401	800
1976	565	2 100
1977	715	4 300
1978	300	323
1979	539	360
1980	540	305
1981	492	300
1982	675	400
1983	1 040	710
1984	924	595
1985	1 156	302
1986	1 082	362
1987	1 105	370
1988	1 428	291
1989	1 959	370
1990	2 205	399
1991	2 163	364
1992	1 631	661
1993	1 609	716
1994	1 136	860
1995	1 750	1 032
1996	1 838	1 121
1997	1 749	1 077
1998	1 887	1 021
1999	2 146	1 069
2000	2 247	923
2001	2 304	977
2002	2 250	810
2003	1 980	807
2004	2 013	814
2005	1 558	871
2006	1 753	666
2007	1 306	933
2008	1 067	1 170
2009	1 089	1 009
2010	1 346	1 063
2011	1 733	1 011
2012	1 744	976
2013	1 915	1 045
2014	1 420	1 190
2015	1 561	1 157
2016	1 669	1 149
2017	1 998	1 187
2018	1 940	1 230
2019	1 487	1 347