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Tini a Tangaroa

Stock assessment of ling (*Genypterus blacodes*) in the Sub-Antarctic (LIN 5&6) for the 2017–18 fishing year

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An updated Bayesian assessment is presented for the LIN 5&6 (Sub-Antarctic) ling stock, using the general-purpose stock assessment program CASAL v2.30. This assessment incorporated all relevant biological parameters, the commercial catch histories, updated catch-per-unit-effort (CPUE) series, updated research trawl survey series, and a series of catch-at-age data from the commercial trawl and line fisheries.

The current status of the LIN 5&6 stock was estimated to be around 86–91% B_0, although the stock biomass was uncertain, due to a lack of contrast in the principal abundance index. Six alternative model runs were examined, and all produced similar estimates of current stock status. The 2015 assessment model updated to 2017 estimating free trawl survey *q*'s (as opposed to nuisance *q*'s) was used as the 2018 reference model. The 2018 base model was configured the same as the reference model, but with some changes. The base model suggested that B_0 was about 278 000 t and was very unlikely to be lower than 186 000 t; B_{2018} was approximately 254 000 t (90% of B_0). Model sensitivity runs gave different estimates of stock biomass, though similar estimates of stock status. Current stock size of LIN 5&6 was estimated to be well above the management target of 40% B_0, and was predicted to increase slightly over the next 5 years at the recent catch levels, or to decrease slightly at the level of the TACC.

1. INTRODUCTION

This document reports part of the results of Ministry for Primary Industries Project DEE201701LIND. The specific project objectives were to carry out a descriptive analysis of the commercial catch and effort data, update the standardised catch and effort analyses for the ling fisheries, and conduct a stock assessment including estimating biomass and sustainable yields for LIN 5&6 in 2017–18. The updated CPUE index series was completed by Ballara (in press), and the indices used in this assessment are presented in Appendix A.

Ling are managed as eight administrative QMAs, although five of these (LIN 3, 4, 5, 6, and 7) (Figure 1) have recently produced about 95% of landings. Research has indicated that there are at least five major biological stocks of ling in New Zealand waters (Horn 2005): the Chatham Rise, the Sub-Antarctic (including the Stewart-Snares shelf and Puysegur Bank), the Bounty Platform, the west coast of the South Island, and Cook Strait. In the stock assessment process, the same five biological stocks of ling are recognised, and are defined as follows: Chatham Rise (LIN 3 and LIN 4), Sub-Antarctic – incorporating Campbell Plateau and Stewart-Snares shelf (LIN 5, and LIN 6 west of 176º E), Bounty Plateau (LIN 6 east of 176º E), west coast South Island (LIN 7 west of Cape Farewell), and Cook Strait (those parts of LIN 2 and LIN 7 between latitudes 41° and 42° S and longitudes 174° and 175.4° E, equating approximately to Statistical Areas 016 and 017). These stocks are referred to as LIN 3&4, LIN 5&6, LIN 6B, LIN 7WC, and LIN 7CK, respectively. The previous stock assessment for LIN 5&6 was described by Roberts (2016).

The 2018 assessment for the Sub-Antarctic ling stock (LIN 5&6) used CASAL v2.30, a generalised age- or length-structured fish stock assessment model (Bull et al. 2012). This assessment incorporated two trawl biomass indices (research survey and commercial CPUE), and catch-at-age data from research survey series and from commercial line and trawl fisheries.

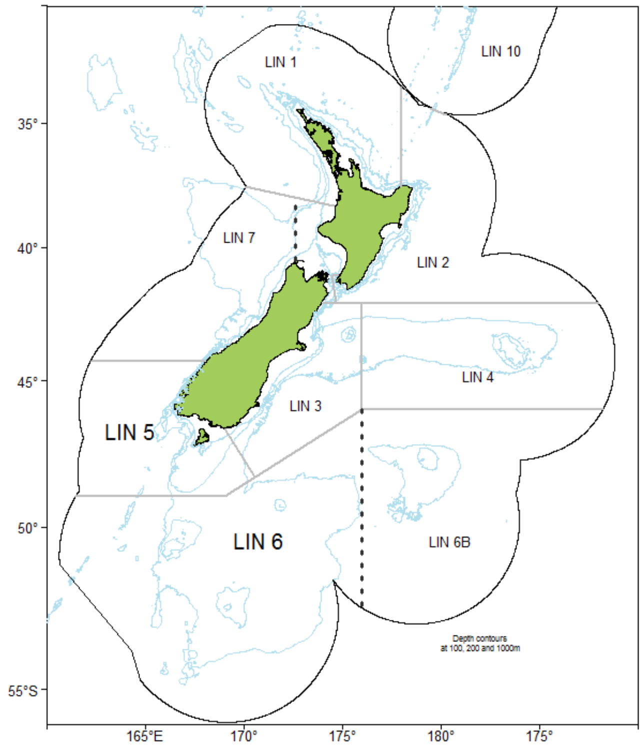

Figure 1: Area of Fishstocks LIN 3, 4, 5, 6, and 7. Adjacent ling fishstock areas are also shown, as is the 1000 m isobath. The boundaries used to separate biological stock LIN 6B from the rest of LIN 6, and the west coast South Island section of LIN 7 from the rest of LIN 7, are shown as dashed lines.

2. REVIEW OF THE FISHERY

Estimated catch histories of ling in LIN 5&6 are summarised in Table 1 (Fisheries New Zealand 2018). The trawl fishery has operated since the mid-1970s and has taken the majority of the estimated ling catch in all years since. The annual catch of the two longline fisheries (spawn and non-spawn) has varied, taking an increased proportion of the total estimated catch in the late-1970s and the 1990s. The TACC is set separately for LIN 5 and LIN 6. Landings in LIN 5 have been close to the TACC in nearly all seasons since 1986–87. The LIN 6 TACC has not been met since 2003–04 and less than 50% has been taken since 2008–09. From 1 October 2004, TACCs for LIN 5 and 6 were increased by about 20% to 3600 t and 8500 t, respectively. This followed an assessment (Horn 2004) indicating that the level of exploitation during the 1990s had little impact on the size of the Sub-Antarctic stock. The TACC for LIN 5 was then increased again to 3955 t for the 2013–14 fishing year, following the assessment by Horn et al. (2013).

Table 1: Estimated catch histories (t) for LIN 5&6. Landings have been separated by fishing method (trawl or line, "line home" refers to the non-spawning line fishery). 2018 values are required for the current assessment and were assumed based on recent landings trends.

Year	Trawl	Line home	Line spawn	Year	Trawl	Line home	Line spawn
1973	500	0	0	1996	7 351	1 012	636
1974	1 120	0	0	1997	7 137	2 471	1 152
1975	900	118	192	1998	7 512	2 567	1 330
1976	3 402	190	309	1999	5 574	2 143	986
1977	3 100	301	490	2000	7 461	1 163	1 138
1978	1 945	494	806	2001	7 950	684	1 498
1979	3 707	1 022	1 668	2002	7 637	438	1 281
1980	5 200	0	0	2003	8 103	196	1 000
1981	4 427	0	0	2004	8 355	730	512
1982	2 402	0	0	2005	7 082	262	965
1983	2 778	5	1	2006	6 805	160	624
1984	3 203	2	0	2007	7 899	34	671
1985	4 480	25	3	2008	7 809	343	873
1986	3 182	2	0	2009	5 389	263	422
1987	3 962	0	0	2010	4 282	863	316
1988	2 065	6	0	2011	4 697	481	137
1989	2 923	10	2	2012	4 275	852	351
1990	3 199	9	4	2013	6 320	33	313
1991	4 140	236	97	2014	5 902	806	258
1992	7 070	429	291	2015	5 931	612	242
1993	7 633	677	829	2016	5 782	414	198
1994	5 130	562	885	2017	5 841	677	215
1995	5 906	1 433	1 085	2018	5 864	627	228

3. MODEL INPUTS, STRUCTURE, AND ESTIMATION

3.1 Model input data

A summary of all observations used in this assessment is given in Table 2**Error! Reference source not found.**. The latest catch-at-age distributions for LIN 5&6 were created as part of Project MID201001D and were reported by Horn & Sutton (2017). These include age composition estimates for the commercial longline spawning fishery, commercial longline non-spawning fishery and commercial trawl fishery. The initial formulation of series of numbers-at-length data for ling from various trawl and longline fisheries was described by Horn (2002). These series have been included in some previous stock assessment models where a lack of age data precludes their input as catch-at-age. However, considerable volumes of catch-at-age data are now available and catch-at-length data are no longer used as model inputs for this stock. The updated commercial fishery CPUE index series was completed by Ballara (in press) and indices used in this assessment are presented in Appendix A.

Table 2: Summary of the data series used for the assessment modelling, including source years (Years).

Data series	Years
Trawl survey biomass (*Tangaroa*, Nov-Dec)	1992–94, 2001–10, 2012–13, 2015, 2017
Trawl survey proportion at age (*Tangaroa*, Nov–Dec)	1992–94, 2001–10, 2012–13, 2015, 2017
Trawl survey proportion at age (*Amaltal Explorer*, Nov-Dec)	1990
Trawl survey biomass (*Tangaroa*, Mar–May)	1992–93, 1996, 1998
Trawl survey proportion at age (*Tangaroa*, Mar–May)	1992–93, 1996, 1998
CPUE (longline, spawning fishery)	1992–2017
CPUE (longline, non-spawning fishery)	1992–2017
Commercial longline proportion-at-age (spawning, Oct–Dec)	2000–08, 2010, 2017
Commercial longline proportion-at-age (non-spawn, Feb–Jul)	1999, 2001, 2003, 2005, 2009–12, 2014
Commercial trawl proportion-at-age (Sep–Apr)	1992–94, 1996, 1998, 2001–13, 2014–2017

Estimates of biological parameters and assumed values for model parameters used in the assessments are given in Table 3. Growth and length-weight relationships were revised most recently by Horn (2005). The maturity ogive represents the proportion of fish that are estimated to be mature at each age (Horn 2005). The proportion spawning was assumed to be 1.0 in the absence of data to estimate this parameter. A stock-recruitment relationship (Beverton-Holt, with steepness 0.84) was assumed (steepness following Shertzer & Conn 2012). Variability around mean length from the von Bertalanffy age-length relationship was assumed to be normal with a constant CV of 0.12. The values of stock-recruitment steepness and CV associated with the age-length relationship were agreed by the Deepwater Working Group.

Table 3: Biological and other input parameters used in the ling assessment.

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

Female		Male	
a	*b*	*a*	*b*
0.00128	3.303	0.00208	3.190

2. von Bertalanffy growth parameters (n, sample size)

Male				Female			
n	*k*	t_0	L_∞	*n*	*k*	t_0	L_∞
2 884	0.188	–0.67	93.2	4 093	0.124	–1.26	115.1

3. Maturity ogives (proportion mature at age)

Age	3	4	5	6	7	8	9	10
Male	0.00	0.00	0.10	0.30	0.50	0.80	1.00	1.00
Female	0.00	0.00	0.05	0.10	0.30	0.50	0.80	1.00

4. Miscellaneous parameters

Stock-recruitment steepness	0.84
Recruitment variability *CV*	0.60
Ageing error *CV*	0.06
Proportion by sex at birth	0.50
Proportion spawning	1.00
Maximum exploitation rate (U_{max})	0.60

Two series of research trawl survey indices were available – from the Summer and Autumn trawl surveys (
Table 4). Biomass estimates from the trawl surveys were used as relative biomass indices, with associated CVs estimated from the survey analysis (O'Driscoll et al., 2018). The CVs available for these estimates of relative abundance allow for sampling error only. An additional (process) error CV of 0.15 was added to the trawl survey biomass index and the longline CPUE index, following the recommended method of Francis (2011).

Table 4: Series of relative biomass indices (t) from *Tangaroa* (TAN) trawl surveys (with coefficients of variation, CV) available for the assessment modelling.

Trip code	Date	Biomass (t)	CV (%)
TAN9105	Nov-Dec 1991	24 090	7
TAN9211	Nov-Dec 1992	21 370	6
TAN9310	Nov-Dec 1993	29 750	12
TAN0012	Dec 2000	33 020	7
TAN0118	Dec 2001	25 060	7
TAN0219	Dec 2002	25 630	10
TAN0317	Nov-Dec 2003	22 170	9
TAN0414	Dec 2004	23 790	12
TAN0515	Dec 2005	19 700	9
TAN0617	Dec 2006	19 640	12
TAN0714	Dec 2007	26 490	8
TAN0813	Dec 2008	22 840	10
TAN0911	Dec 2009	22 710	10
TAN1117	Nov-Dec 2011	23 180	12
TAN1215	Nov-Dec 2012	27 010	11
TAN1412	Nov-Dec 2014	30 010	8
TAN1614	Nov-Dec 2016	26 656	16
TAN9204	Mar-Apr 1992	42 330	6
TAN9304	Apr-May 1993	33 550	5
TAN9605	Mar-Apr 1996	32 130	8
TAN9805	Apr-May 1998	30 780	9

Data from trawl surveys could be entered into the model either as (i) biomass and proportions-at-age, or (ii) numbers-at-age. For the ling assessments the preference was for (i), i.e., entering trawl survey biomass and trawl survey proportions-at-age data as separate input series (as recommended by Francis et al., 2003). Lognormal errors, with known CVs, were assumed for all relative biomass observations.

Catch proportions-at-age were estimated using the NIWA catch-at-age software (Bull & Dunn 2002). Ageing error for the observed proportions-at-age data was assumed to have a discrete normal distribution with a CV of 0.06. As in the previous assessment (Roberts 2016), the age composition data for the trawl survey and commercial fisheries were sexed in all model runs.

The assumed errors for the proportion-age-age observations were multinomial, and were lognormal for all other observations. The effective sample sizes for the proportion-at-age estimates were estimated following method TA1.8 as described in Appendix A of Francis (2011). The initial effective sample sizes were reweighted to give the multinomial effective sample sizes for the proportion-at-age data given in Table 5.

Table 5: Multinomial effective sample sizes (EFS) assumed for the age composition data sets. The initial EFS are estimated from the sample data, and the reweighted EFS have been scaled following the technique of Francis (2011).

Summer trawl survey proportion-at-age

Fishing Year	Initial EFS	Reweighted EFS
1990	283	58
1992	541	111
1993	481	99
1994	483	99
2001	583	120
2002	517	106
2003	526	108
2004	420	86
2005	370	76
2006	364	75
2007	367	75
2008	435	89
2009	334	68
2010	401	82
2012	407	83
2013	489	100
2015	458	94
2017	379	78

Autumn trawl survey proportion-at-age

Fishing Year	Initial EFS	Reweighted EFS
1992	437	70
1993	483	78
1996	397	64
1998	399	64

Fishery longline spawn proportion-at-age

Fishing Year	Initial EFS	Reweighted EFS
2000	489	73
2001	240	36
2002	393	59
2003	480	72
2004	411	61
2005	175	26
2006	322	48
2007	276	41
2008	90	13
2010	139	21
2017	171	25

Fishery trawl proportion-at-age

Fishing Year	Initial EFS	Reweighted EFS
1992	475	39
1993	318	26
1994	259	21
1996	321	27
1998	236	20
2001	249	21
2002	338	28
2003	579	48
2004	375	31
2005	411	34
2006	453	38
2007	327	27
2008	352	29
2009	593	49
2010	425	35
2011	421	35
2012	465	39
2013	586	49
2014	447	37
2015	546	45
2016	600	50
2017	708	59

Fishery longline non-spawn proportion-at-age

Fishing Year	Initial EFS	Reweighted EFS
1999	614	76
2001	304	37
2003	235	29
2005	307	38
2009	192	24
2010	189	23
2011	261	32
2012	329	40
2014	215	26

3.2 Model structure

The stock assessment model partitions the Sub-Antarctic population into sexes and age groups 3–25, with a plus group at age 25. There are three fisheries (trawl, longline spawn and longline non-spawn) in the stock. The model's assumed annual cycle for the stock is described in Table 6.

As in the previous assessment, natural mortality (M) was estimated. A constant M with respect to age was assumed. Sex-specific age-based selectivity ogives were estimated separately for the two trawl survey series, trawl fishery and the two line fisheries. The trawl fishery ogives were estimated assuming a double normal (females) and capped-double normal parameterisation (males). For the trawl survey and line fisheries, a logistic selectivity was used for females and a capped-logistic parametrisation was used for males. A sensitivity run used a double normal selectivity for the trawl and non-spawning line fisheries. The parameterisations of the double normal and logistic curves are given by Bull et al. (2012). Selectivity parameters were assumed constant.

Table 6: Annual cycles of the LIN 5&6 stock models, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur within a time step occur after all other processes, with half of the natural mortality for that time step occurring before and half after the fishing mortality.

Step	Period	Processes	M^1	Age[2]	Observations	
					Description	$\%Z^3$
1	Dec–Sep	Trawl & Line Spawn fisheries	0.33	0.0	Trawl survey (summer)	0.1
					Trawl survey (autumn)	0.5
		Increment ages			Line (spawn) CPUE	0.7
					Line (spawn) catch-at-age	
					Trawl catch-at-age	
2	Oct–Nov	Recruitment	0.67	0. 5	Line (non-spawn) CPUE	0.5
		Line Non-spawn fishery			Line (non-spawn) catch-at-age	

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 have occurred by the start of that time step.
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.

3.2.1 Prior distributions and penalty functions

The assumed prior distributions used in the assessment are given in Table 7**Error! Reference source not found.**. Most priors were intended to be uninformative and were specified with wide bounds. The exception was the choice of informative priors for the *Tangaroa* trawl survey *q*, which were estimated assuming that the catchability constant was a product of areal availability (0.5–1.0), vertical availability (0.5–1.0), and vulnerability between the trawl doors (0.03–0.40). The resulting (approximately lognormal) distribution had mean 0.13 and CV 0.70, with bounds assumed to be 0.02 to 0.30.

A penalty function was added to the likelihood to constrain the model so that any combination of parameters that did not allow the historical catch to be taken was penalised (see Bull et al., 2012). A penalty was also applied to the estimates of year class strengths to encourage estimates that average to 1.

Table 7: Assumed prior distributions and bounds for estimated parameters in the assessment. Parameter values are the mean (in natural space) and CV for lognormal.

Parameter description	Distribution	Parameters		Bounds	
				lower	upper
B_0	Uniform-log	–	–	50 000	800 000
Year class strengths	Lognormal	1.00	0.70	0.01	100
Trawl survey *q*	Lognormal	0.13	0.70	0.02	0.30
Selectivities	Uniform	–	–	0.00	5–200*
M	Uniform	–	–	0.01	0.6

* A range of maximum values were used for the upper bound

3.3 Model estimation

Model parameters were estimated with Bayesian methods implemented using the CASAL v2.30 software. Only the mode of the joint posterior distribution (MPD) was estimated in preliminary runs. For final runs, the full posterior distribution was sampled using Markov Chain Monte Carlo (MCMC) methods, based on the Metropolis-Hastings algorithm. Full details of the CASAL algorithms, software, and methods were detailed by Bull et al. (2012). The 2015 assessment noted strong correlation between B_0 and q in the 2015 base model configuration (Roberts, 2016), which led to poor MCMC diagnostics. In this assessment, after running a complete MCMC run, the covariance matrix was re-calculated, and this updated covariance matrix used in each of three new chains for each of the three final models. MCMCs had a total chain length of 4×10^6 iterations, a burn-in length of 1×10^6 iterations, with every 1000th sample kept from the final 3×10^6 iterations (i.e., a final sample of length 3000 was taken from the Bayesian posterior).

Year class strengths were assumed known (and equal to 1) when observational data was deemed inadequate (i.e., fewer than three observed data points) or when no catch-at-age data were available for that cohort. Otherwise, year class strengths were estimated, under the assumption that the estimates from the model must average 1. The Haist parameterisation for year class multipliers was used here (see Bull et al. (2012) for details).

4. MODEL ESTIMATES

4.1 The base model and sensitivity runs

An array of model sensitivity runs was examined relative to a reference model, which differed in terms of their parameterisation, types of observations used, and the relative weighting of different observation types (Table 8). The base model run (base model) was configured as the 2014–15 assessment (Roberts 2016), with the exception that: a process error of 0.11 was used for the trawl survey biomass indices (previously 0.15), M was constant with respect to age, and a revised annual cycle for the spawn and non-spawn line fisheries was used (to align the CPUE with the fishery timing within the model). Details of the base model configuration are given in Table 8. As in the previous assessment, a sensitivity run fitting the base model to CPUE was investigated, however, this model was deemed by the Deepwater Working Group (DWWG) to be unacceptable. Although, this sensitivity run predicted %B_0 was still above the 40% threshold, the DWWG decided that the CPUE spawn index was not adequately reflecting abundance due to a decline in catch in recent years; i.e., there was too much uncertainty as to whether the CPUE index was a reliable index of abundance for LIN5&6. The DWWG decided that the 2018 assessment should not include CPUE, but subsequent assessments should explore the efficacy of using CPUE.

Five other MPD sensitivity runs were done: (1) the updated 2015 model using free q’s (hereafter referred to as the reference model) (2) using nuisance q’s, (3) using a logistic selectivity ogive for longline spawn only, (4) double the mean of the prior for q for the trawl surveys, and (5) halved multinomial weightings associated with age composition estimates.

Table 8: Key assumptions for MPD model runs, showing estimated B_0 (t) and B_{2018} (%B_0).

Key run assumptions	B_0 (t)	B_{2018} (%B_0)
1. Reference model	308 952	93.5
Process error = 0.15 for trawl survey biomass indices		
Logistic (or capped logistic for male) selectivity for survey and all line fisheries (double normal for trawl fishery)		
Double exponential functional form - M		
Free q’s		
CPUE data not included		
2. Base model	326 604	91.1

Same as reference run, except: Model annual cycle changed to align CPUE and fishery timing Updated catches (1992–2017); adjusted to account for annual cycle change Process error = 0.11 for trawl survey biomass indices Constant (estimated) *M*		
3. Nuisance *q*’s run	356 730	92.5
Same as base model, except nuisance *q*’s for trawl survey		
4. Domed run	352 725	91.1
Same as base model, except logistic selectivity ogive for longline spawn only		
5. *q* Prior run	253 844	85.8
Same as base model, except the mean of prior for *q* was doubled for both summer and autumn Trawl surveys		
6. Multinomial run	333 183	92.1
Same as base model, except multinomial weightings halved		

4.2 MPD runs

All MPD model runs produced a similar biomass trajectory: an overall slight decline from the early 1970s to the late 1990s, followed by a rebuilding phase to 2018 (Figure 2). The slight biomass decline about 1980 corresponded with a period of moderate catches (Table 1) followed by the recruitment of some strong year classes in the mid-1970s to early-1980s (Figure 3), resulting in a slight rebuild of biomass to 1990. Throughout the 1990s, catches increased to peak in 1997 and recruiting year classes were generally weak, resulting in a steady decline in the biomass trajectory to its minimum in the late-1990s. During the 2000s there was a steady rebuild in biomass particularly in the early part of the decade when three very strong year classes (e.g. 1993–1995) would have recruited into the fishery (Figure 3).

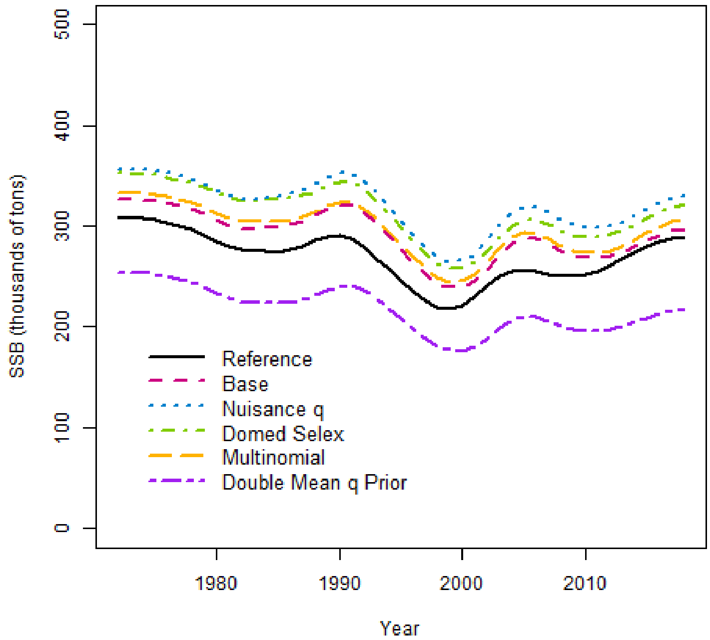

Figure 2: Estimated spawning stock biomass (SSB) for all MPD model runs.

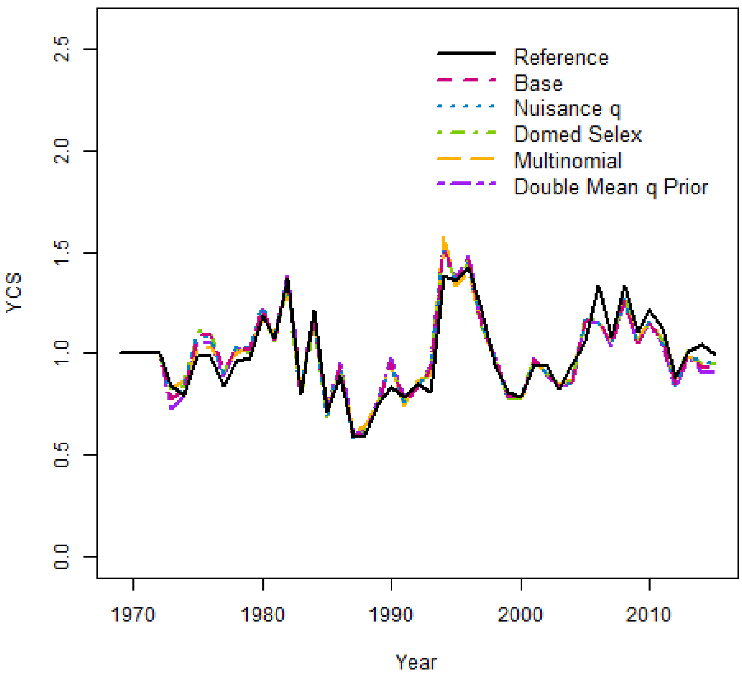

Figure 3: Estimated relative year class strength for all MPD model runs.

The summer survey proportion-at-age observations and fits are shown in Figure 4 and Figure 5. The fits to the composition data were reasonably good for the reference run. Relatively weak or strong year classes (e.g. in the mid-1990s) could be identified in survey data (Table 9 and Table 10), although they were not easily differentiated at ages 15 and older when the relative catch proportions were too low (Figure 4 and Figure 5).

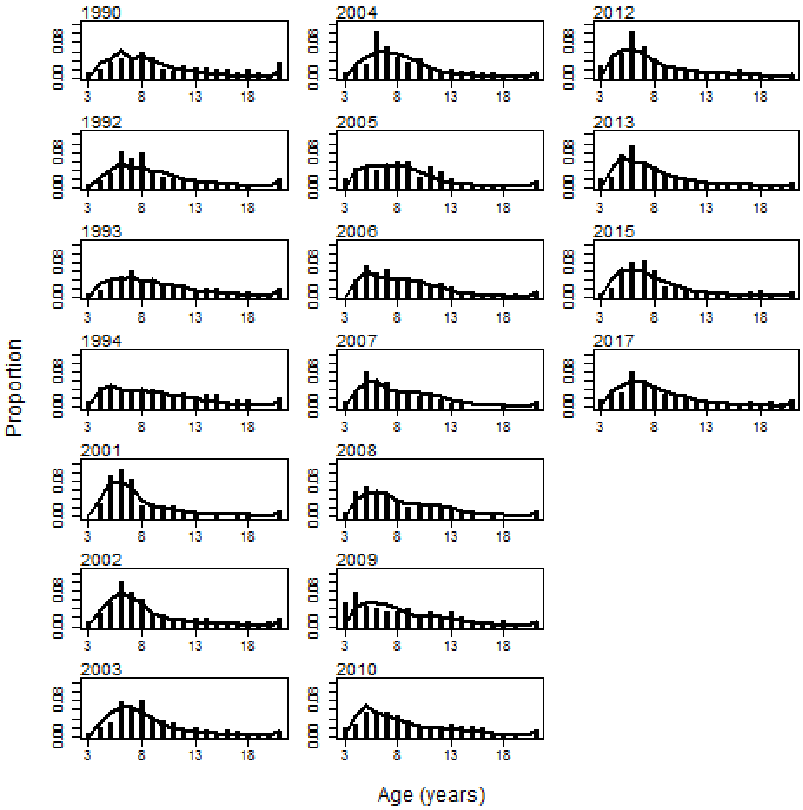

Figure 4: Base run fit (line) to observed proportion-at-age (bars) for male ling in the summer trawl survey.

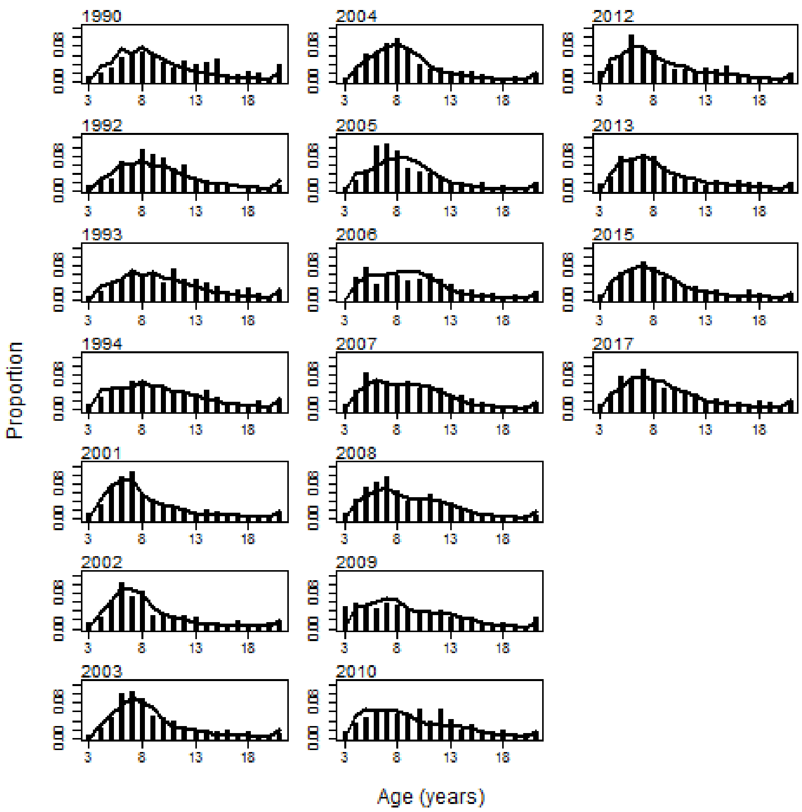

Figure 5: Base run fit (line) to observed proportion-at-age (bars) for female ling in the summer trawl survey.

Table 9: Proportions of ling at age by fishing year (labelled as year-ending) for males in the summer trawl survey. Higher values have darker shading.

Age	1990	1992	1993	1994	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2012	2013	2015	2017
3	0.0074	0.0051	0.0046	0.0102	0.0036	0.0063	0.0013	0.0062	0.0152	0.0023	0.0093	0.0050	0.0493	0.0154	0.0212	0.0161	0.0033	0.0134
4	0.0135	0.0099	0.014	0.0397	0.0265	0.0273	0.0162	0.0235	0.0402	0.0346	0.0316	0.0537	0.071	0.0238	0.0387	0.0212	0.0179	0.0279
5	0.0298	0.0290	0.0303	0.0461	0.0879	0.0482	0.0277	0.0256	0.0390	0.0670	0.0765	0.0661	0.0413	0.0492	0.0514	0.0698	0.0563	0.0299
6	0.0378	0.0774	0.0440	0.0347	0.1036	0.0976	0.0737	0.1014	0.0346	0.0512	0.0514	0.0469	0.0389	0.0497	0.1009	0.0912	0.0744	0.0760
7	0.0352	0.0627	0.0558	0.0328	0.0794	0.0712	0.0591	0.0644	0.0411	0.0596	0.0507	0.0493	0.0315	0.0505	0.0667	0.0563	0.0792	0.0571
8	0.0549	0.0735	0.0350	0.0360	0.0202	0.0566	0.0777	0.0439	0.0552	0.0333	0.0341	0.0320	0.0301	0.0406	0.0368	0.0421	0.0542	0.0439
9	0.0412	0.0304	0.0349	0.0363	0.0239	0.0262	0.0392	0.0321	0.0565	0.0384	0.0256	0.0175	0.0366	0.0295	0.0173	0.0290	0.0213	0.0230
10	0.0143	0.0212	0.0239	0.0273	0.0232	0.0218	0.0322	0.0398	0.0203	0.0354	0.0189	0.0214	0.0160	0.0171	0.0141	0.0242	0.0241	0.0209
11	0.0112	0.0154	0.0220	0.0195	0.0203	0.0159	0.0271	0.0209	0.0432	0.0217	0.0281	0.0170	0.0299	0.0135	0.0153	0.0145	0.0174	0.0164
12	0.0242	0.0160	0.0254	0.0283	0.0056	0.0153	0.0056	0.0102	0.0298	0.0289	0.0133	0.0174	0.0158	0.0173	0.0145	0.0101	0.0115	0.0113
13	0.0200	0.0087	0.0098	0.0203	0.0062	0.0150	0.0149	0.0144	0.0146	0.0220	0.0064	0.0185	0.0308	0.0240	0.0065	0.0071	0.0091	0.0096
14	0.0191	0.0080	0.0172	0.0231	0.0033	0.0124	0.0088	0.0112	0.0043	0.0032	0.0048	0.0069	0.0188	0.0167	0.0075	0.0069	0.0068	0.0044
15	0.0163	0.0078	0.0178	0.0261	0.0054	0.0075	0.0037	0.0106	0.0051	0.0076	0.0026	0.0094	0.0110	0.0185	0.0115	0.0024	0.0049	0.0060
16	0.0132	0.0034	0.0077	0.0109	0.0032	0.0048	0.0114	0.0069	0.0039	0.0045	0.0024	0.0022	0.0077	0.0131	0.0137	0.0049	0.0028	0.0048
17	0.0068	0.0049	0.0073	0.0129	0.0043	0.0066	0.0054	0.0068	0.0025	0.0042	0.0007	0.0060	0.0028	0.0035	0.0089	0.0061	0.0070	0.0085
18	0.0134	0.0034	0.0077	0.0111	0.0067	0.0062	0.0016	0.0035	0.0022	0.0050	0.0035	0.0012	0.0084	0.0022	0.0029	0.0036	0.0129	0.0050
19	0.0078	0.0010	0.0064	0.0014	0.0019	0.0026	0.0034	0.0048	0.0008	0.0051	0.0014	0.0018	0.0020	0.0013	0.0026	0.0038	0.0032	0.0072
20	0.0021	0.0016	0.0035	0.0025	0.0018	0.0070	0.0036	0.0018	0.0001	0.0008	0.0011	0.0005	0.0001	0.0007	0.0004	0.0030	0.0011	0.0033
21	0.0323	0.0148	0.0171	0.0152	0.0085	0.0124	0.0075	0.0068	0.0110	0.0053	0.0080	0.0076	0.0014	0.0121	0.0040	0.0084	0.0083	0.0138

Table 10: Proportions of ling at age by fishing year (labelled as year-ending) for females in the summer trawl survey. Higher values have darker shading.

Age	1990	1992	1993	1994	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2012	2013	2015	2017
3	0.0056	0.0059	0.0051	0.0071	0.0102	0.0094	0.0027	0.0025	0.0027	0.0001	0.0091	0.0085	0.0445	0.011	0.0172	0.0131	0.0073	0.0097
4	0.0162	0.0204	0.0154	0.0251	0.0276	0.0227	0.0190	0.0216	0.0188	0.0475	0.0386	0.0397	0.0529	0.0316	0.0347	0.0277	0.0361	0.0291
5	0.0284	0.0247	0.034	0.0430	0.0726	0.0593	0.0426	0.0576	0.0422	0.0715	0.0797	0.0684	0.0482	0.0405	0.0501	0.0736	0.0588	0.0700
6	0.0518	0.0618	0.0432	0.0445	0.0931	0.1016	0.0974	0.0569	0.0964	0.0339	0.0650	0.0792	0.0421	0.0635	0.1005	0.0702	0.066	0.0695
7	0.0557	0.0592	0.0627	0.0599	0.1050	0.0697	0.1015	0.0801	0.1005	0.0519	0.0605	0.0924	0.0524	0.0579	0.0752	0.0789	0.0833	0.0875
8	0.0606	0.0907	0.0525	0.0585	0.0484	0.0802	0.0862	0.0929	0.0854	0.0505	0.0541	0.0600	0.0486	0.0501	0.0650	0.0731	0.0728	0.0639
9	0.0540	0.0789	0.0519	0.0477	0.0421	0.0261	0.0458	0.0698	0.0454	0.0405	0.0601	0.0389	0.042	0.0501	0.0364	0.0512	0.0491	0.0437
10	0.0396	0.0692	0.0375	0.0441	0.0297	0.0260	0.0411	0.0350	0.0407	0.0450	0.0451	0.0359	0.0384	0.0631	0.0214	0.0281	0.0382	0.0473
11	0.0285	0.0453	0.0674	0.0332	0.0234	0.0257	0.0352	0.0238	0.0348	0.0575	0.0481	0.0517	0.0286	0.0325	0.0242	0.0267	0.0229	0.041
12	0.0414	0.0537	0.0446	0.0349	0.0206	0.0242	0.0231	0.0272	0.0229	0.0428	0.0435	0.0377	0.0392	0.0624	0.0179	0.0164	0.0297	0.0336
13	0.0341	0.0234	0.0435	0.0338	0.0094	0.0214	0.0163	0.0192	0.0161	0.0333	0.0296	0.0345	0.0238	0.0378	0.028	0.0085	0.0192	0.0183
14	0.0393	0.0195	0.0352	0.0392	0.0181	0.0113	0.0145	0.0198	0.0144	0.0183	0.0294	0.0218	0.0211	0.0151	0.0232	0.0183	0.0217	0.0202
15	0.0466	0.0157	0.0289	0.0235	0.0151	0.0096	0.0091	0.0178	0.0090	0.0202	0.0189	0.0091	0.0199	0.0249	0.0302	0.0142	0.0128	0.0151
16	0.0124	0.0136	0.0147	0.0126	0.0084	0.0080	0.0164	0.0096	0.0162	0.0119	0.0136	0.0111	0.0098	0.0151	0.0109	0.0193	0.0098	0.0133
17	0.0105	0.0017	0.0202	0.0114	0.0102	0.0128	0.0056	0.0049	0.0055	0.0129	0.0088	0.0059	0.0062	0.0089	0.0059	0.0149	0.0212	0.0093
18	0.0172	0.007	0.0223	0.0082	0.0066	0.0070	0.0090	0.0049	0.0089	0.0064	0.0042	0.006	0.0096	0.0146	0.0066	0.0155	0.0133	0.0150
19	0.0165	0.0043	0.0113	0.0156	0.0058	0.0036	0.0037	0.0058	0.0037	0.0068	0.005	0.0048	0.0073	0.0082	0.0018	0.0092	0.0055	0.0130
20	0.0052	0.0025	0.0052	0.0058	0.0051	0.0084	0.0031	0.0032	0.0031	0.0032	0.0044	0.0066	0.0013	0.008	0.0024	0.005	0.0056	0.0048
21	0.0358	0.0083	0.0198	0.0174	0.0133	0.0121	0.0077	0.0125	0.0138	0.0157	0.0118	0.0072	0.0207	0.0061	0.0136	0.0155	0.0112	0.0136

Two trawl survey biomass series were available for the LIN 5&6 stock (see
Table 4) and fits to the two series are shown in Figure 6. The autumn series was relatively short but appeared to be well-fitted. The summer series was well-fitted, with the exception of 1994 and 2001. Estimates of trawl survey *q* in the Base model run were very similar – these were 0.11 for the autumn survey and 0.08 for the summer survey.

The reference model assumed an additional 'process' error of 0.15 for both the summer and autumn trawl surveys. The Base model run estimated a process error for the trawl surveys of 0.11 and 0.0001 for the summer and autumn surveys respectively. The DWWG decided to use the same process error for both summer and autumn surveys, due to the small sample size in the autumn survey (i.e., only 4 data points). Based on Francis (2011), an iterative recalculation method was then applied to recalculate the catch-at-age sample size multipliers (N_{eff}).

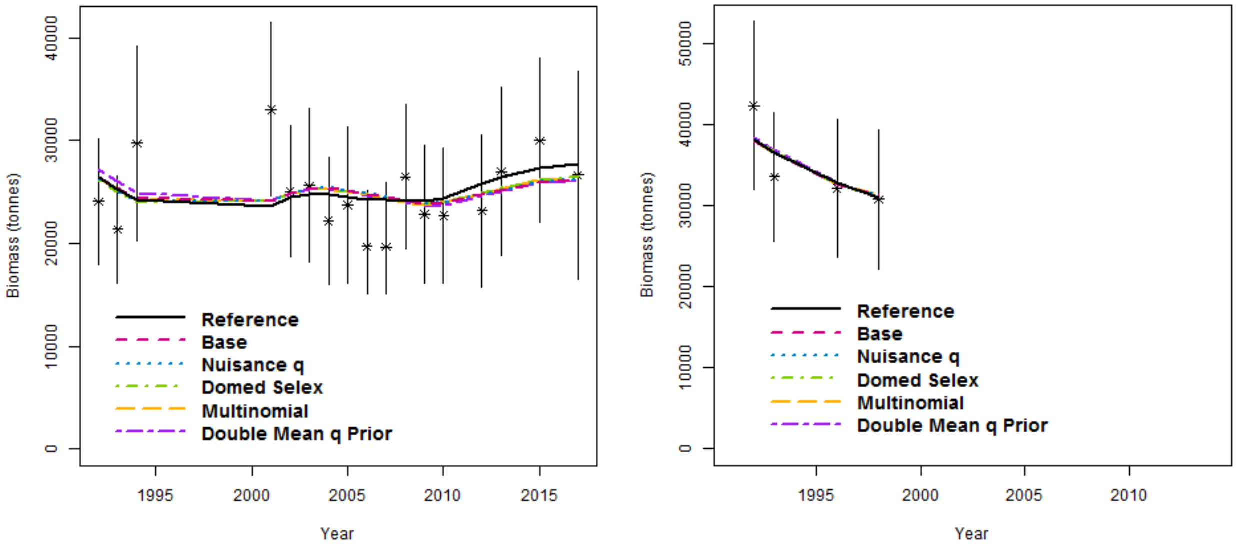

Figure 6: MPD model fit (lines – all 6 MPD runs) to observed relative biomass (points – error bars are the 95% confidence intervals) for the summer (left) and autumn (right) research trawl survey.

The base model, and all other sensitivity runs, assumed a constant *M* with respect to age. Among all 6 model runs, the estimated *M* was between 0.19–0.21, with an average estimate of 0.20 across the runs.

The effect of allowing the trawl and non-spawning line fishery selectivity ogives to be domed was examined in the Domed model (i.e. a logistic selectivity was used for the spawning longline fishery only). This had the effect of reducing the estimated selectivity of females after age 10 (Figure 7). The domed trawl survey ogives indicated that fish became less vulnerable to the trawl with increasing age (Figure 8). This would suggest that there was a cryptic biomass of older-aged fish unavailable to the trawl fisheries and surveys in the stock area.

The overall fit for the model allowing domed trawl survey and non-spawning line fishery ogives was slightly better than for the Base model, particularly for the trawl survey and non-spawning line fishery at-age data (Table 11), though the gain in likelihood values (3 relative to the Base model) was not deemed sufficient to warrant the inclusion of this run in the final (MCMC) runs.

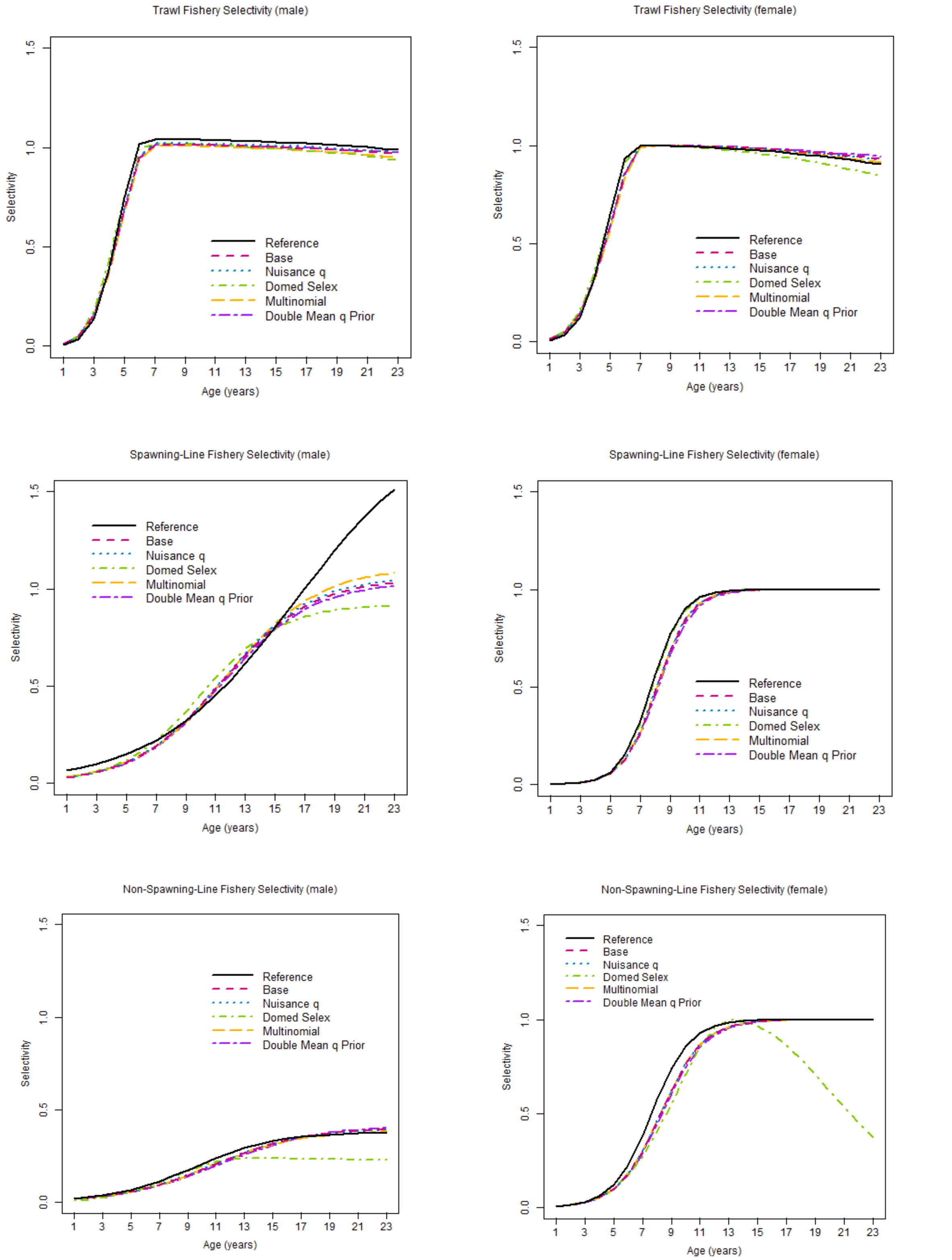

Figure 7: Estimated ogive for selectivity-at-age male (left) and female ling (right) for the trawl fishery (top), spawning line fishery (middle) and non-spawning line fishery (bottom) for all MPD runs.

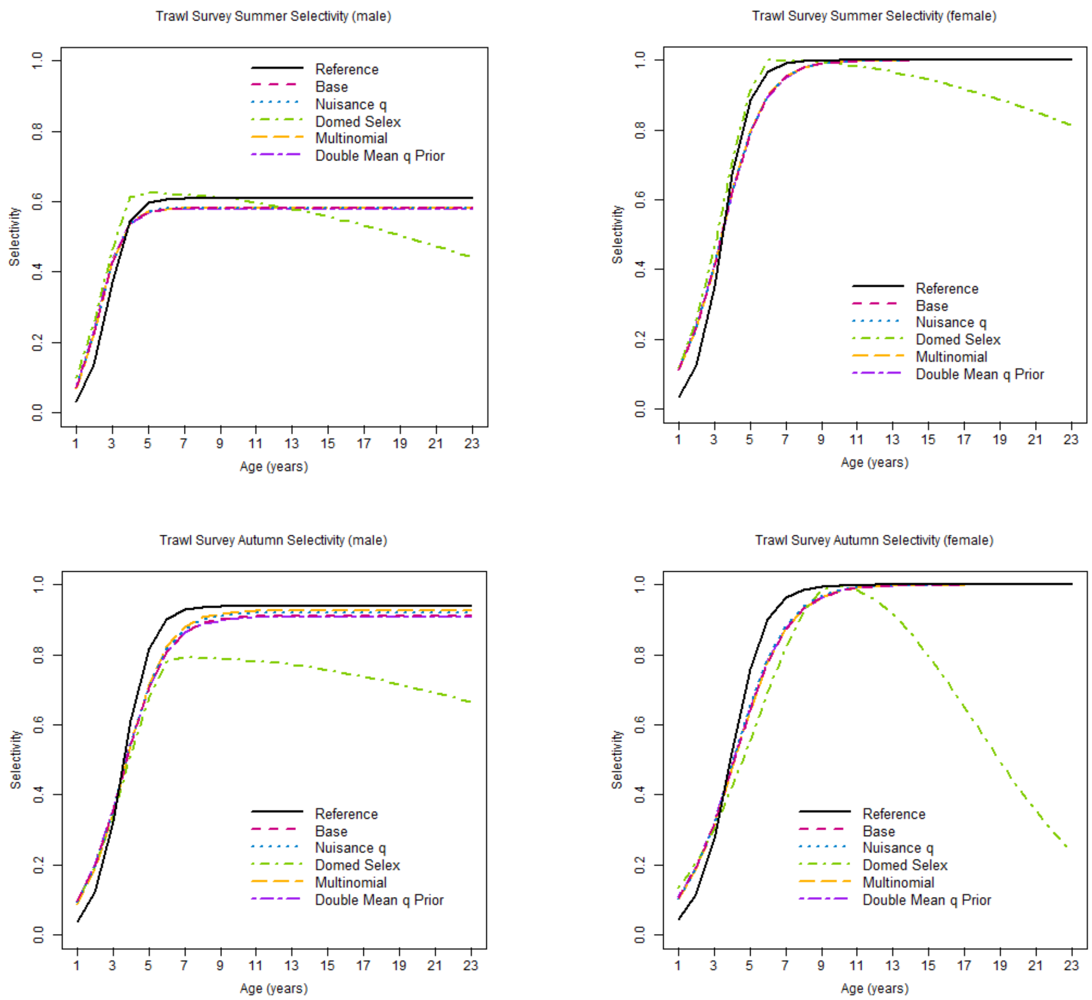

Figure 8: Estimated ogive for selectivity-at-age male (left) and female ling (right) for the summer (top) and autumn trawl (bottom) survey for all MPD runs.

Table 11: Negative log likelihood of all data series for MPD fits of all model runs.

Data series	Reference	Base	Nuisance *q*'s	Domed	Double Mean q Prior	Halved Multinomial Weightings
Survey biomass (autumn)	-6.8	-7.5	-7.5	-7.5	-7.5	-7.5
Survey biomass (summer)	-23.9	-23.9	-23.9	-24.1	-23.8	-24.2
Survey age (autumn)	175.7	186.6	186.6	184.9	186.7	133.1
Survey age (summer)	835.9	897.9	897.9	897.3	898.2	646.3
Line fishery age (non-spawn)	275.7	275.7	275.7	274.4	275.6	212.7
Line fishery age (spawning)	363.3	363.2	363.2	364.9	363.0	257.0
Trawl fishery age	682.6	696.4	696.3	695.0	696.4	486.9
Priors & penalties	-6.1	-6.3	-6.3	-6.2	-5.4	-4.6
Total	2297.2	2382.9	2382.9	2379.5	2384.0	1698.5

Two CPUE series were available for the LIN 5&6 stock, one from each of the two line fisheries (see Appendix A). No obvious sources of bias were apparent for either of the series, but because they were fishery-dependent series they were considered to be less reliable as indices of relative abundance compared to the trawl survey series. Fits to the two CPUE series, when they were included in a sensitivity run, were reasonable and there was no obvious trend in the residuals (Figure 9).

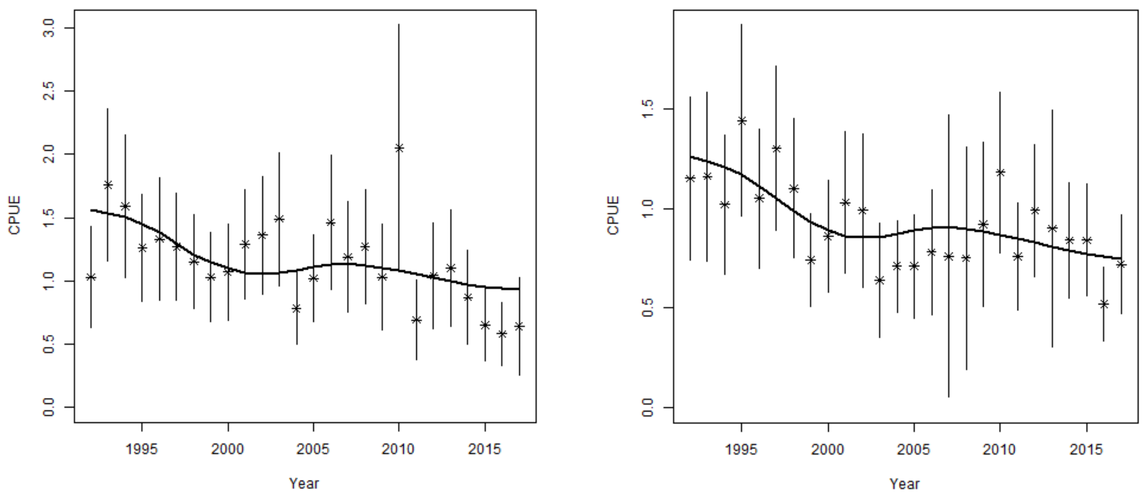

Figure 9: MPD model fit (line) to observed CPUE series (points – error bars are the 95% confidence intervals) for the spawning (left) and non-spawning (right) line fisheries.

All six models produced very similar estimates of stock status in 2018 (B_{2018}), ranging from 86% to 93% of B_0 (91% B_0 for the base run), though B_0 was quite variable across model runs (ranging from 253 000 t – 357 000 t) (Table 8). Estimated annual fishing pressures did not exceed 0.10 for any model run (Figure 10).

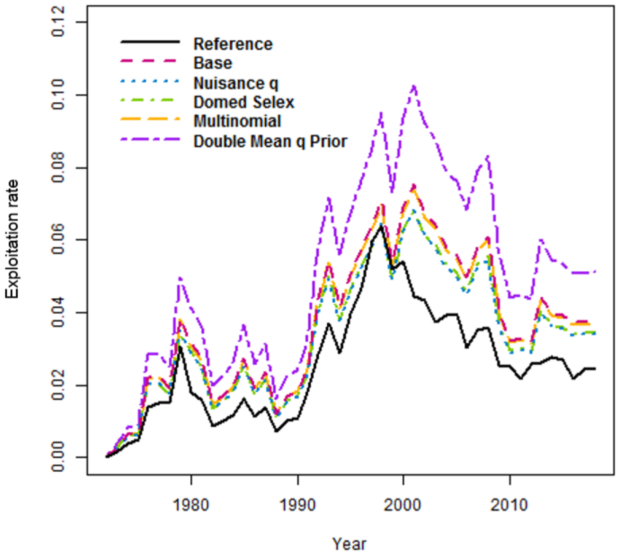

Figure 10: Estimated total annual exploitation rate for all MPD model runs.

4.3 MCMC runs

Following the investigations above with MPD model fits, the Deepwater Working Group concluded that three of the six models were to be fully investigated in MCMC runs: the Reference model, Base model and one sensitivity model (Nuisance q) were investigated. Descriptions of all three models are provided in Section 5.1 and Table 8.

4.3.1 MCMC estimates

MCMC estimates of the median of the posterior distribution, and 95% percentile credible intervals, are reported for the key output parameters. A visual inspection of the chains for B_0 suggested reasonably good mixing for the three model runs (Figure 11). For the Base run, there was a small difference in the upper limit to the estimates of B_0, across the three chains, although the medians were very similar (Figure 13). The chains for B_{2018} (%B_0) were reasonable for all model runs (Figure 12) and, for the Base run, the Working Group considered that there was acceptable agreement between the three chains, and they were combined for final parameter estimates (Figure 13). As such, the degree of convergence under the Base model was deemed adequate by the Deepwater Working Group for the purposes of this stock assessment.

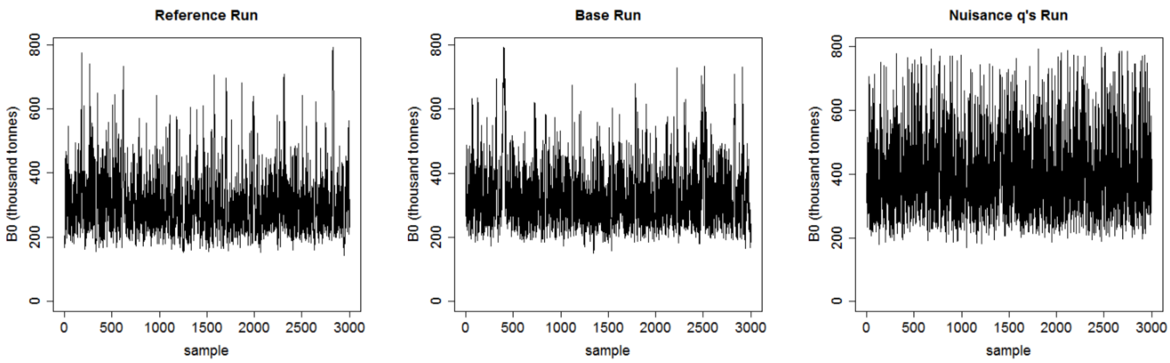

Figure 11: Trace diagnostic plot of the MCMC chain for estimates of B0 for the Reference, Base, and Nuisance q's runs.

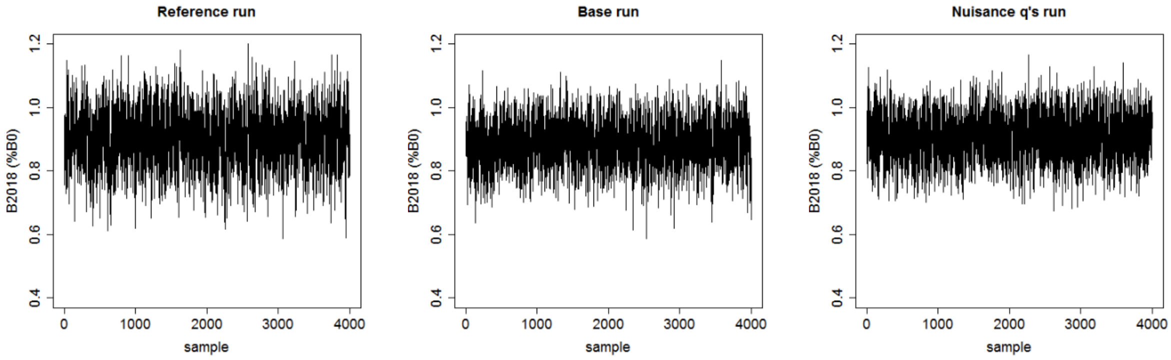

Figure 12: Trace diagnostic plot of the MCMC chain for estimates of B2018 (%B0) for the Reference, Base, and Nuisance q's runs.

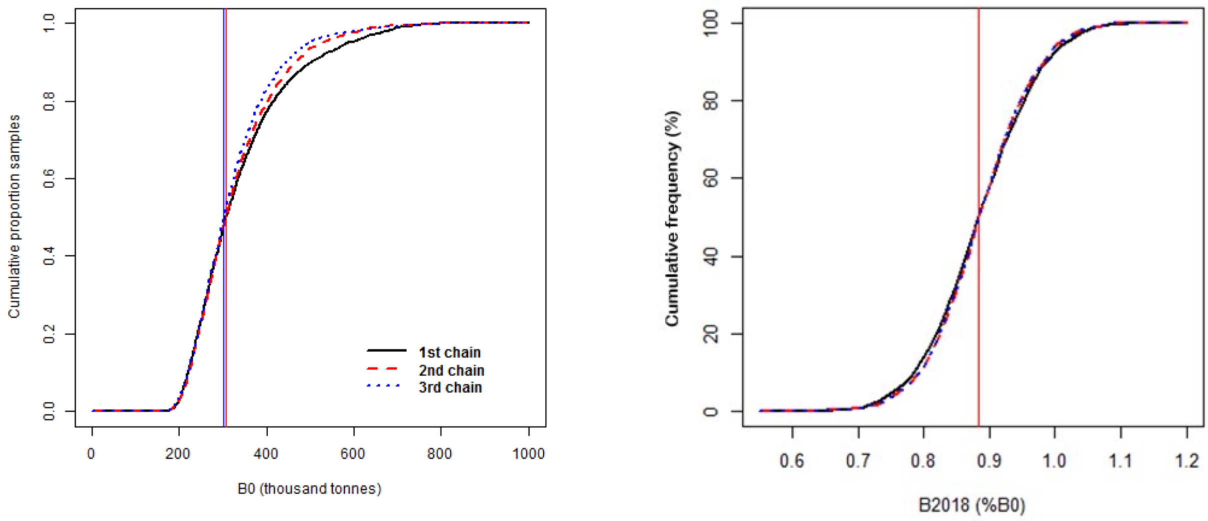

Figure 13: MCMC diagnostic plot showing the cumulative frequencies of B_0 (left) and B_{2018} (%B_0) (right) for the first (black), second (red), and third (blue) MCMC chains for the Base model run.

A median *M* of 0.20, with relatively tight credible intervals (95% credible intervals 0.19 – 0.23; Figure 14) was obtained from the Base run. As expected, estimates of *M* for this run were positively correlated with B_0 (Figure 14).

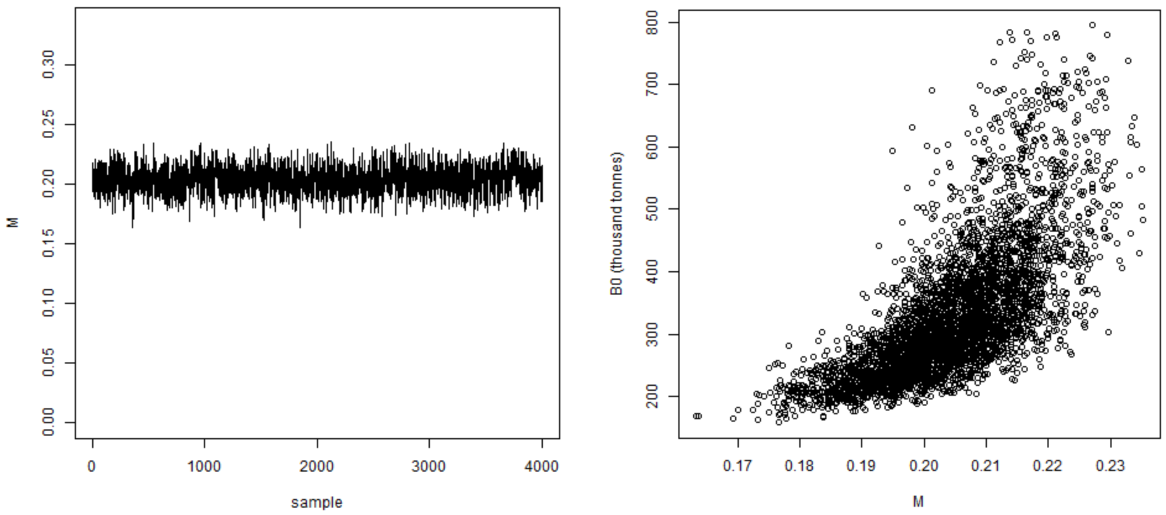

Figure 14: Trace plot of estimated M (left) and correlation between estimated M and B_0 (right) for the Base model run.

Trawl survey and fishery selectivity ogives were relatively tightly defined; ling were fully selected by the research trawl at about age 7–9 (Figure 15); fully selected by the trawl fishery at about age 9 years; and fully selected by the line fisheries at age 12–16 (Figure 16). The uncertain ogives for males in the line fisheries (particularly at ages 15 and over) are explained by the low relative catch proportion of males (and therefore few age frequency observations) in line fisheries (e.g. Figure 17).

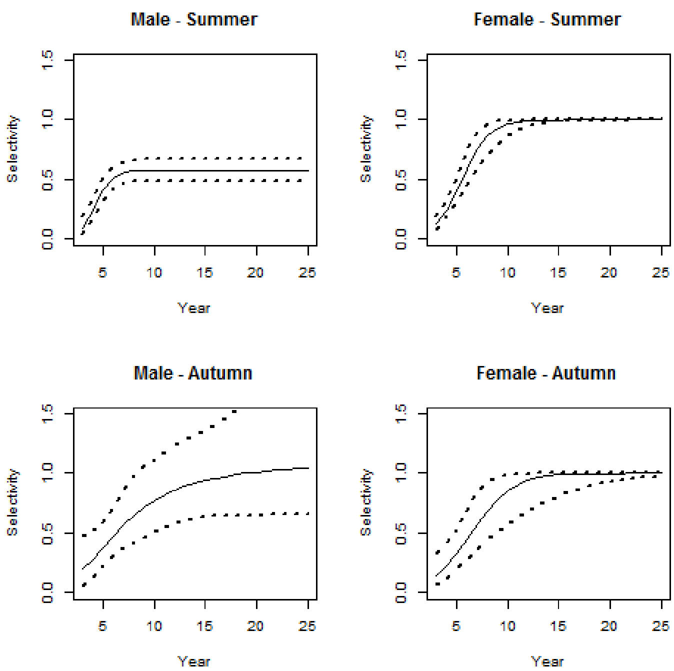

Figure 15: Estimated posterior distributions of selectivity ogives for the base model run for the summer (top) and autumn trawl survey (bottom), for males (left) and females (right). Dashed lines show the 95% credible intervals and the solid line the median.

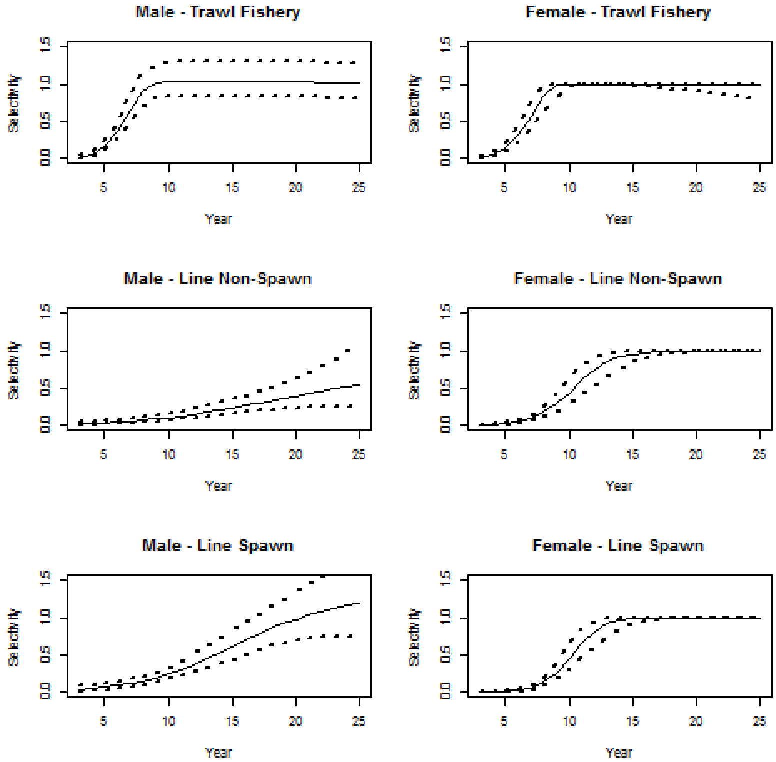

Figure 16: Estimated posterior distributions of selectivity ogives for the base model run for the trawl fishery (top), non-spawning line fishery (middle) and spawning line fishery (bottom), for males (left) and females (right). Dashed lines show the 95% credible intervals and the solid line the median.

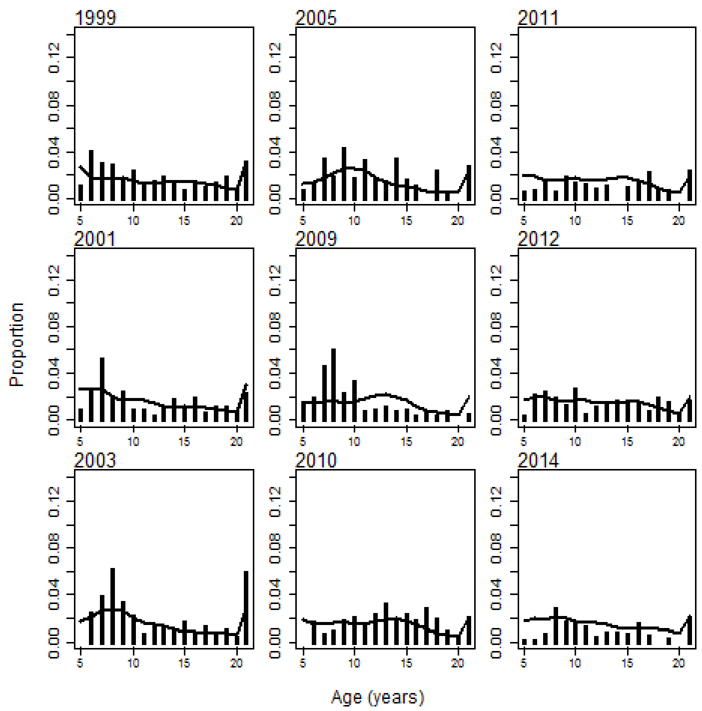

Figure 17: Base run fit (line) to observed proportion-at-age (bars) for male ling in the non-spawning line fishery.

Posterior distributions of year class strength (YCS) estimates were almost identical for the Reference and Base model runs (Figure 18). YCS was not well estimated and had wide credible bounds for years where only older fish were available to determine age class strength (i.e., before 1980) or where there were relatively few observations (i.e., after 2006); intermediate YCSs appear well estimated. Since

1980, year class strengths were around or below average, except for between 1993 and 1996, and in 2005 when YCS estimates were above average. Estimated annual YCS were not widely variable, with all medians being between 0.5 and 1.5 (Figure 18).

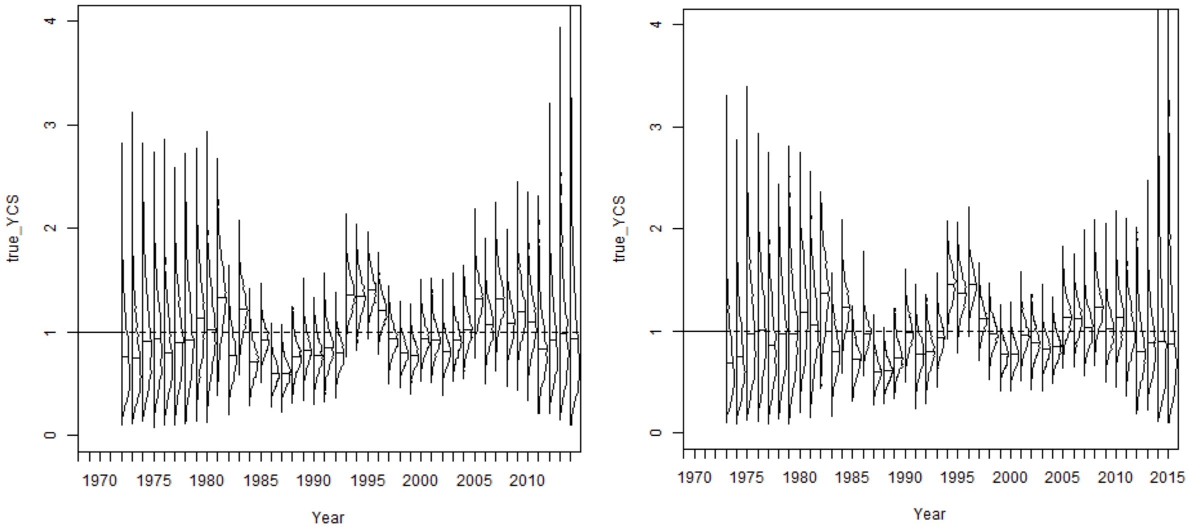

Figure 18: Estimated posterior distributions of year class strength for the reference model run (left) and base model run (right).

Estimated median catchability coefficients (*q*, with 95% credible intervals) for the reference model run were 0.11 (0.04–0.20) and 0.14 (0.06–0.26) for the summer and autumn surveys, respectively (Figure 19). The summer survey *q* was lower than the autumn value. The base model run gave slightly lower estimates of *q* for both the summer and autumn surveys: 0.09 (0.04–0.16) and 0.13 (0.06–0.23), respectively.

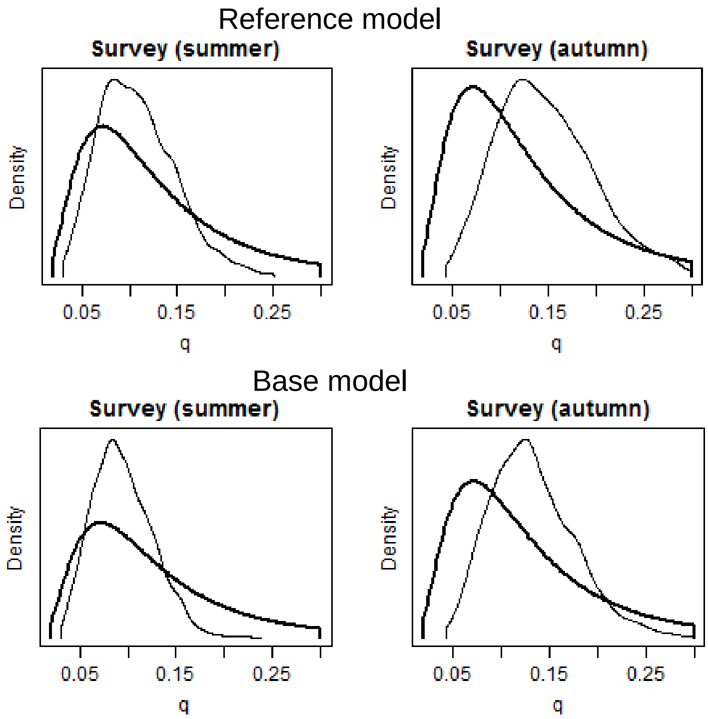

Figure 19: Estimated posterior distributions (thin lines) of the trawl survey *q* and distributions of priors (thick lines), for the autumn and summer trawl survey series for the reference model and base model runs.

Estimated biomass for the Sub-Antarctic stock declined slightly throughout the 1980s, but more steeply throughout the 1990s owing to increased fishing pressure and the recruitment of the relatively weak year classes spawned throughout the 1980s (Figure 18). Biomass then increased following a reduction in fishing pressure and the recruitment of average to strong year classes. Current stock size was estimated to be about 88% of B_0 (95% credible interval 75–101%) (Figure 20 and Table 12). Annual exploitation rates (catch over vulnerable biomass) were low (less than 0.08) in all years (Figure 21).

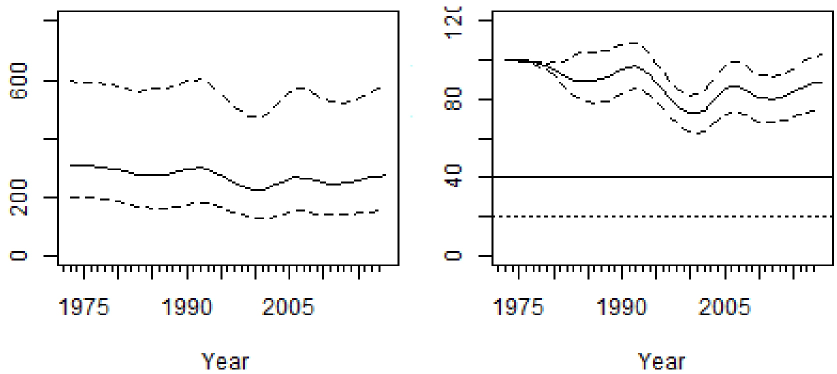

Figure 20: Estimated median trajectories (with 95% credible intervals shown as dashed lines) for spawning stock biomass (SSB), and SSB as a percentage of B_0, for the base model run.

Table 12: Bayesian median and 95% credible intervals of B_0, B_{2018}, and B_{2018} as a percentage of B_0 for the reference, base and nuisance *q*'s model runs.

Model run	B_0	B_{2018}	B_{2018} (%B_0)
Reference	305 000 (206 000 – 568 000)	272 000 (164 000 –499 000)	88 (75 – 101)
Base	278 000 (186 000 – 507 000)	254 000 (142 000 – 508 000)	90 (74 – 105)
Nuisance *q*'s	374 000 (233 000 –657 000)	340 000 (190 000 – 639 000)	91 (79 – 103)

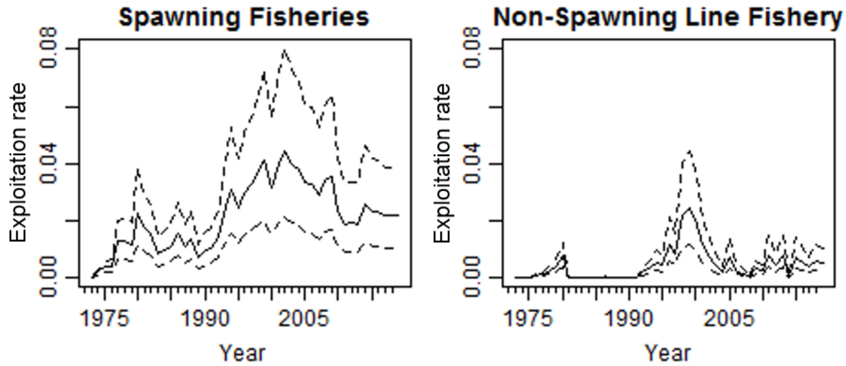

Figure 21: Estimated exploitation rates for spawning fisheries (left) and non-spawning line (right) fisheries for the base model run. Dashed lines show the 95% credible intervals and the solid line the median.

4.3.2 Biomass projections

Biomass projections were made under two assumed future catch scenarios, as specified by Fisheries New Zealand. The first, lower catch scenario (5900 t by the trawl fishery, 230 t by the spawning line fishery and 520 t by the non-spawning line fishery) was the mean catch level reported from the last five years. The second, higher catch scenario (10 200 t by the trawl fishery, 650 t by the spawning line fishery and 1250 t by the non-spawning line fishery) assumed that the TACC was taken. Recruitments were drawn randomly from the distribution of year class strengths for the period 1980–2013 estimated by the model and applied from year 2014 onward.

Projections with all three model runs suggested that biomass in 2023 would be between 86 and 90 %B_0 under the current catch scenario. If instead the TACC was caught, the biomass in 2023 would be 81–85 % B_0 (Table 13 and Figure 22).

Table 13: Bayesian median and 95% credible intervals of projected B_{2023} (t) and B_{2023} as a percentage of B_0 for the four MCMC model runs, under two alternative future annual catch scenarios.

Future catch	Model run	B_{2023}	B_{2023} (%B_0)
6 650	Reference	244 000 (115 000 – 546 000)	89.0 (65.4 – 116.4)
	Base	270 000 (135 000 – 551 000)	86.3 (67.6 –109.7)
	Nuisance q’s	344 000 (173 000 – 694 000)	89.7 (71.1 – 112.7)
12 100	Reference	231 000 (100 000 – 589 000)	81.9 (55.5 – 110.7)
	Base	247 000 (120 000 – 554 000)	80.7 (58.2 –106.4)
	Nuisance *q*’s	316 000 (144 000 – 681 000)	84.9 (63.1 – 108.9)

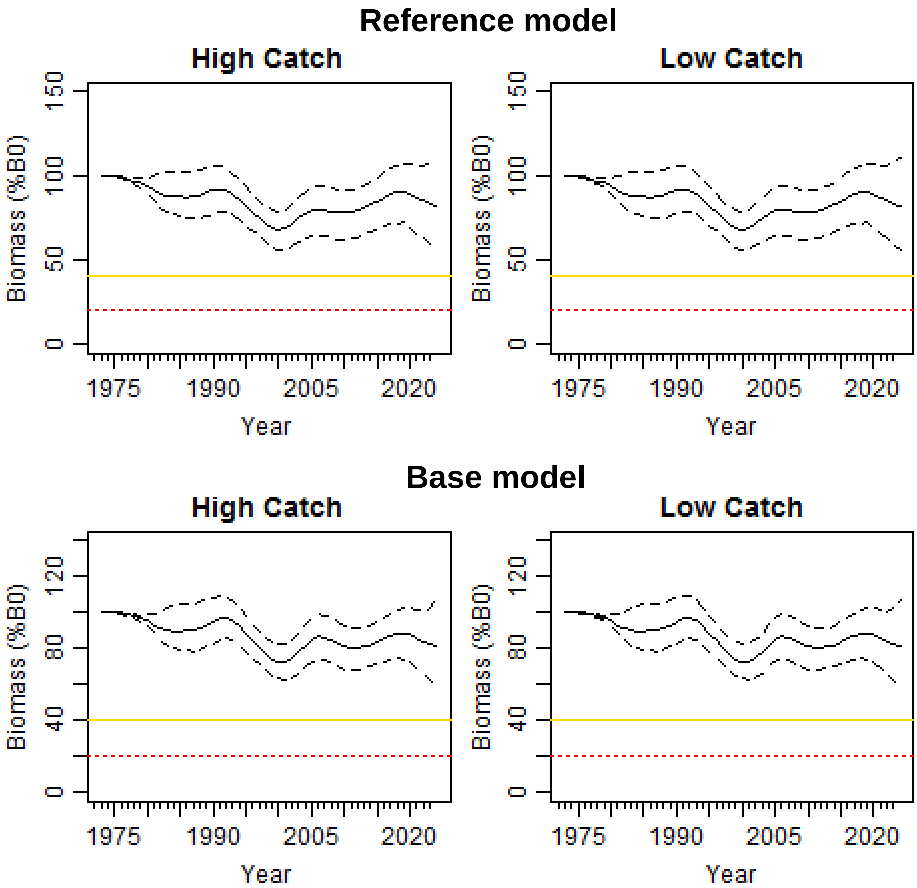

Figure 22: Estimated median trajectories (with 95% credible intervals shown as dashed lines) for biomass as a percentage of B_0, projected to 2023 under the reference and base models, with future catches assumed to be 12 100 t ("High"; left panel) or 6650 t ("Low"; right panel) annually.

4.3.3 Management biomass targets

Probabilities that current and projected biomass would drop below selected management reference points (i.e., target, 40% B_0; soft limit, 20% B_0; hard limit, 10% B_0) are shown for the Base model run, in Table 14. It appears very unlikely (i.e., less than 1% probability) that B_{2023} would be lower than the target level of 40%B_0, even for the high future catch scenario.

Table 14: Probabilities that current (B_{2018}) and projected (B_{2023}) biomass will be less than 40%, 20% or 10% of B_0. Projected biomass probabilities are presented for two scenarios of future annual catch (i.e., 6650 t, and 12 100 t).

Biomass	Model run	Management reference points		
		40% B_0	20% B_0	10% B_0
B_{2018}	Reference	0.000	0.000	0.000
	Base	0.000	0.000	0.000
	Nuisance *q*'s	0.000	0.000	0.000
B_{2023}, 6650 t catch	Reference	0.000	0.000	0.000
	Base	0.000	0.000	0.000
	Nuisance *q*'s	0.000	0.000	0.000
B_{2023}, 12 100 t catch	Reference	0.000	0.000	0.000
	Base	0.000	0.000	0.000
	Nuisance *q*'s	0.000	0.000	0.000

5. DISCUSSION

Previous assessments have produced relatively uncertain results because there is little contrast in any of the abundance series (i.e., trawl surveys or line fishery CPUE). This led to conclusions that the stock had been only lightly fished and that the absolute biomass was poorly known. This latest assessment also produced imprecise estimates of B_0 (95% credible intervals of 206 000 – 568 000 tonnes under the base model run) and optimistic estimates of stock status for all model runs (88–91% of B_0 and current biomass very unlikely to be less than 70% of B_0).

Model estimates indicated that minor variations in stock biomass have occurred over the assessment period, explained by periods of strong and weak YCS and changes in fishing pressure. One example of this includes the shallow trough in biomass in the late-1990s and subsequent recovery in response to reduced catches and the recruitment of some relatively strong year classes (Table 1, Figure 2 and Figure 3). However, catches at the recent level are likely to be sustainable in the long term (assuming no exceptional decline in future recruitments). Projections indicated that catches at the TACC may lead to a slight decline in biomass, although the probability of B_{2023} being below 60% was very small when assuming either the low or high future annual catch scenarios (6650 t or 12 100 t, respectively).

The Sub-Antarctic biological stock is spread across two administrative fish stocks (LIN 5 and LIN 6). Although it is likely that the current TACCs allows the harvest of biomass in proportion to its abundance in each area, the actual proportion of the available ling biomass harvested from LIN 5 each year is probably greater, because the LIN 6 TACC is usually under-caught, whilst the LIN 5 TACC is often fully caught. An analysis of the Summer trawl survey biomass index of ling in different regions (including a region that includes most of the fished grounds within LIN 5), found no evidence for a long-term biomass trend in any region, such as could arise from spatial variation in fishing pressure within the stock area (see Appendix B). This suggests that the current method for allocating the TACC to LIN 5 and LIN 6 is appropriate, though it is recommended that future assessments continue to monitor survey biomass estimates in LIN 5.

6. ACKNOWLEDGMENTS

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7. REFERENCES

Ballara, S.L. (2018). A descriptive analysis of all ling (*Genypterus blacodes*) fisheries, and CPUE for ling fisheries in LIN 5&6, from 1990 to 2017. Draft New Zealand Fisheries Assessment Report held by Fisheries New Zealand.

Bull, B.; Dunn, A. (2002). Catch-at-age: User manual v1.06.2002/09/12. NIWA Internal Report 114. 23 p. (Unpublished report held in NIWA library, Wellington.)

Bull, B.; Francis, R.I.C.C.; Dunn, A.; McKenzie, A.; Gilbert, D.J.; Smith, M.H.; Bian, R.; Fu, D. (2012). CASAL (C++ algorithmic stock assessment laboratory): CASAL user manual v2.30-2012/03/21. *NIWA Technical Report 135*. 279 p.

Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences 68*: 1124–1138.

Francis, R.I.C.C.; Haist, V.; Bull, B. (2003). Assessment of hoki (*Macruronus novaezelandiae*) in 2002 using a new model. *New Zealand Fisheries Assessment Report 2003/6.* 69 p.

Horn, P.L. (2002). Stock assessment of ling (*Genypterus blacodes*) around the South Island (Fishstocks LIN 3, 4, 5, 6, and 7) for the 2001–02 fishing year. *New Zealand Fisheries Assessment Report 2002/20*. 53 p.

Horn, P.L. (2004). Stock assessment of ling (*Genypterus blacodes*) on the Campbell Plateau (LIN 5 and 6) and off the west coast of the South Island (LIN 7) for the 2003–04 fishing year. *New Zealand Fisheries Assessment Report 2004/7*. 45 p.

Horn, P.L. (2005). A review of the stock structure of ling (*Genypterus blacodes*) in New Zealand waters. *New Zealand Fisheries Assessment Report 2005/59*. 41 p.

Horn, P.L.; Dunn, M.R.; Ballara, S.L. (2013). Stock assessment of ling (*Genypterus blacodes*) on the Chatham Rise (LIN 3&4) and in the Sub-Antarctic (LIN 5&6) for the 2011–12 fishing year. *New Zealand Fisheries Assessment Report 2013/6*. 87 p.

Horn, P.L. and Sutton, C.P. (2017). Catch-at-age for hake (*Merluccius australis*) and ling (*Genypterus blacode*s) in the 2016–17 fishing year and from a research trawl survey in 2018, with a summary of all available data sets from the New Zealand EEZ. *New Zealand Fisheries Assessment Report 2017/21*. 66 p.

Fisheries New Zealand (2018). Fisheries Assessment Plenary, May 2018. Fisheries New Zealand, Wellington. 512 p.

O'Driscoll, R.L.; Ballara, S.L.; MacGibbon, D.J.; Schimel, A.C.G. (2018). Trawl survey of hoki and middle depth species in the Southland and Sub-Antarctic, November–December 2016 (TAN1614). *New Zealand Fisheries Assessment Report 2018/39*. 84 p.

Roberts, J. (2016). Stock assessment of ling (*Genypterus blacodes*) in the Sub-Antarctic (LIN 5&6) for the 2014–15 fishing year *New Zealand Fisheries Assessment Report 2016/05*. 34 p.

Shertzer, K.W.; Conn, P.B. (2012). Spawner-recruit relationships of demersal marine fishes: prior distribution of steepness. *Bulletin of Marine Science*, *88*: 39–50

APPENDIX A. COMMERCIAL FISHERY CPUE INDICES USED IN THE 2017–18 STOCK ASSESSMENT FOR SUB-ANTARCTIC LING (LIN 5&6)

Table A1: Commercial fishery CPUE indices and associated CVs for the Sub-Antarctic spawning and non-spawning longline fisheries, used in the 2017–18 stock assessment for Sub-Antarctic ling (LIN 5&6); as reported by Ballara (2018).

	Spawning longline fishery		Non-spawning longline fishery	
Year	**Index**	**CV**	**Index**	**CV**
1990/91	1.03	0.13	1.15	0.1
1991/92	1.76	0.09	1.16	0.11
1992/93	1.59	0.1	1.02	0.09
1993/94	1.26	0.08	1.44	0.08
1994/95	1.33	0.11	1.05	0.08
1995/96	1.27	0.08	1.3	0.06
1996/97	1.15	0.07	1.1	0.06
1997/98	1.03	0.09	0.74	0.06
1998/99	1.07	0.1	0.86	0.07
1999/00	1.29	0.08	1.03	0.09
2000/01	1.36	0.09	0.99	0.13
2001/02	1.49	0.1	0.64	0.17
2002/03	0.78	0.11	0.71	0.07
2003/04	1.02	0.08	0.71	0.11
2004/05	1.46	0.11	0.78	0.14
2005/06	1.19	0.11	0.76	0.45
2006/07	1.27	0.1	0.92	0.17
2007/08	1.03	0.14	1.18	0.09
2008/09	2.05	0.19	0.76	0.1
2009/10	0.69	0.18	0.99	0.08
2010/11	1.04	0.14	0.84	0.09
2011/12	1.1	0.15	0.84	0.08
2012/13	0.87	0.16	0.52	0.10
2013/14	0.65	0.16	0.72	0.09
2015/16	0.58	0.16	1.15	0.10
2016/17	0.64	0.27	1.16	0.11

APPENDIX B. TRAWL SURVEY BIOMASS INDICES OF SUB-ANTARCTIC LING BY GEOGRAPHICAL REGION

The low degree of inter-annual variation in the Sub-Antarctic trawl survey biomass index for ling suggests that biomass of ling has remained relatively constant throughout the time series of the summer survey used in the assessment (1991–2012). However, the combined survey strata cover a large area, including the Stewart-Snares Shelf and Puysegur Bank (LIN 5) and the Campbell Plateau (LIN 6). Furthermore, fishing effort is not distributed evenly across the stock area, with a greater proportion of the overall ling catch taken in LIN 5, which is smaller than LIN 6, in all years since 2008–09 (Fisheries New Zealand 2018). Should local depletions of ling occur, this may not lead to a detectable change in the Sub-Antarctic-wide survey biomass. As such, it would be desirable to know if the biomass of ling is likely to have changed across smaller regions of the survey area.

For this analysis, Sub-Antarctic trawl strata were grouped into three regions: North – approximating to LIN 5; Central – the northern Campbell Plateau; and South – the southern Campbell Plateau (See Figure B1 and Table B1). The summed biomass for each region was then reported for each survey (Table B2). No obvious year-trend was observed from the biomass estimates of any of the regions, suggesting that the Sub-Antarctic survey trend is representative of the smaller regions through the time period of the survey (i.e., there is limited evidence for depletions in smaller regions).

Table B1: Stratum groupings used to generate regional biomass estimates.

Stratum	Name	Region	Area (km^2)
1	Puysegur Bank	North	2 150
2	Puysegur Bank	North	1 318
3a	Stewart-Snares	North	4 548
3b	Stewart-Snares	North	1 556
4	Stewart-Snares	North	21 018
5a	Snares-Auckland	Central	2 981
5b	Snares-Auckland	Central	3 281
6	Auckland Is.	Central	16 682
7	South Auckland	South	8 497
8	N.E. Auckland	Central	17 294
9	N. Campbell Is.	Central	27 398
10	S. Campbell Is.	South	11 288
11	N.E. Pukaki Rise	Central	23 008
12	Pukaki	Central	45 259
13	N.E. Camp. Plateau	South	36 051
14	E. Camp. Plateau	South	27 659
15	E. Camp. Plateau	South	15 179
Total			**288 417**

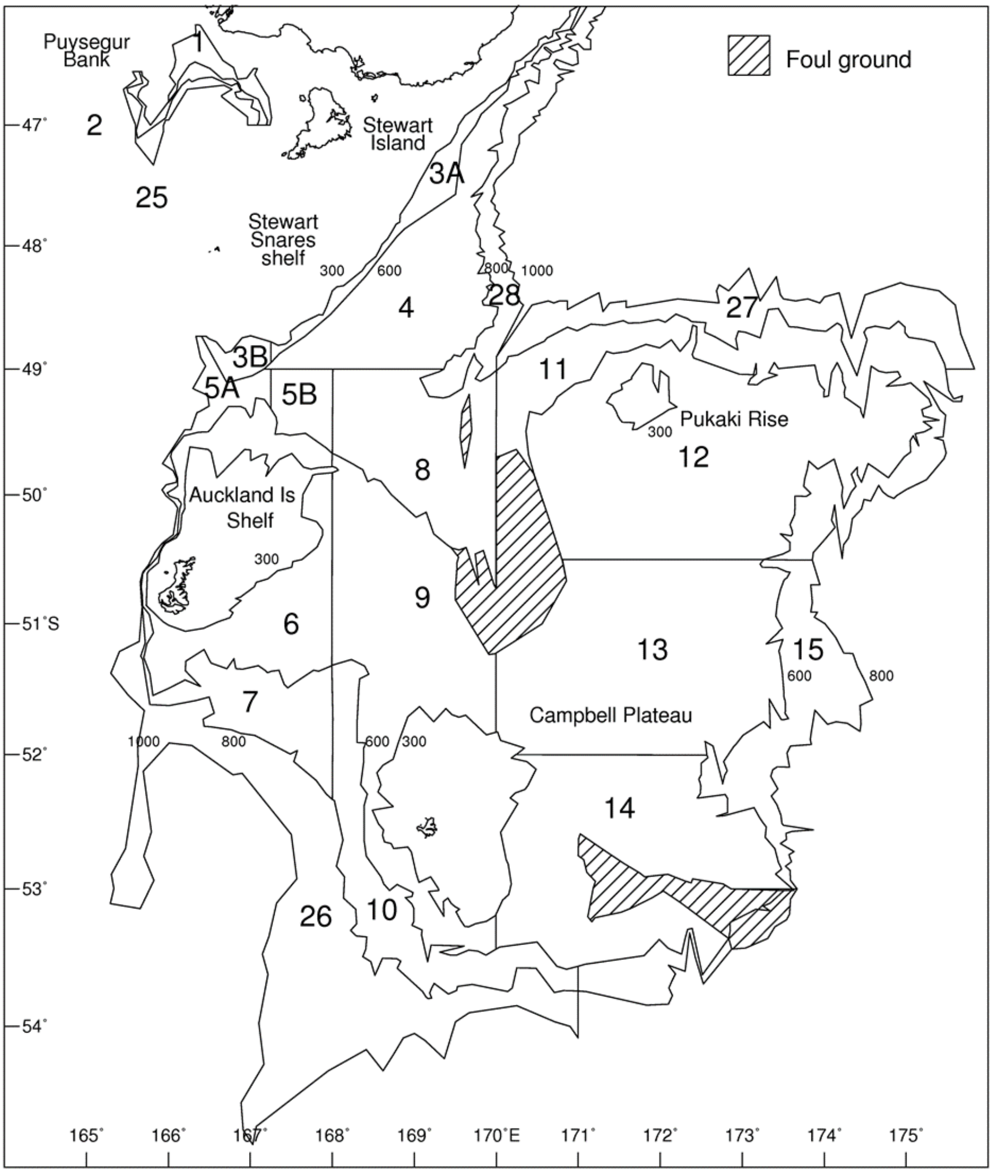

Figure B1: Stratum boundaries for the summer 2000–17 Sub-Antarctic trawl surveys.

Table B2: Combined biomass estimates by stratum region and survey year.

		Biomass index (t) by stratum region		
Survey year	**Survey name**	**North**	**Central**	**South**
1991	TAN9105	2 712	13 439	7 954
1992	TAN9211	3 120	11 849	6 407
1993	TAN9310	7 950	13 699	8 089
2000	TAN0012	3 944	19 675	9 393
2001	TAN0118	4 228	12 095	8 735
2002	TAN0219	6 908	12 175	6 547
2003	TAN0317	5 711	10 852	5 612
2004	TAN0414	7 823	9 725	6 196
2005	TAN0515	2 941	10 889	5 853
2006	TAN0617	2 591	10 502	6 185
2007	TAN0714	3 168	13 346	9 974
2008	TAN0813	5 280	10 195	7 356
2009	TAN0911	3 044	13 229	6 440
2011	TAN1117	5 334	12 440	5 403
2012	TAN1215	4 664	12 396	9 950