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Stock assessment of blue cod (*Parapercis colias*) in BCO 5 using data to 2023

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PLAIN LANGUAGE SUMMARY

The fishery for blue cod in BCO 5 (Foveaux Strait and surrounding sea) is the largest blue cod fishery in New Zealand. Within its boundaries it has a commercial pot fishery in four Statistical Areas (025, 030, 027, 029) plus a sizable recreational fishery in Statistical Area 025.

Fishery management is based on setting a catch quota for BCO 5 that is based on combining the results from three independent stock assessments for Statistical Areas 025, 027+029, and 030.

The stock assessments use blue cod abundance series based on catch per unit effort (CPUE) from the commercial fisheries. Statistical Area 025 also has an abundance index based on a pot survey completed every four to five years.

Since the catch quota was reduced following the 2019 assessment, there have been spatial shifts in fishing effort into near-pristine blue cod habitat. This change biased the CPUE series and the blue cod age composition in assessment units 027+029 and 030. Consequently, CPUE series for assessment units 027+029 and 030 were rejected by the Inshore Working Group.

The assessment results for blue cod in Statistical Area 025 were accepted by the Inshore Working Group, but rejected by the Fisheries Plenary.

EXECUTIVE SUMMARY

Doonan[1], I.J.; McKenzie, A. (2024). Stock assessment of blue cod (*Parapercis colias*) in BCO 5 using data to 2023.

***New Zealand Fisheries Assessment Report 2024*/56. 41 p.**

The stock assessment was conducted using a Bayesian age- and sex-based model in the software Casal2. Models were constructed that allowed explicit modelling of the blue cod sex change process. The Inshore Working Group reviewed this work periodically, and all technical decisions were agreed by that group.

Separate data sets were compiled and analysed for Statistical Areas 025, 027+029, and 030, i.e., there were to be three independent stock assessments which would be combined to produce the stock status for BCO 5. However, there was no assessment attempted for 030 since the east/west parts of this area had very different age and length distributions suggesting different rates of depletion, but the catch and catch per unit effort prior to 2020 cannot be split spatially.

There was also no assessment for 027+029 as work on it stopped when it became apparent that there was a spatial shift in the fishery to the deeper and relatively unfished southern parts, compromising the signal from the age composition and catch per unit effort data (Note there is no fine scale spatial information on catch or effort prior to 2019).

Only Statistical Area 025 had a completed stock assessment, estimating stock size from 1900 to 2024.

The Statistical Area 025 assessment included three fisheries: commercial line fishing, commercial pot fishing, and recreational fishing. Additionally, non-reported blue cod bait usage for the rock lobster fishery was estimated and included with commercial landings. Fisheries were modelled assuming length-based selectivity for catch and discards. Two stock abundance indices were fitted: relative abundance indices based on standardised catch per unit effort (CPUE) from the commercial pot fishery (beginning 1989–90); and estimates of fish density from a random stratified pot survey series (beginning in 2010). Age composition data from the pot surveys and commercial catches were compiled and fitted. Length composition data from previous commercial fishery logbook and shed sampling projects, recreational fishery catch sampling, and two mesh-size selectivity studies, were also fitted. Numerous model runs were conducted to develop the Statistical Area 025 assessment base case, with the base case used for the final MCMC assessment and projections. Reasonable fits were obtained to all data, with no indications of model misspecification.

The 025 assessment was rejected by the Fisheries Plenary in May 2024, as that forum concluded that the catch per unit effort was not reliable

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1. INTRODUCTION

This document describes the 2024 stock assessment of blue cod (*Parapercis colias*) in BCO 5 (Figure 1), using data up to the 2022–23 fishing year (1 October to 30 September). The first assessment of this stock was completed in May 2013 (Haist et al. 2013) and it was length-based. The 2013 assessment estimated that the stock size in 2013 was close to the target level of depletion, which was assumed to be 40% of the pre-fishing stock size. The next assessment was in 2019 (Doonan 2020), but it was changed to an age-based model and was implemented in Casal2 (Doonan et al. 2016). The 2019 assessment estimated that the stock size in 2019 was 36% of the pre-fishing stock size, and was projected to decline in the period up to 2024. On the basis of the 2019 stock assessment (Doonan 2020), the TAC for BCO 5 was reduced to 925 t, with a TACC of 800 t.

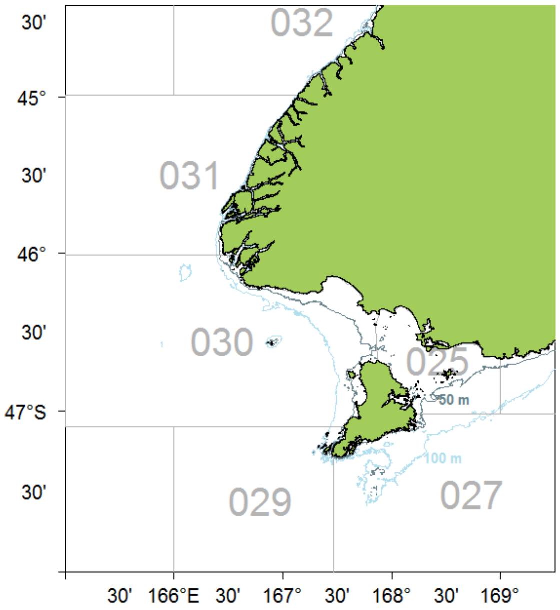

Figure 1: Blue cod BCO 5 management area showing the reporting sub-areas. Assessments were completed separately for the assessment unit based on: Statistical Area 025, the combined Statistical Area 027 and 029, and Statistical Area 030; which together account for 90% of the total catch for BCO 5.

Data used in the assessment were pot survey abundances and standardised catch per unit effort (CPUE), age compositions from commercial catch and potting surveys, length compositions from commercial and recreational sampling, and length frequency data from two pot mesh experiments completed before the changes in mesh size regulations. Data collected since the 2019 assessment included: one further pot survey abundance estimate and age composition in 2024, age compositions from the pot commercial fishing for 2022 and 2023, catch and CPUE since 2018.

An important biological feature of blue cod is that they are protogynous hermaphrodites and can change sex from female to male, a behaviour that can make this species more vulnerable to heavy fishing because one sex can be preferentially depleted (Robinson et al. 2017, Easter & White 2016, Carbines 2004). Fished populations are frequently dominated by males, hypothesized to be because of the removal of the inhibitory effect large males have on females changing to male, resulting in a higher rate (and possibly earlier onset) of sex change by primary females (Beentjes & Carbines 2005). Mariani et al. (2013) recommended that sex change be explicitly considered in stock management and assessment. For New Zealand stocks of blue cod where biomass is very low relative to its virgin state (e.g., Motunau, an area between Clarence Point to the mouth of the Conway River, North Canterbury), very few mature females are observed so that the sex ratio for mature fish is close to 95% male, and fish size is considerably reduced (Beentjes & Sutton 2017). This has been attributed to sex change over-compensating for the loss of males, at some (unknown) trigger threshold (Beentjes & Carbines 2005, Beentjes & Sutton 2017). Transitioning fish (i.e., individuals with both male and female reproductive tissue) have been observed in one study in 1995 (Carbines 2004), and two other studies reported very low rates, with only one such individual found in each study (Mutch 1983, Brandt et al. 2017). It is unclear how important sex change is to the BCO 5 stock dynamics when a stock is believed to not be substantially depleted, but the 2019 and 2024 assessment model was nevertheless constructed to allow sex change so the potential impact could be investigated.

This work was contracted by Fisheries New Zealand under contract BCO2023-01, Specific Objectives 2 & 3: (2) to undertake a quantitative stock assessment of blue cod in BCO 5 to estimate current biomass in relation to target and limit reference points; and (3) to undertake simulations predicting biomass projections under alternative catch limits (i.e., projections).

1.1 Stock assessment status for 2024

There were several changes in this assessment round. First, there was a small adjustment to the spatial strata used for the assessment. In 2019, there were four assessments: one each for Statistical Areas 025, 027, 030, plus a combined one covering all three areas. A change in relative catch by area, with a reduction of catch in Statistical Area 025 from about half of the total to a third, meant that effort and catch from the southeastern corner of Statistical Area 029 has become significant, and so it was joined onto Statistical Area 027 making an assessment area 027+029 (Beentjes et al. 2024). Statistical Area 029 also borders Statistical Area 030, but Beentjes et al. (2024) found that Statistical Area 029 age and length data fitted best with Statistical Area 027.

Second, temporal shifts in spatial fishing effort distribution after the 2019 assessment created problems in the interpretation of CPUE for Statistical Areas 027+029 and 030 and the commercial age composition, resulting in these data been judged by the Inshore Working Group (INSWG) to be unsuitable for inclusion in a stock assessment (Beentjes et al. 2024, Fisheries New Zealand 2024).It was not possible to attribute catch and effort to areas within statistical areas prior to 2019. This meant that there were no abundance data for the assessments, and they were discontinued until further studies can be completed.

For Statistical Area 027 plus Statistical Area 029, the attempted assessment indicated that the current status of the stock was well above the target, which was considered implausible by the INSWG (Fisheries New Zealand 2024) given the long history of the fishery and anecdotal reports from fishers. The large proportion of older fish in commercial catches during the 2021–22 and 2022–23 fishing years is thought, in part, to be the result of fishers fishing previously lightly fished areas in deeper water further offshore.

Beentjes et al. (2024) discuss the Statistical Area 030 problems in detail. In brief, there was a shift in effort from east to west since around 2018, but the western part has been relatively unfished and so had larger and older fish than the east. In addition, effort had begun on an offshore reef in the west part that had almost pristine stock structure, but from which several age composition data were obtained that biased the age-length distributions towards large and older fish. Further, it was not possible to create western and eastern catch and effort histories prior to the introduction of the Electronic Reporting System in 2019.

Thirdly, whilst the INSWG accepted the Statistical Area 025 assessment with reservation, it was rejected by the May 2024 Fisheries Plenary (Fisheries New Zealand 2024). The rejection centred around the conclusion that the later part of the CPUE series was biased upwards, that the commercial fishery was predominately on male fish, and because there were a lower proportion of older ages in the recent commercial age composition samples than estimated by the model. All of which indicate a much lower stock status than estimated by the assessment.

Here, we present the assessment for Statistical Area 025 for completeness, since the INSWG did accept it in its deliberations.

2. METHODS

2.1 Data

Data were compiled from a number of sources, including Fisheries New Zealand databases and research programmes, the field studies conducted through the Ecosystem Spatial Management programme (ESM, Middleton et al. 2013), and the characterisation work completed under Objective 1 of this contract, which is reported elsewhere (Beentjes et al. 2024).

The general categories of data used in the stock assessment models for each statistical area include catch and landings, fishery length and age compositions, a catch per unit effort (CPUE) abundance index, pot survey age compositions and abundance indices (Statistical Area 025 only), and biological information on growth and maturation. Separate data sets were compiled and analysed for Statistical Areas 025, 027+029, and 030. The data available for each of these areas differed, and few data were available for the remainder of the BCO 5 Statistical Areas. Combined, Statistical Areas 025, 027, 029, and 030 represented 97% of all commercial fishery landings, and 98% in 2023. Note that for overall commercial fishery landings, Statistical Area 025 accounted for 50%, reducing to 34% in 2023, whilst Statistical Area 029 accounted for 6% and 13%, respectively.

Catch and landings

Haist et al. (2013) constructed a historical time series of BCO 5 landings for three gear types: commercial line fishing, commercial pot fishing, and recreational fishing. Additionally, non-reported blue cod catch used as bait in the CRA 8 rock lobster fishery was estimated and included with the commercial landings, and customary catch estimates were included with the recreational harvest. These estimates were up to fishing year 2011–12. Beentjes et al. (2024) updated these series and recalculated the entire series of recreational landings.

For the 2023–24 landings, we used the average landings over 2020–21, 2021–22, and 2022–23 fishing years.

Appendix 1 shows the full landing history used in the stock assessment.

Pot survey

There have been four random-site blue cod potting surveys in Foveaux Strait, in February 2010, 2014, 2018 and 2023 (Beentjes & Millar 2023). The surveys use eight spatial strata and, as an example, the 2023 survey used 40 random sites (6 pots per site, producing 240 pot lifts) (Figure 2). These surveys estimated both total relative biomass and scaled length sample distributions. The survey covered all of Statistical Area 025, but had only one stratum in Statistical Area 027, and a stratum consisting of half of Statistical Area 030 and half 025. Hence, these data were only used for the Statistical Area 025 assessment (excluding stratum 10 in Statistical Area 027), and for the assessment sensitivity run that covered all three sub-areas (not completed). The survey age compositions are given in Appendix 2.

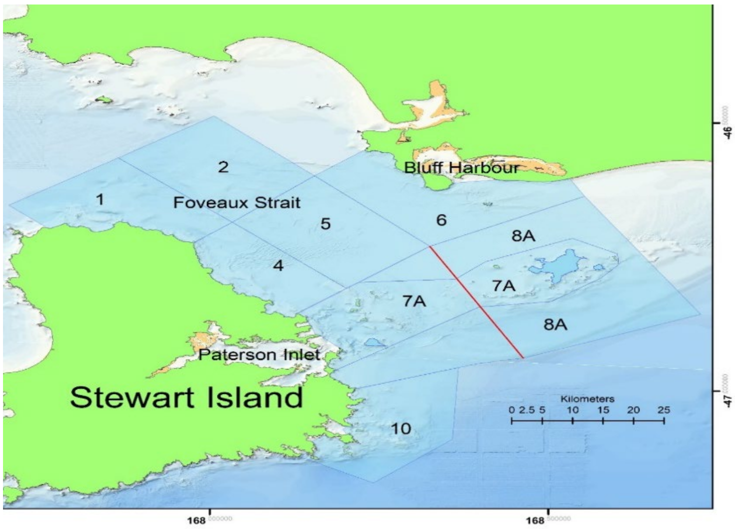

Figure 2: Foveaux Strait 2023 pot survey strata. The same design was used for 2014 and 2018. For the 2010 survey, 7A and 8A strata were replaced by strata 7 and 8 which were left (7) and right (8) the red line (from Beentjes et al. 2019).

For this assessment, the biomasses were reworked as abundance in units of fish pot^{-1} (Table 1).

Table 1: Blue cod abundance (fish pot^{-1}) by stratum for the three surveys in 2010, 2014, 2018, and 2023.

Year	Abundance	CV (%)
2010	11.1	12.5
2014	17.6	13.5
2018	12.5	21.5
2023	5.34	21.1

Fisheries data

The pot fishery has operated under three different regimes of Minimum Legal Size (MLS) and mesh regulations. Before 1994, the MLS was 30 cm total length, then 33 cm from 1994 onwards. In 1994 and in 2018, the mesh regulations were changed to enforce larger mesh sizes (48 mm in 1994 and 54 mm in 2018), but the operational mesh size between 1994 and 2017 was between 50 and 52 mm.

The MLS determines which fish may be landed (and hence reported), whereas the mesh dictates the number of fish below the MLS brought on board and then discarded (but not reported). It was assumed that the fraction of discards would be reduced after both introductions of increased mesh size. Thus, there were three periods with different catch selectivity: pre-1994, 1994 to 2017, and 2018 onwards. The catch selectivity was modelled using time blocks so that different selectivity parameters could be used in each period. The alternative method would have been to split the pot fishery into three fisheries, one for each period, with each fishery having its own selectivity, and also to split the CPUE into three series (and re-standardised within each split). To keep one CPUE series throughout, the method using time block selectivities was adopted.

For the pre-1994 fishery, Haist et al. (2013) extracted the length frequency distribution (LF) data from a 1986 pot mesh experiment, which was used to inform the change in mesh size and MLS in 1994. One set of pots used the pre-1994 pot design, and length data from these pots were used to inform the pre-1994 selectivity. The data were collected close to Stewart Island, and also close to Bluff, so that the larger fish expected offshore were less prevalent at the experimental sites than in the fishery. Consequently, the right-hand side of the LF could not be fitted because large fish were not fully available, and therefore data for fish over 33 cm were excluded. This keeps the part of the LF that is under the influence of the catch selectivity and excludes the part that is influenced by ontogenetic migrations and fishing mortality.

Haist et al. (2013) analysed the length data collected as part of the ESM programme with length data collected over the years 2009–2011 to produce an LF for 2010 that represented the composition of catch-on-board. There were two variations: logbooks filled out on the vessels, and shed data. Shed data were collected from the last catch of the day, all of which was brought into the sheds without discarding or processing. The shed data recorded lengths as well as sex. The INSWG concluded that the logbook data were more accurate samples of the whole catch, because they were from the whole fishery – the shed data often came from catches from heavily exploited areas closer to port, and consisted of smaller fish There was a separate LF for each assessed Statistical Area. This LF was assumed to represent selectivity of the catch for the period 1994 to 2017.

For the pot fishery post-2017, there were data from the mesh experiments conducted by G. Carbines in 2015, which were designed to quantify the effects of the new proposed mesh size (as adopted in 2018). Although more extensive than similar 1986 experiments, the 2015 experiments were nevertheless similarly restricted to sites near land, and so had the same potential bias of under-representing larger/older fish. As a result, when these datasets were used, data for fish lengths over 38 cm were excluded.

Both experimental data sets would have been applied to all three Statistical Area assessments (if they had been done).

The last data set from the commercial pot fishery comprised age and sex data collected in 2018 and the first three months of the 2018–19 fishing year (Beentjes et al. 2019). Two further years were sampled in 2022 and 2023 (Beentjes & Bian 2024). Data were available for each of the Statistical Areas in 2018, 2022, and 2023, but only Statistical Area 025 had enough data for an age sample distribution (AF) to be estimated for 2019. The samples were collected from a small number of fishers who put aside the unprocessed fish from the first pot lift of the day, and the legal sized fish were landed whole and otoliths were extracted and other biological data collected. This circumvented the bias from sampling areas close to port and missing the larger fish. The assessment model in 2019 and 2024 did not use age data for ages 1 and 2 (see later section on sex change), so these age compositions were truncated below age 3.

All fisheries data used in the assessment are shown in Appendix 3, which also has more details of the 2015 pot mesh experiments.

Haist et al. (2013) estimated the recreational fishery LF using data collected during the 2009–10 fishing year from a survey of the Southland recreational blue cod fishery (Davey & Hartill 2011). This study included a boat ramp survey (at Bluff, Riverton/Colac, and Halfmoon Bay) and a logbook survey of charter and recreational vessels. Only logbook data are used in the 2019 assessment model to inform the selectivity for the recreational fishery.

Between October 2009 and September 2010, 1471 blue cod were measured during the boat ramp survey. Over the same period, logbook participants measured 586 fish caught by recreational vessels and 1878 fish caught by charter vessels.

Fish measured during the boat ramp survey were assumed to represent landings, and fish measured through the logbook programme were assumed to represent catch. The proportion of BCO 5 recreational catch taken by charter vessels was estimated by dividing the 1997/98 Marine Recreational Charter Vessel catch estimate by the average of the three Marine Recreational Fishery survey estimates. This proportion (27.5%) was used to weight the charter vessel and recreational vessel LFs to obtain an overall LF to represent the recreational fishery catch (Haist et al. 2013).

The same recreational fishery LF dataset was fitted in stock reconstructions for Statistical Area 025, and had they been required, also for Areas 027+029 and 030. Appendix 3 shows the recreational fishery LFs.

Biological data

Ageing error

Ageing error estimates applied the off-by-one method, which used a probability, p, that the age differed by one from the true age. In 2019, Doonan (2020) estimated p to be 8.6% and that value was used here.

Growth

Sex-specific von Bertalanffy (vB) growth models were fitted to age, sex, and length data from the pot surveys and the commercial fishery. Survey data were combined, because vB curves estimated from individual pot surveys all had very similar curves, only diverging at older ages for which there were few data. Only survey data with ages 10 or less were used as after age 10 the larger fish were truncated by the commercial pot fishery. i.e. faster growing fish in older year classes are selected by the fishery causing biased estimation of growth rate. For the commercial data, fish below 15 years of age were excluded because 15 years is when the length-at-age distribution is fully selected into the fishery and, hence, the sampling (i.e., length at age data from the commercial fishery would be biased for younger fish). For males, the commercial data for Statistical Area 025 appeared to be also clipped at larger lengths as a result of heavy fishing, and so these data were excluded. The commercial data from the other areas had many old and large fish so it was thought that they were unbiased, or nearly unbiased. The age estimates were all based on the new ageing protocol (Walsh 2017).

The same vB curve was applied to all three assessment sub-areas. The parameter estimates were: L_∞ = 48.9 cm, K = 0.12, and t_0 = -1.2 for females; L_∞ = 55.8 cm, K = 0.136, and t_0 = -0.80 for males. Model fits are shown in Figure 3. The length-at-age distribution was approximately normal with a CV of 10% (*see* Q-Q plots in Figure 3, i.e., 1:1 line fits to the quantiles), but we used a CV of 9% in the model to allow for ageing error.

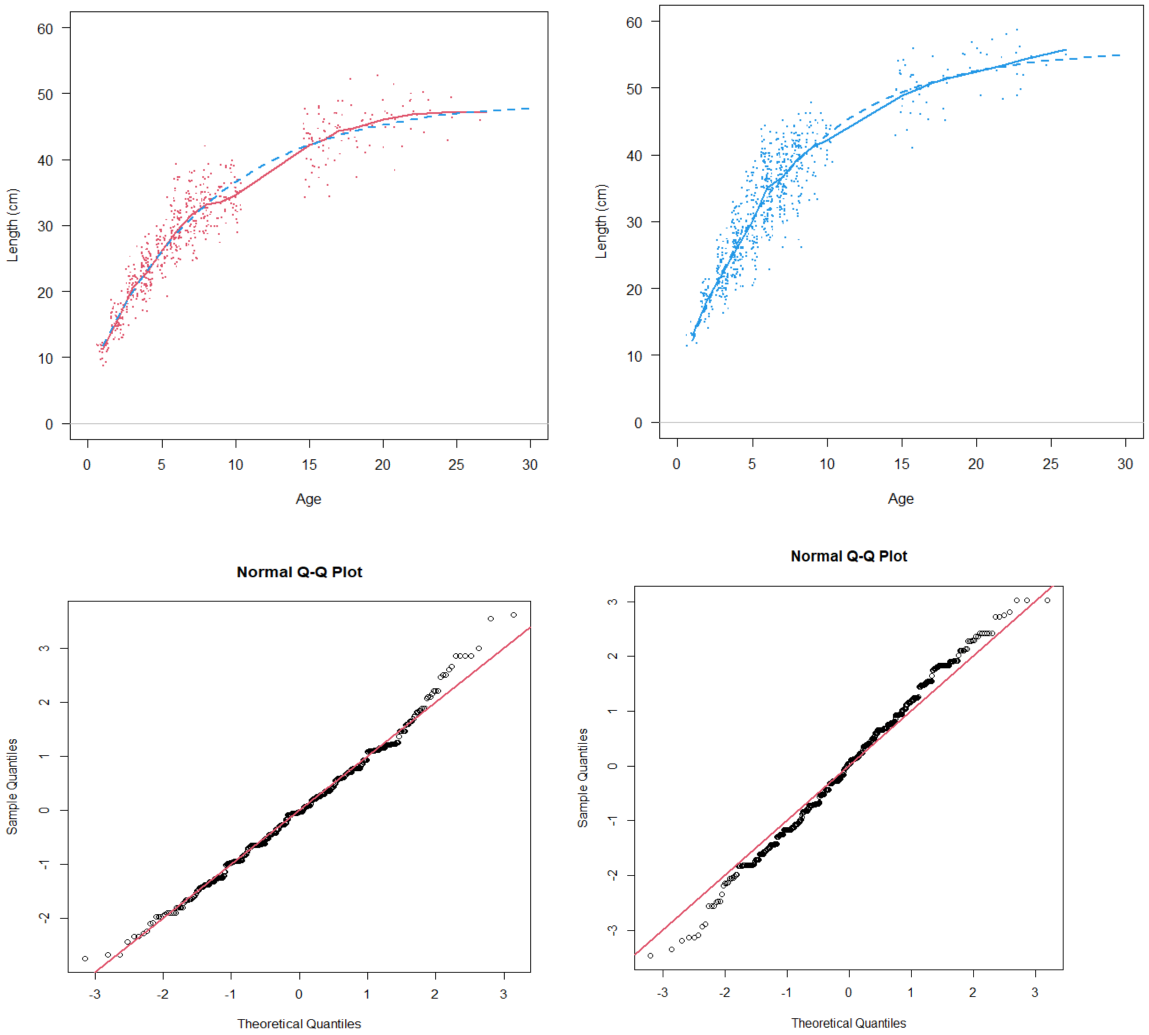

Figure 3: Fits of the estimated vB (dashed blue line) to the age-length data. Left panels, top, female with a red smooth curve through age data; bottom, QQ plot against standard normal distribution with 1:1 red line. Right panels, males with a blue smooth curve through age data; bottom, QQ plot against standard normal distribution with 1:1 red line. Estimated CV for the length-at-age distribution was 10%.

Splitting growth into three growth paths

The fisheries selectivities were assumed to be a function of length since legal size was specified by a minimum legal length (MLS). In an age-based model, the application of a length ogive results in an asymmetrical length-at-age distribution if the length-at-age distribution falls across the operating part of the selectivity (when cohort selection is not complete). This asymmetrical nature is only preserved for one time step. In a later time step (or year), the distribution reverts to being normal again. Model runs in 2019 found that the latter caused misfits in the LHS of the LF from the 2015 pot mesh experiments, because these had a relatively steep LHS to represent fewer discards from the new 2018 pots. To preserve the distributional changes induced by length ogives, growth was divided into three paths: slow, medium, and fast (Figure 4). These divisions cannot, in general, be observed in the data except at the extremes, e.g., the very fast growers which would be at the leading edge of the length-at-age distribution, so this modelling should be viewed as an artificial modelling device to (partly) preserve LF distributional changes induced by the selectivity. Nevertheless, a wide distribution of observed length-at-age does indicates that growth rate varies substantially among individual blue cod in BCO 5.

The growth paths required some subjective constraints because only the combined distribution is observable, and this can be replicated in several different ways, but we need to reduce the number of parameters estimated (two here). Firstly, when combining the length-at-age distribution over the growth paths, the resulting combined distribution should be normal with a CV of 9% (when that age is not vulnerable). Secondly, the medium growth vB was set using the parameters estimated above. The fast and slow paths were made inversely symmetrical about the mean length with the same initial proportions of fish in them, the same CV, and their means are the same interval from the medium mean length, but in opposite directions. For fast and slow growth paths, both *t0* and *K* are set to the same values for medium growth. To change the growth rate, the values of L_∞ are changed for the slow and fast growth paths.

To estimate the slow and fast growth path values of L_∞, a fit was made to a single length distribution at one age: first with the CV of the component growth paths *cv1* (the CV for growth paths slow and fast) and *cv2* (CV for the medium growth path); *p1*, the proportion of fish in the slow or fast paths; the proportion in the medium growth path is 1 – 2 × *p1*; and the fractional change to derive the means for slow and fast paths from the medium mean length, $d\mu$. Given a $d\mu$ and *p1,* both *cv1* and *cv2* are varied to make the combined distribution over the three growth paths normal with a CV of 9%. To make *cv1* and *cv2* more general (to scale for other ages), they were re-parameterised to $\sigma 1 = R_1 \sigma$ and $\sigma 2 = R_2 \sigma$, where σ is the standard deviation of the full length-at-age distribution, and R_1 and R_2 are now the estimable parameters. Estimation of growth path parameters was done at a fixed mean length, but the estimated parameters scale to any mean length, e.g., the vB L_∞ for the slow growth path is $L_\infty \times (1 - d\mu)$.

Estimation of parameters was done using a mean length of 48 cm, normal distribution, and a CV of 9%, so that σ was 4.32 cm. The objective function was the sums-of-squares of the overall normal curve from the sum of the three growth paths normal curves. Other parameters were $d\mu$, set to ± 5/48 (~ 10% shift ≈ one standard deviation), and *p1,* set to 0.25 (i.e., 50% were in the medium growth path). R_1 was estimated to be 0.637, and R_2 was estimated to be 0.581. The fit is shown in Figure 4. The CVs for the three growth paths were 5.7% for the slow and fast paths, and 5% for medium growth path. The $d\mu$ meant that the largest and smallest fish in a LF were from the fast and slow growth paths exclusively.

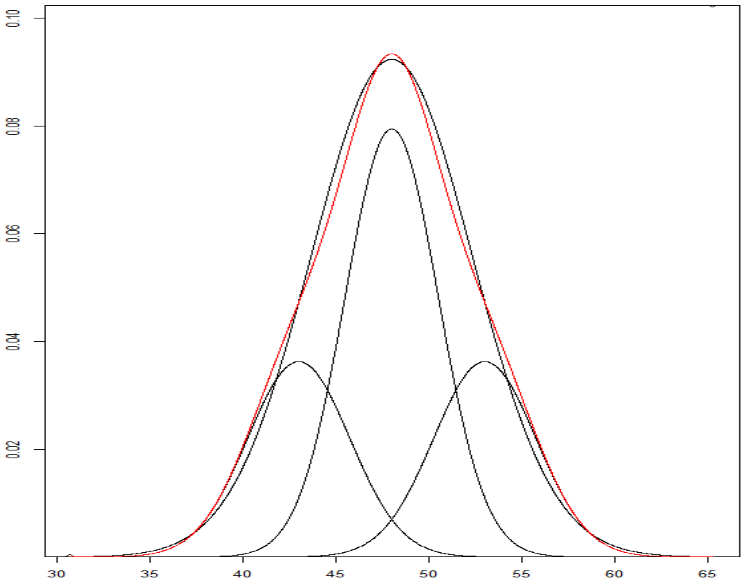

Figure 4: Best estimated growth paths (three smaller black curves), with the combined distribution over the three paths having the larger black curve, and the normal distribution with a CV of 9% (red line). $d\mu$ **was set to 5/48 and estimated parameters were:** ***p1*** **= 0.25,** ***cv1*** **and** ***cv2*** **determined using** $R_1 = 0.637$ **and** $R_2 = 0.581$**.**

The vB L_∞ for the slow growth path was $L_\infty \times (1 - d\mu,) = L_\infty \times 0.8966$, and for the fast path it was $L_\infty \times (1 + d\mu,) = L_\infty \times 1.1034$, where L_∞ is the value for the medium growth path.

To show the result of using growth paths, we plotted the numbers within the fast and slow paths from two cohorts, one from 1900 under no fishing pressure, and one from 2004 when under current fishing effort (Figure 5). Slow and fast paths have the same numbers at birth and so scale for the plots. At birth, 50% of the recruitment goes into the medium growth path (and 25% into each of the fast and slow paths), so the medium growth path has twice as much as the others and so would not show the relative change as clearly.

With no fishing, the fast and slow paths track each other with a decline due to natural mortality which applies to both equally. Applying fishing pressure using a MLS management measure, the 2004 cohort's male fast path is clearly impacted earlier than the others since it is the fastest growth and so enters the fishery first. In contrast, female slow path has little, if any, impact from fishing. The other two have an impact that starts later than the male fast path.

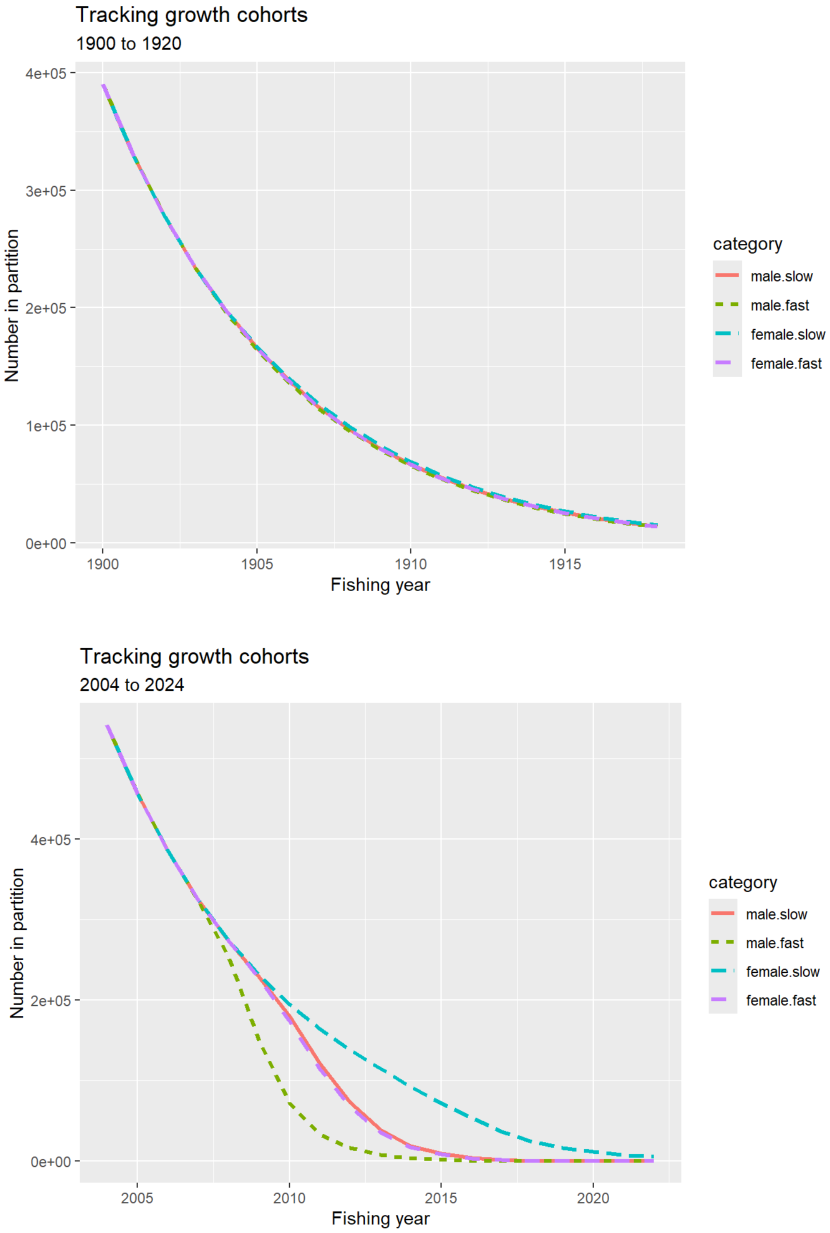

Figure 5: Following two cohorts in the slow and fast growth paths for 20 years under no fishing (1900) and under current exploitation (2004 cohort). Top, 1900 cohort. Bottom, 2004 cohort.

Maturity

In 2019, the INSWG decided to use one maturity ogive for both sexes, based on A_{to95} being 2.47 (female estimate) and the A_{50} being 4.1, the average of the male and female estimated values (male 4.4, female 3.7). These were based on age and gonad stage data from two pot surveys that were conducted at the right time of year to detect maturing and spawning fish: Paterson Inlet in 2018 (Beentjes & Miller, 2020) and Dusky Sounds in 2014 (Beentjes & Page 2016).

Natural mortality (M)

In 2019, Doonan (2020) estimated *M* to be 0.17 which was also used here. The estimation is explicitly corrected for sample size by using the 99-percentile age from surveys of nearly unfished stocks in Hoenig's (1983) equation. The age data came from the survey of Banks Peninsula, offshore strata, completed in 2016 (Beentjes & Fenwick 2017) which was the only survey of blue cod in New Zealand on a nearly unfished stock that also used the new ageing protocol.

Sex change

Although blue cod change sex from female to male (i.e., are protogynous hermaphrodites), sex ratios vary spatially and the mechanisms causing sex change are not well understood, although they are believed to have a strong behavioural component. There are insufficient data from studies on blue cod in New Zealand to model reliably the impact of sex change on blue cod dynamics in specific regions.

A management concern about sex change in blue cod is that under heavy fishing, large males will be preferentially depleted in the stock because they grow faster and so are subject to fishing mortality sooner and for longer than females. This could lead to an imbalance in the sex ratio, instability in sex ratio, and insufficient numbers of each sex for reproduction, making blue cod more vulnerable to fishing than "normal" fish stocks (Reinboth 1980, Huntsman & Schaaf 1994). The blue cod fishery is controlled by the MLS, which means males also enter the fishery at an earlier age than females. Depending on the mechanism, sex change can make species more vulnerable to fishing than "normal" species, and there may be a compounding effect from sperm limitation (Robinson et al. 2017, Easter & White 2016, Provost 2013). Some authors advocate a revision of reference points to account for this effect (Brooks et al. 2008).

The concern about sex change dynamics does have a basis in observations from severely depleted stocks, e.g., Motunau and Marlborough Sounds, in which males dominate, and mature fish have smaller average sizes than in other stocks and there is a very low proportion of mature females (about 5% in Motunau, Beentjes & Sutton 2017). At some point in the stock dynamics, blue cod in this stock manifest a nearly total transition of females to males. What the threshold is and why it occurs this way is largely unknown, but the removal of the inhibitory effect of large males is thought to result in a higher rate (and possibly earlier onset) of sex change by primary females (Beentjes & Carbines 2005).

Blue cod belong to the family Pinguipedidae or sandperches, of which there are four genera including *Parapercis*, all members of which are all thought to be protogynous hermaphrodites (Randall 1995). In New Zealand, transitional blue cod gonads (having both male and female parts in the ovaries) have been identified in three studies using microscopic methods to evaluate the gonads (more accurate, but more time consuming than using macroscopic gonad staging). The study that first suggested that blue cod is a protogynous hermaphrodite was by Mutch (1983), but this was based on one transitional fish, a rate of 0.2% of the females sampled (site in Leigh Reserve). The Carbines (2004) study collected data in 1995 at sites just outside Paterson Inlet, off Stewart Island and found 28 females that were judged to be transitional female, which represented an average of 20% of all females. These data were fitted in the previous 2013 assessment (Haist et al. 2013), but the fit was poor, even using penalties to force a fit. The third study was by Brandt et al. (2017) using data collected in a pot survey in Marlborough Sounds in 2013. Again, only one transitional female was found, less than 1% of the female sample; whereas according to Carbines, about 10 such fish might have been expected. This transitioning fish was not reproductively active (M. Dunn, NIWA, pers. comm.). It seems very hard to reconcile these observations without further information and a clear mechanism for sex change in blue cod.

The 2013 assessment (Haist et al. 2013) used a sex ratio at birth of 20% male, based on a regression fit of sex ratio against length, extrapolated back to age zero. In the 2019 assessment (Doonan 2020), to find the fraction male at birth for the model, the sex ratio at age from the three pot surveys available at that time were each extrapolated back to age zero, which gave a wide range of values. The INSWG was uncomfortable with this analysis because recruited fish were not dominated by males as occurs in other blue cod areas so there is little evidence of sex change in BCO 5. The INSWG was also concerned with the effect of the pot selectivity on the youngest fish. The INSWG initially decided to start the model at age three with a 1:1 sex ratio. However, this led to problems with fits to the recreational LF, which had lengths consistent with age one and age two fish, and so this LF could not be fitted at all well. The model was started at age one, but age data for ages one and two were excluded.

As in the 2019 assessment, for BCO 5, we assume that sex change occurs primarily in the first two years of life, and is unimportant as a dynamic element in maturity, at least at the densities that currently occur in this stock. As such, the assessment model assumes that the stock dynamics operate as a conventional separate-sex model over the ages selected by the fishery (i.e., blue cod is gonochoristic rather than hermaphroditic; hypotheses about the direction and magnitude of sex change are irrelevant). A sensitivity model was run using sex change, where the sex change rate from female to male was modelled as a capped logistic ogive and the cap, A_{50}, and A_{to95} parameters estimated.

For the sex change sensitivity, females from the fast growth path were moved into the male medium growth path using a capped logistic ogive, where the cap, A_{50}, and A_{to95} were estimated. Similarly, female medium growth path fish were moved into the male slow growth path using another capped logistic ogive.

2.2 Assessment modelling

Model structure and assumptions

We planned to use a Bayesian statistical catch-at-age model as implemented in Casal2 (Doonan et al. 2016) independently for each Statistical Area: 025, 027+029, and 030. Beentjes et al. (2024) found that the catch in Statistical Area 029 was no longer trivial and that it was best represented as part of Statistical Area 027, hence, 029 was merged into 027 to form an area 027+029. Previously, Area 029 was ignored for the individual assessments. For the BCO 5 management area, the estimates were to be added over the three assessments to get overall stock status. However, only the assessment for Statistical Area 025 was accepted by the INSWG in 2024 and so only those results are reported here.

The models were age-based (1–20 years with a plus group) with a partition made up by sex (male and female) and three growth paths (slow, medium, and fast), i.e., six categories. The model was run for the years 1900 to 2024. A single time step each year was used, and the fisheries were assumed to be year-round. There were three fisheries: line, pot, and recreational. Spawning was taken to occur after 93% of the natural mortality, and 100% of mature fish were assumed to spawn each year. Natural mortality was assumed to be constant at 0.17 y^{-1} and the stock-recruitment relationship was assumed to follow a Beverton-Holt function with steepness of 0.75. Relative year class strengths (YCS) were parameterised in the model such that the mean was equal to one. Recruits entered the model at age one, and the sex ratio was assumed to be 1:1. Ageing error was assumed to be 8.6% for a one-off error. Retained catch selectivity for fisheries were knife-edged at the MLS. Estimated model parameters and priors are summarised in Table 2; and observations, their distribution, and process error used are given in Table 3.

Table 2: Estimated model parameters for the BCO 5 assessments. "All" means Statistical Areas 025, 027+029, and 030.

Parameter	Number of parameters	Statistical Areas	Prior	Comments
B_0	1	All	Uniform-log	–
Base case				
Pot fishery selectivity	6	All	Uniform	Three time blocks, length-based logistic
Recreational selectivity	2	All	Uniform	Length-based logistic
Pot survey selectivity	4	025	Uniform	Age-based, separate sex versions
Year class strengths	42	All	Lognormal, CV 0.6; Haist parameterisation	Estimated from 1980 to 2020
Pot abundance q	1	025	Uniform	Nuisance
CPUE q	1	025	Uniform	Nuisance
Sensitivity models				
Sex change	3	025	Uniform	Capped logistic

Table 3: Observations and their distributions and process error. AF is age sample distribution; LF is length sample distribution.

Observation	Likelihood	Process error		
		CV	N	
Pot survey abundance	Lognormal	20	-	
CPUE	Lognormal	10	-	Re-weighted following Francis (2011)
AF, pot survey	Multinomial		20	
AF, pot fishery	Multinomial		20 (2019, 1)	Down-weighted since it was just from 3 months. Poor sampling for females
LF, logbook	Multinomial		20	
LF, 1986 experiment	Multinomial		5	
LF, 2015 experiment	Multinomial		5	

Lengths-at-age were converted to weights-at-age in the model using the length-weight relationship estimated by Beentjes et al. (2019), i.e., assuming the relationship, weight = $a \times \text{length}^b$ for length in centimetres and weight in kilograms. The parameters a= 0.000007289, and b = 3.2055 were assumed for both sexes for all model years.

Penalty functions were used to constrain the model so that any combinations of parameters that did not allow the historical catch to be taken were strongly penalised. A small penalty was applied to encourage the estimates of year class strengths to have mean equal to one.

Maximum of posterior distribution model runs

Maximum of posterior distribution (MPD) model runs were conducted on Statistical Area 025 to assess fits to the observations. Establishing a base model was done with the Area 025 model because it had the most data and largest historical catches. Model runs were also used to determine the data weighting for the CPUE. The CPUE was the only observation with a long enough series to warrant a formal data weighting analysis. All other data were assigned a process error: usually N = 20 for multinomial distributions (following the practice by Haist et al. 2013), and 20% for the pot survey abundance (the default choice recommended by Francis et al. (2001)). Three data sets were down-weighted further: the two mesh experiments, and the age sample distribution (AF) for the pot fishery in 2019. The mesh experiments had much fewer data collected than the other data sets and they were in the model primarily to estimate pot fishery selectivity, so they should not out-weigh other data sets (i.e., influence on YCS); a somewhat arbitrary N of 5 was used for these data. The 2019 commercial AF was down weighted with an N of 1, because it covered just the first three months of the 2019 fishing year, and the female AF had an influential but unwarranted effect on the fits in the other commercial AFs. Specifically, the 2018 AF had a strong cohort at age eight in both the male and female AFs. The 2019 male AF had a strong cohort at age 9, i.e., it was internally consistent. However, the 2019 female AF did not have a strong cohort at age 9, but it did have one at age 15+. Because the AFs were entered as a single joint sex sample distribution, the entire 2019 AF was down-weighted (N = 1).

To explore potential uncertainties in the assessment model structure, sensitivities were conducted on the Area 025 model. The following sensitivities were conducted:

1. Change M by ± 0.02,
2. Set pot discard mortality to 50%,
3. 2019 growth model
4. Single growth path,
5. Allow sex change
6. Fit the survey abundance better
7. Exclude CPUE (i.e., abundance data was only that for the survey)

MCMC runs

To estimate the joint posterior distribution of the parameters in a Bayesian analysis, Casal2 uses a straightforward implementation of the Metropolis algorithm (Gelman et al. 1995, Gilks et al. 1998) to execute the Markov Chain Monte Carlo (MCMC). The initial covariance matrix comes from the MPD run from inverting the Hessian matrix.

MCMC runs were conducted on the Statistical Area 025 model for one million iterations, keeping every 1000th value for the posterior sample. The covariance matrix was recalculated once, using the MCMC parameters of the previous run, the samples from which were then discarded. Three chains of one million iterations were run, each starting independently of each other, and these were combined for final results after discarding the 20 000 burn-in iterations.

We assessed convergence using the *Rhat* convergence statistic (Vehtari et al. 2021) and diagnostic plots. *Rhat* compares the variances from between- and within-chain estimates, i.e., it requires several independent chains, and if *Rhat* is larger than 1.05, then there is evidence of non-convergence. Plots of the MCMC trace, over-plotting cumulative parameter distributions from each chain, and the posterior distributions were generated. For acceptance, the trace should have no long-term drift and the overlaid cumulative curves should be “tight”, especially for parameters of interest, e.g., B_0 and $B_{current}$ (%B_0).

Projections

Parameter samples obtained from the MCMC posterior distribution were used to run the model into the future for 5 years using a specified constant future catch, i.e., there were 1000 runs, one for each parameter set. Summary statistics are the probabilities that B_{2029} was below 10 and 20% B_0, and above 40% B_0.

In the stock assessment, the 2023–24 commercial catch level was set at the average of the years 2020–21, 2021–22, and 2022–23. This level of catch was also used in projections of current catch for the years 2024–25 onwards.

Future recruitment was simulated by randomly re-sampling (with replacement) from the 2013–2020 YCS, applied to the stock-recruitment relationship. In 2019, the INSWG decided that the last 10 estimated YCS represented "normal" conditions, and that YCS variability for these had also been estimated using age data. For the 2019 assessment, the YCS from 1980 to 1995 were not determined by age data, but by fitting to the initially flat then increasing section of the CPUE series, which resulted in a period of much lower-than-average YCS, followed a period of much higher YCS.

3. RESULTS

Only results for the Area 025 assessment model are shown.

3.1 MPD

The base model provided good MPD fits to the data (Figures 6, 7, 8, 9, and 10).

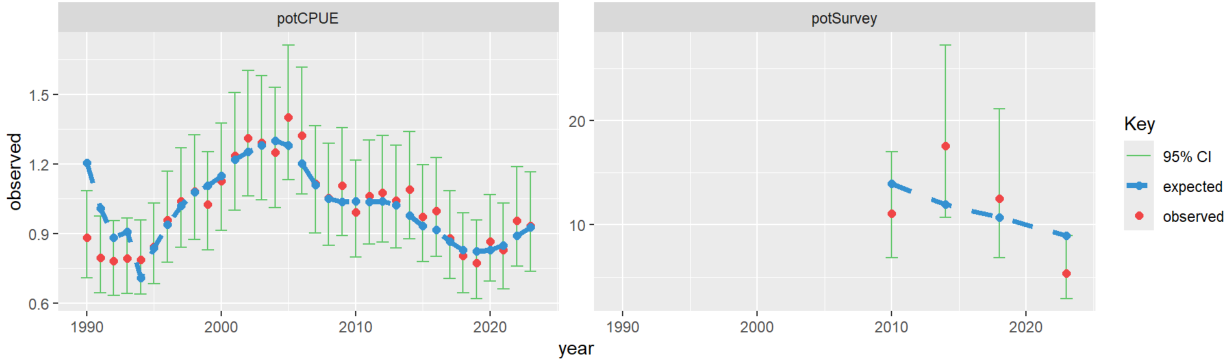

Figure 6: MPD fits to abundance indices for Area 025, base model run: (red dots, observations; vertical line, 95% CI; blue thick lines, predictions): (left) commercial catch per unit effort; (right) pot survey catch abundance.

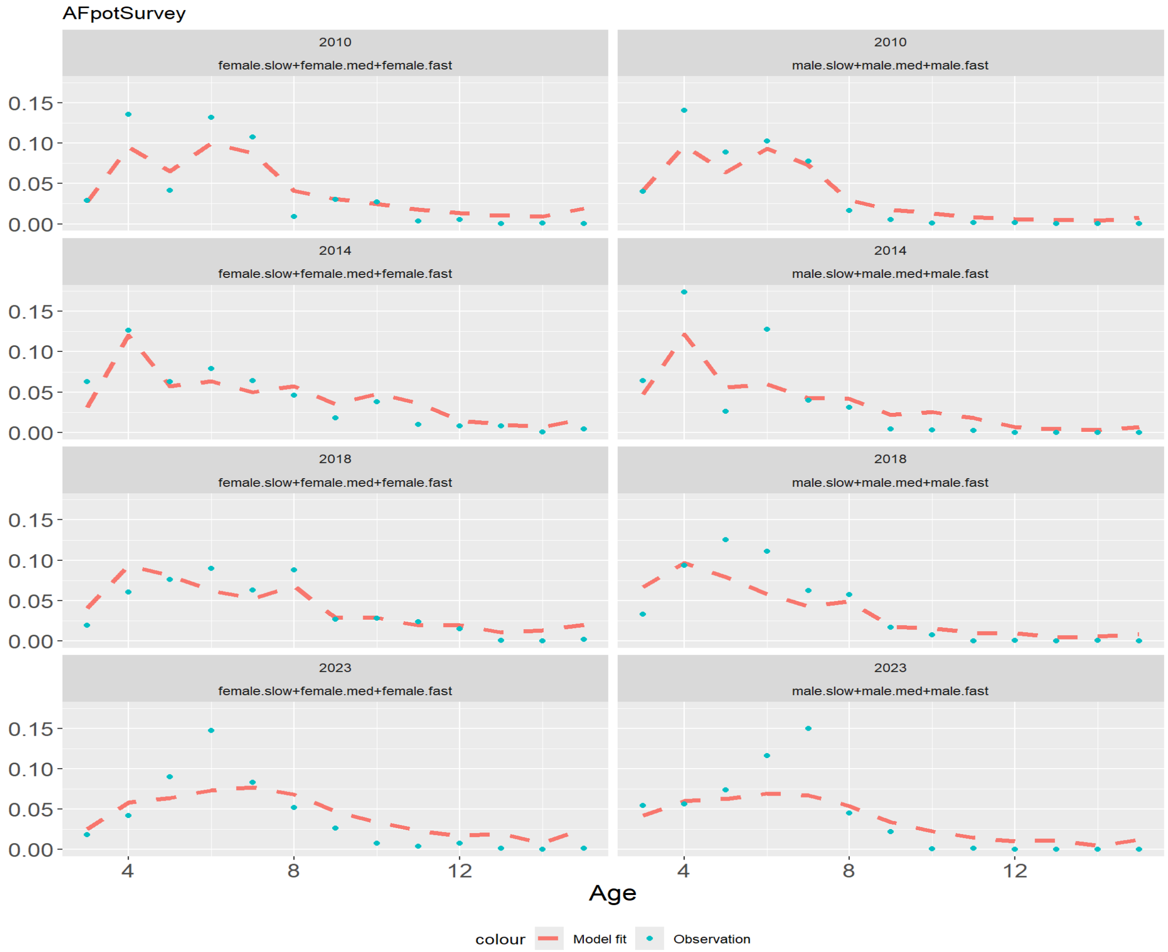

Figure 7: Pot survey age data MPD fits for Statistical Area 025, base model run: (green dots, observations; red thick lines, predictions). Left panels, female; right panels, males.

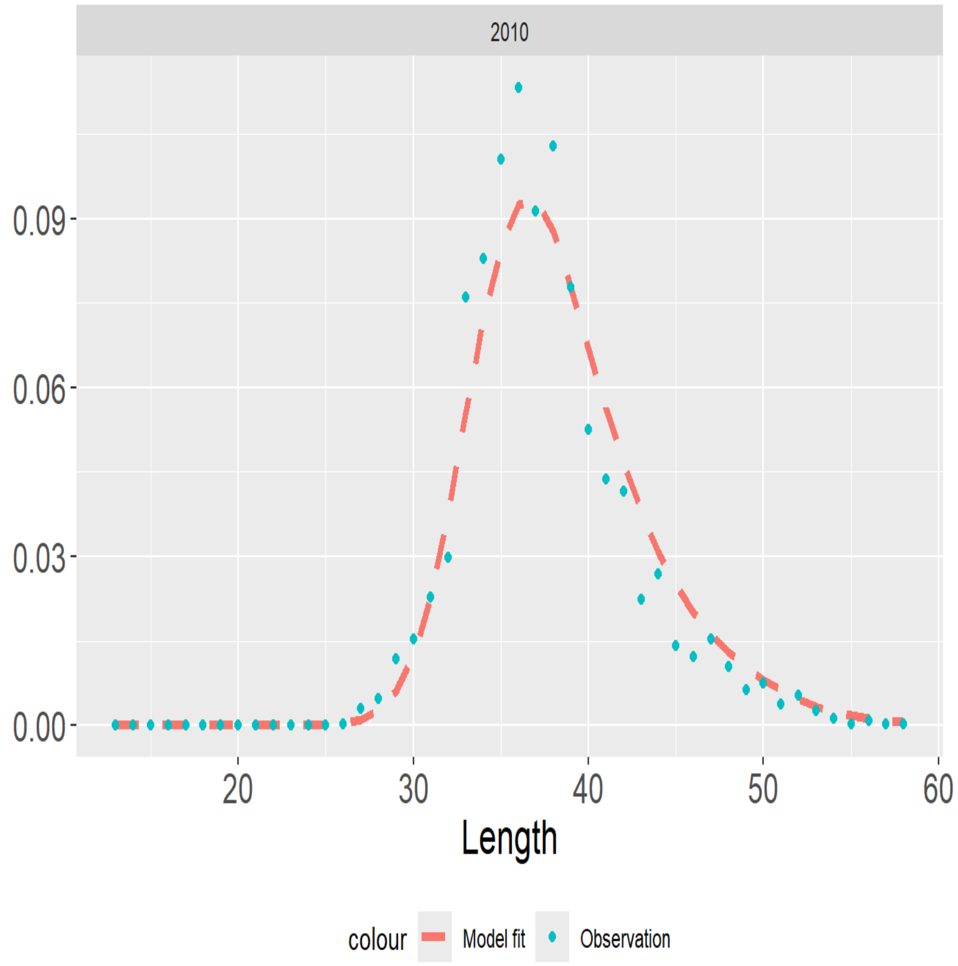

Figure 8: **Logbook LF MPD fits for Statistical Area 025, base model run: green dots, observations; red dotted line, prediction.**

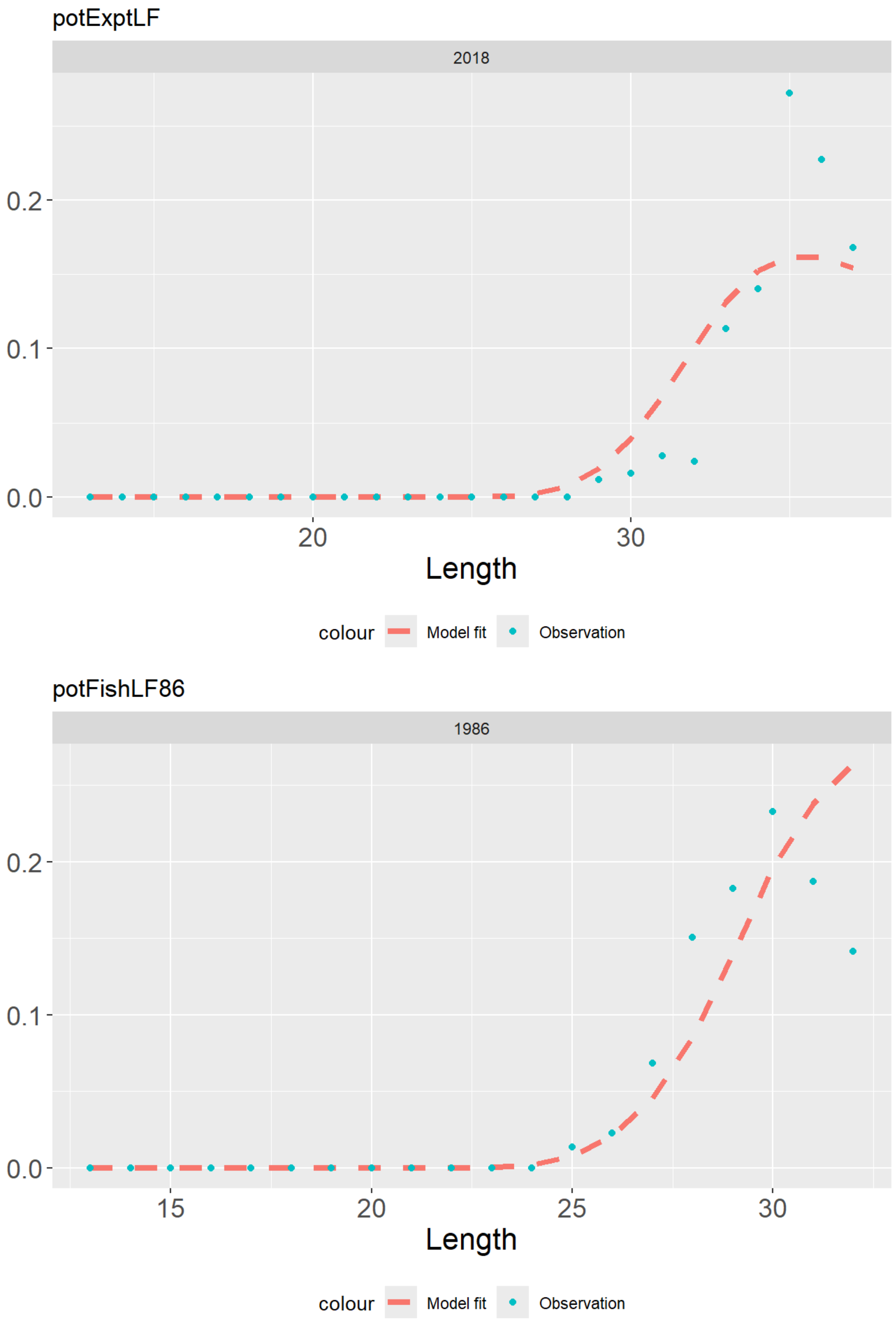

Figure 9: Pot mesh experimental LF data MPD fits for Statistical Area 025, base model run: green dots, observations; red dotted line, prediction. Top, 2018 data; bottom, 1986 data.

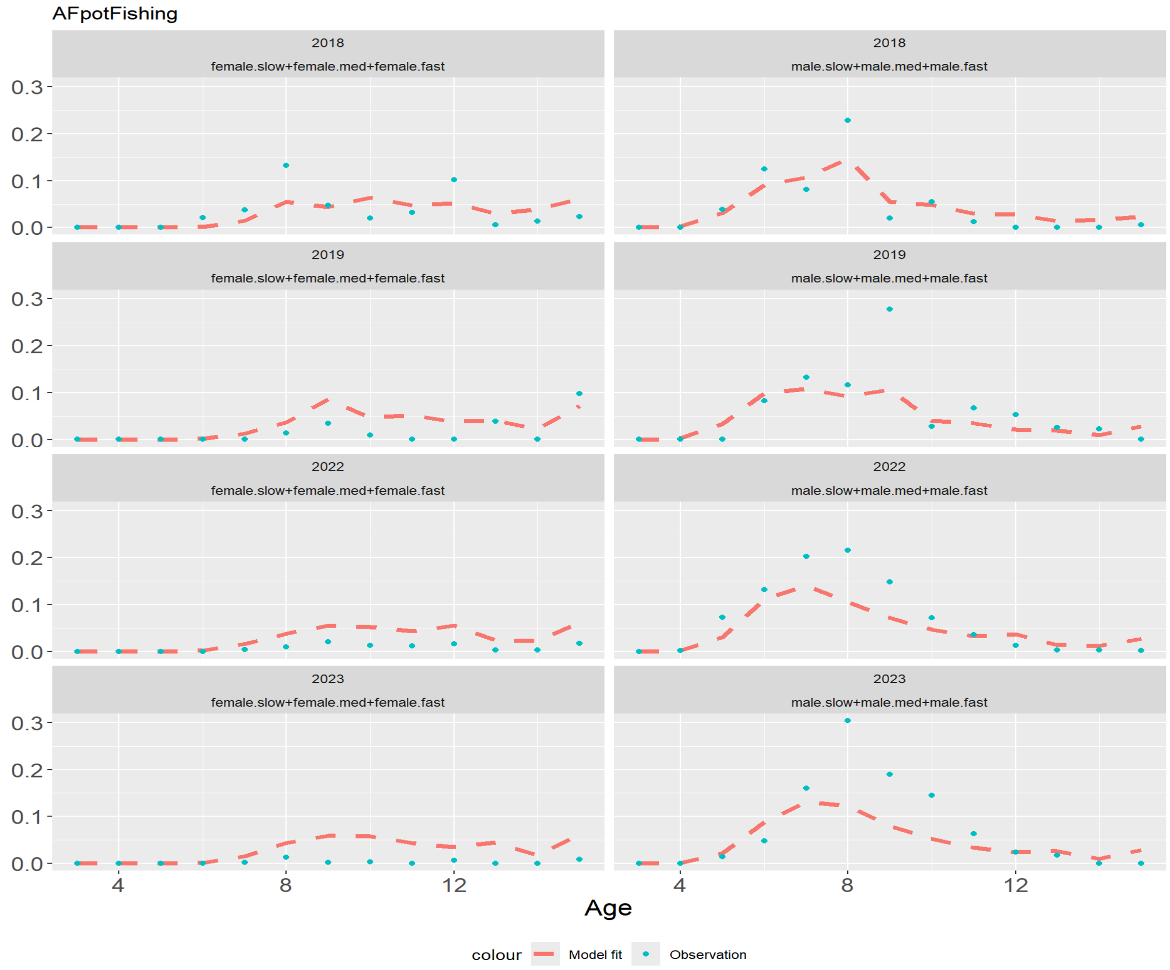

Figure 10: Pot fishery age data MPD fits for Statistical Area 025, green dots, observations; red dotted line, prediction: (left panels) female data; (right panels) male data.

For the Statistical Area 025 base case the estimated B_0 and $B_{current}$ (% B_0) were 10 200 t, and 33.3% B_0.

Estimated $B_{current}$ from the sensitivity runs varied little from the base case: a range of 28.2% to 35.9 % (Table 4). The largest change occurred when the CPUE was excluded which reduced $B_{current}$ to 28.2%. When the period to use for standardizing the YCS was reduced to 2000–2021 (the YCS for 2000 is the earliest one to affect the first age composition in 2010) $B_{current}$ was 32.5%. Adding sex change did not change the status much, but it did allow the model to fit the commercial age compositions for 2022 and 2023 much better (Figure 11).

Table 4: Estimated B_0 and B_{2024} estimated from the sensitivity runs for BCO 5.

Sensitivity	*B_0 (t)*	*B_{2024} (% B_0)*	*Comment*
Base	10 200	33.3	
N=1 for pot fishing AF	10 500	35.7	
M = 0.19	9 400	34.2	
M = 0.15	11 400	33.4	
Set steepness to 0.90 (cf 0.75)	9 100	33.0	
Use 2019 model's growth	9 500	35.6	
Exclude survey data, only abundance series is from CPUE	10 400	35.9	
Exclude CPUE, only abundance series is from the survey	10 100	28.2	
Exclude CPUE, only abundance series is from the survey; YCS range for standardisation is 2000–21	10 300	32.5	
Increase 1900–1985 catches by 25%	10,100	29.6	
Put in sex change transition by year blocks.	9 700	32.6	Time blocks: 2021–24, 2018–20, 2015–17. Block with an estimated non-zero sex transition was 2021–24.

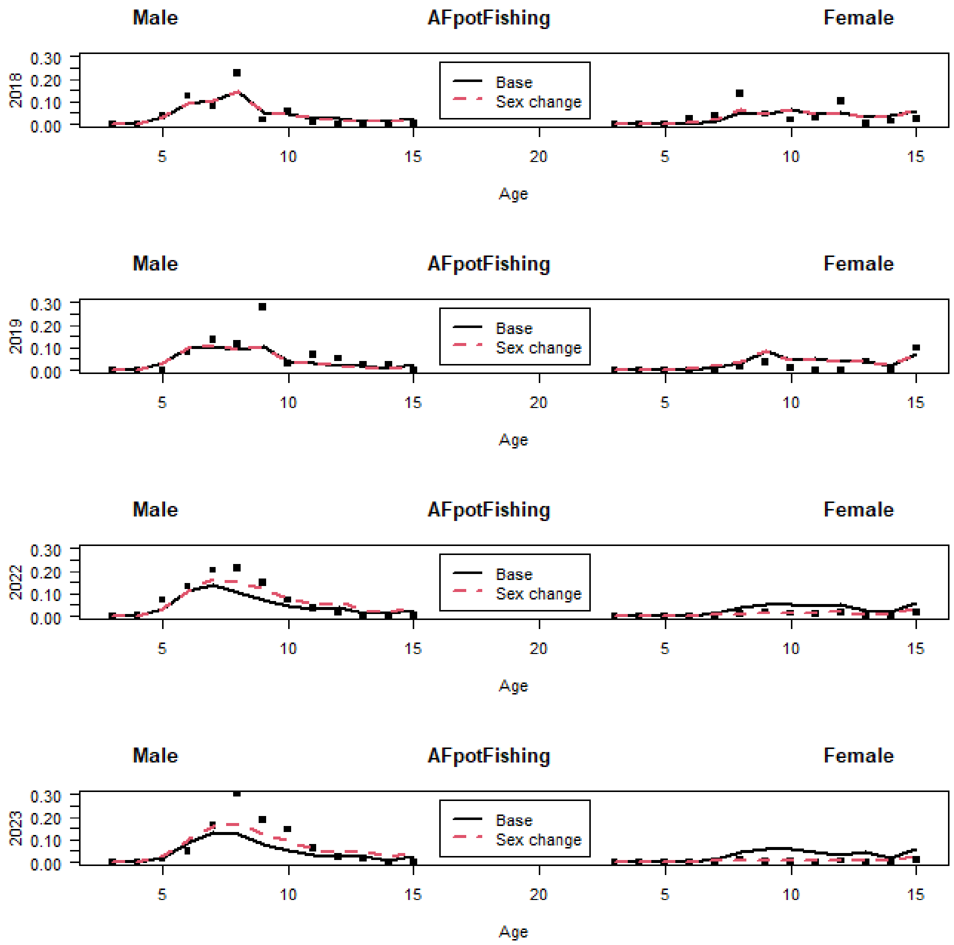

Figure 11: Commercial age compositions fits to the base case (black lines) and to the sensitivity where sex change was allowed (red dash lines). Observations are squares.

3.2 MCMC runs

There was no evidence of non-convergence for B_0 and $B_{current}$ (%B_0) (Appendix 4). The median B_0 and $B_{current}$ (%B_0) with the 95% credible intervals (CI) were: 10 600 t (9 800 – 11 800 t) and 35.3% (27.2 – 45.5%).

The spawning stock biomass (SSB) trajectory for Statistical Area 025 is shown in Figure 12 and YCS is shown in Figure 13.

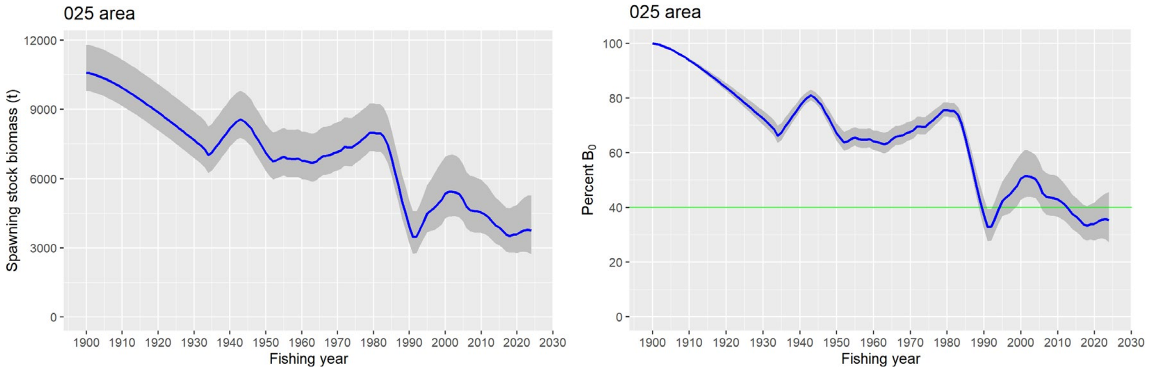

Figure 12: Median estimates (blue line) of spawning stock biomass for the base case of Statistical Area 025, 1900–2024 with 95% credible interval (grey shaded area): (left panel) absolute biomass, (right panel) as a percentage of B_0.

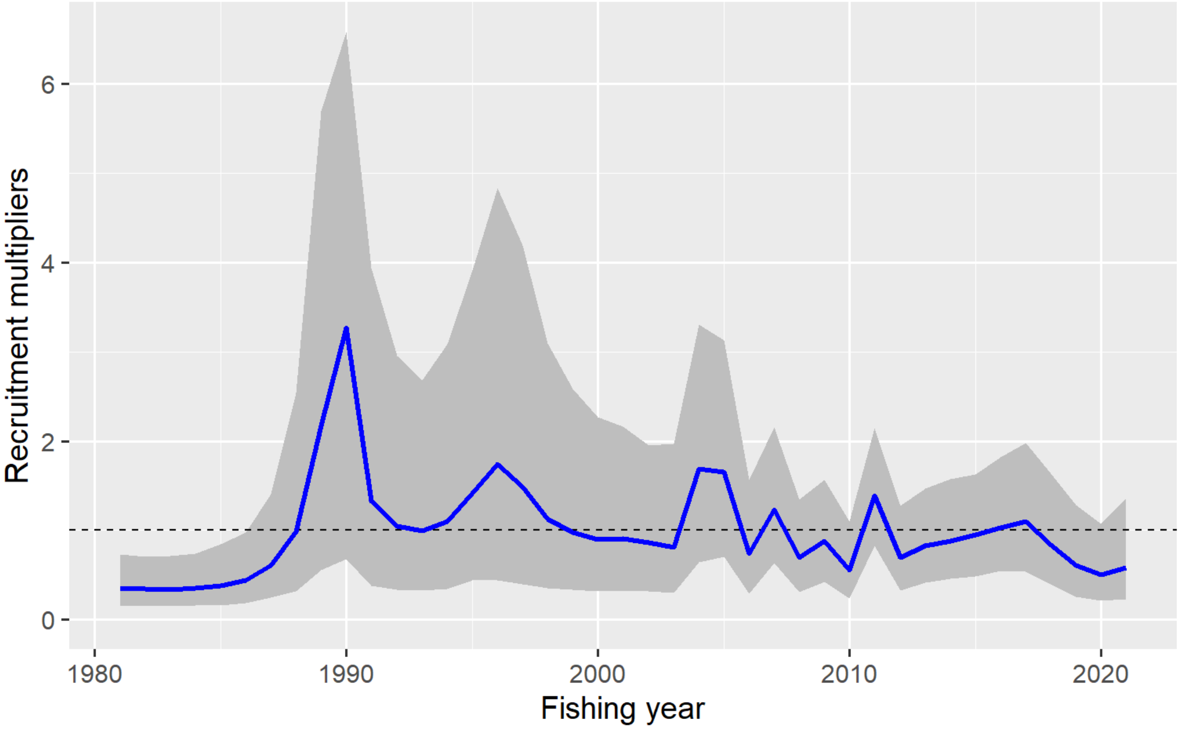

Figure 13: Estimated recruitment multipliers from the base case runs for Statistical Areas 025, 1981–2021. Medians are shown by the blue line and the shaded areas show the 95% range limits. The dotted horizonal line is at a YCS of one, the long-term average by definition.

3.3 Projections

With catches at current levels, the median SSB was projected to increase slowly over the next five years (Figure 14). With catches at current levels, the probability of the stock being less than either the soft or hard limit over the next five years was negligible (Table 5).

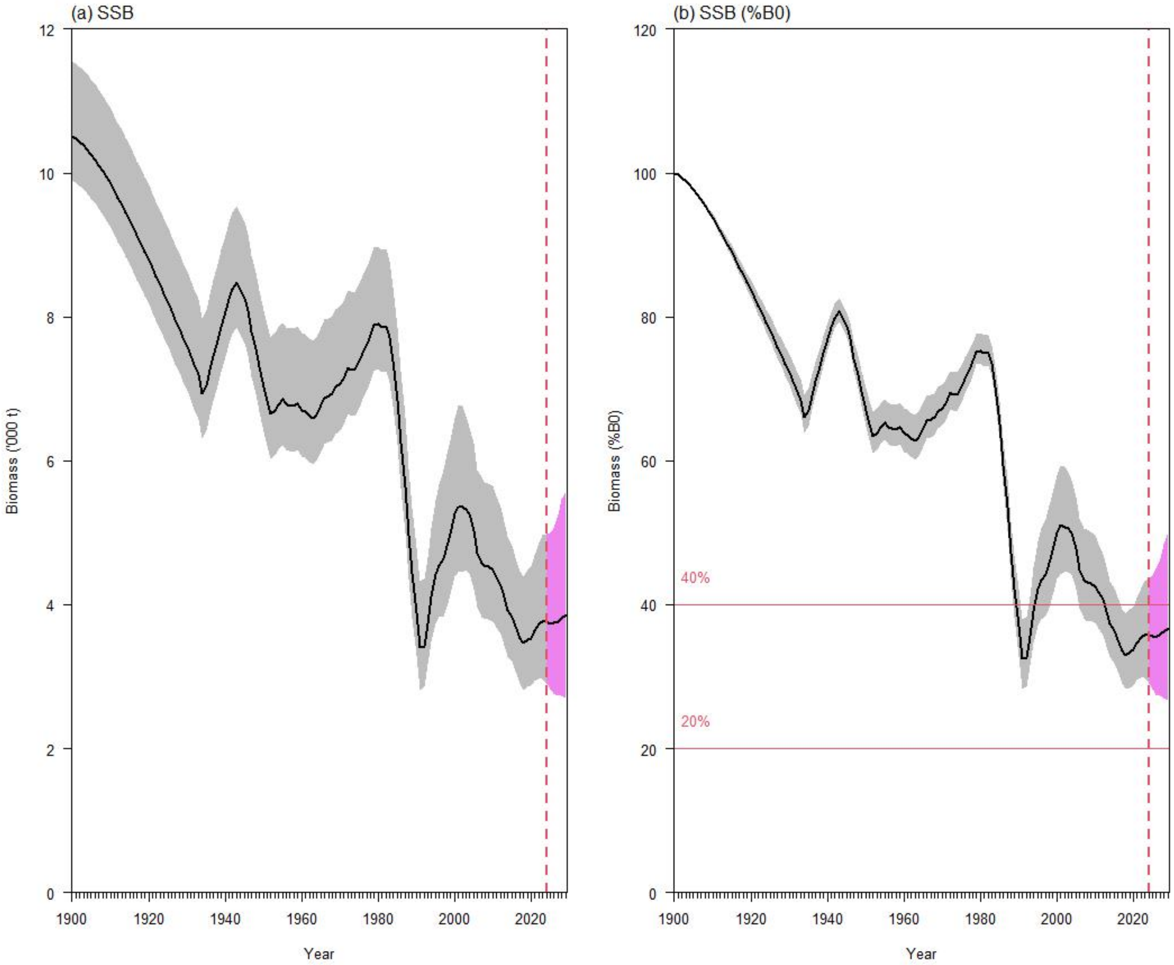

Figure 14: Projected Statistical Area 025 spawning biomass assuming recent recruitment and catch at current levels for the base case run (a), absolute SSB; (b) SSB as a percentage of B_0. Median estimates are shown as solid lines and 95% confidence intervals as shaded polygons. Projections start in 2020.

Table 5: Probabilities of SSB being below B_0 reference levels in 2024 and 2029 at current catch levels for the base case projections. Projected recruitment simulated from the 2012–2021 estimated YCS.

Run	Probability
Current	
P($B_{2019}< 0.1\ B_0$)	0
P($B_{2019}< 0.2\ B_0$)	0
P($B_{2019}>= 0.4\ B_0$)	0.18
5 year projection	
P($B_{2024}< 0.1\ B_0$)	0
P($B_{2024}< 0.2\ B_0$)	0
P($B_{2024}>= 0.4\ B_0$)	0.37

4. DISCUSSION

The fishery independent abundance indices, from the pot surveys, begin after the model SSB trajectory had flattened out, or was declining slowly, and therefore had little leverage in the model. Only the CPUE series covered the time period of stock decline. However, the CPUE started to flatten and then increased over the period when catches were at their highest, which in this model could only be "explained" by a pattern of very low recruitment followed by a period of very high recruitment, with the latter recruiting into the fishery in the period when catches were highest, so that CPUE increased. Figure 13 shows that YCS medians were about one third of average levels for seven years, followed by very good YCS that peaked at three times the average. The age data from the pot survey and the commercial sampling occurred so long after the period of high YCS that the cohorts from these high YCSs were not present in the age data and so had little constraining or confirming influence on the initial pattern of YCS. The B_0 estimate was most influenced by the period of declining CPUE (starting in 2006), under the influence of the (lower) catches attributed to this period along with estimates of more normal recruitment (less extreme and fluctuating about some mean with no time trend). This defines the productivity needed to observe the decline under normal conditions.

It is notoriously hard to evaluate CPUE accuracy, especially with no fishery independent surveys over the same period. In the authors' experience, CPUE can be maintained at some nearly constant rate over multi-year blocks before it steps downwards, so it can often appear as a series of "steps", i.e., the declining part of the CPUE may under-estimate the decline and so over-estimate the productivity. In the 2019 assessment, the CPUE was accepted for all Statistical Areas that had assessments. In 2024, spatial changes in the fisheries meant that Statistical Areas 027+029 and 030 had CPUE withdrawn until further work could be completed (Beentjes et al. 2024) and so no assessments were available for those areas. The CPUE for Statistical Area 025 was accepted by the SIWG but rejected by the May 2024 Fisheries Plenary (Fisheries New Zealand 2024). The Plenary felt that the appearance of 95% males in the 2022 and 2023 commercial catch indicated that the stock was stressed (e.g., like Motunau), yet the CPUE was increasing. The 025 assessment did not fit the 2022 and 2023 commercial age compositions, but it did fit the increasing CPUE. Anecdotal fisher reports (Tony Brett, pers. comms.) indicated that catch rates were poor, but these were from September 2023 onward (i.e., in the 2024 model year) and so the model had no data on this. Other fisher comments indicated that fisher behaviour had changed in recent years, which undermined the basis for recent CPUE tracking abundance, e.g., fishers now haul pots, rebait them, but drop them away from the haul site; previously, they dropped the rebaited pots back at the same site.

Adding sex change into the model resulted in similar stock status as the base case, but it allowed better fits to the commercial age compositions for 2022 and 2023, which were less well fitted in the base case model (i.e., older fish were over-predicted in the base case model). The sex change mechanism was *ad hoc*, just shifting females into the male partition in the last four years (taken as one parameter block) and clearly driven by the 2022 and 2023 commercial age composition fits. Better prediction would come from knowing the drivers for large proportions of sex change, which could then be incorporated into the model. As yet, no experimental data are available, so this is a flaw in the current model if large sex change events are needed. Beentjes & Bian. (2024) noted that sampling rate in Statistical Area 025 was low, and it was difficult to get fishers to participate in sampling programmes, so we cannot rule out some sampling bias.

A successful assessment for assessment units 027+029 and 030 requires an unbiased CPUE series for each. First, determine what changes in fishers' behaviour that has affected CPUE by interviewing fishers. Second, assess the spatial expansion of effort into pristine or little fished areas. Third, establish the split in historical catch between the old and newer areas prior to 2019. Note that the Electronic Reporting System was introduced in 2019 which has positions of pot lift, whereas the old system reported position by statistical area so that spatial distribution within each area is unknown. Hence historical catch splits within statistical areas needs fisher interviews and these should be done sooner rather than wait for the next assessment in five years' time.

5. ACKNOWLEDGMENTS

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APPENDIX 1: LANDINGS USED IN THE MODEL

Table A1.1: Statistical Area 025 landings for the line, pot, and recreational fisheries.

Year	Line	Pot	Recreational
1900	0	0	2
1901	13.2	0	20
1902	26.4	0	20.4
1903	39.6	0	20.8
1904	52.7	0	21.3
1905	65.8	0	21.7
1906	78.8	0	22.1
1907	91.9	0	22.5
1908	104.8	0	23
1909	117.8	0	23.4
1910	130.7	0	23.8
1911	143.6	0	24.2
1912	156.5	0	24.2
1913	169.3	0	24.3
1914	182.1	0	24.5
1915	194.8	0	24.6
1916	207.6	0	24.7
1917	220.3	0	24.8
1918	232.9	0	24.9
1919	245.5	0	25
1920	258.1	0	25.1
1921	270.7	0	25.4
1922	283.2	0	25.6
1923	295.7	0	25.8
1924	308.2	0	26.1
1925	320.6	0	26.3
1926	333	0	26.5
1927	345.3	0	26.7
1928	357.7	0	26.8
1929	370	0	27
1930	382.2	0	27.1
1931	394.4	0	27.2
1932	405.3	0	27.7
1933	444.7	0	28.1
1934	586.5	0	28.5
1935	153.5	0	28.9
1936	62.5	0	29.3
1937	90.7	0	29.3
1938	51	0	29.2
1939	73.5	0	29.2
1940	22.6	0	29.2
1941	67.7	0	29.1
1942	73.2	0	29
1943	112.5	0	28.8
1944	309.1	0	28.6
1945	350.3	0	28.5
1946	394.4	0	28.3
1947	539.3	0	28.8
1948	477.4	0	29.4
1949	536	0	29.9
1950	571	0	30.5
1951	488.8	0	31.1
1952	513.9	0	31.4
1953	245.9	0	31.7
1954	249.7	0	32
1955	266.1	0	32.3
1956	409	0	32.6
1957	354.2	0	33.5
1958	331.6	0	34.4
1959	299	0	35.3
1960	444.5	0	36.2
1961	345.2	0	37.1
1962	397	0	37.8
1963	375.3	0	38.4
1964	276.1	0	39.1
1965	184.9	0	39.8
1966	219.4	0	40.5
1967	309.7	0	40.7
1968	286.1	0	41
1969	208.7	0	41.3
1970	262.6	0	41.5
1971	231.5	0	41.8
1972	120.3	0	42
1973	339.2	0	42.2
1974	289.6	0	42.4
1975	137.3	0	42.6
1976	156.2	0	42.8
1977	126.4	0	42.8
1978	125.8	0	42.7
1979	93.8	0	42.7
1980	205.4	29.2	42.7
1981	211.2	69.9	42.7
1982	125	74.3	42.5
1983	183	180.9	42.2
1984	142.5	33.5	46.1
1985	135.3	34.6	46.5

Table A1.1*:* continued.

Year	Line	Pot	Recreational	Year	Line	Pot	Recreational
1986	61.2	409.9	41.5	2005	0	727.3	37.1
1987	2.6	455.5	41.3	2006	0	800.3	36.9
1988	0	519.3	41.2	2007	0	689.8	36.9
1989	0	425.7	40.9	2008	0	709.6	36.9
1990	0	560	40.8	2009	0	708.5	37.2
1991	0	719.9	40.7	2010	0	658.3	37.5
1992	0	532.9	40.4	2011	0	629.4	37.8
1993	0	637.6	40.4	2012	0	571.7	37.9
1994	0	728.9	40.4	2013	0	579.4	39.5
1995	0	680.8	40.3	2014	0	596.9	41.4
1996	0	704.5	39.1	2015	0	505.5	43.3
1997	0	622.6	38.5	2016	0	544.5	45.3
1998	0	571.4	37.8	2017	0	578.8	47.3
1999	0	654	37.1	2018	0	439.3	49.3
2000	0	597.4	36.7	2019	0	348	48.4
2001	0	752.9	36.9	2020	0	422.2	47.4
2002	0	733.7	37	2021	0	305.8	45.7
2003	0	645.9	37.2	2022	0	279.4	44.2
2004	0	591.4	37.2	2023	0	258.2	43.1

APPENDIX 2: POT SURVEY AGE SAMPLE DISTRIBUTION

Table A2.1: Age sample distribution from the pot surveys: 2010, 2014, 2018, and 2023. Data for ages 1 and 2 are discarded since the model assumes a 50:50 sex ratio, but sex change may occur in these ages.

	Male				Female			
Age	2010	2014	2018	2023	2010	2014	2018	2023
3	0.04055	0.06416	0.03324	0.05451	0.02885	0.06291	0.01937	0.01804
4	0.14075	0.17413	0.0936	0.05604	0.13561	0.12624	0.06046	0.04188
5	0.08901	0.02622	0.1252	0.07387	0.04168	0.0626	0.07586	0.08967
6	0.10256	0.12801	0.11103	0.11596	0.13222	0.07898	0.08982	0.14754
7	0.07751	0.04001	0.06209	0.15009	0.10759	0.06385	0.0627	0.08294
8	0.01632	0.0313	0.05761	0.04494	0.00883	0.04581	0.08819	0.05207
9	0.00554	0.00446	0.01703	0.02201	0.03039	0.01772	0.02661	0.02619
10	0.00082	0.00311	0.00744	0.00092	0.02731	0.03783	0.02783	0.00754
11	0.00164	0.00238	0.0001	0.00143	0.00329	0.00954	0.02345	0.00367
12	0.00164	0.0001	0.00031	0.00010	0.00554	0.00808	0.01519	0.00764
13	0.00051	0.0001	0.0001	0.00010	0.00041	0.00798	0.00051	0.00132
14	0.0001	0.0001	0.00031	0.00010	0.00072	0.00031	0.0001	0.00010
15	0.00021	0.0001	0.0001	0.00010	0.00041	0.00394	0.00173	0.00122

APPENDIX 3: FISHERIES DATA

Table A3.1: Standardised CPUE for Statistical Area 025, 1990–2023.

Year	CPUE	cv(%)	Year	CPUE	cv(%)
1990	0.882	0.042	2007	1.115	0.035
1991	0.797	0.036	2008	1.053	0.038
1992	0.782	0.033	2009	1.106	0.039
1993	0.792	0.030	2010	0.991	0.041
1994	0.787	0.028	2011	1.063	0.04
1995	0.845	0.031	2012	1.076	0.044
1996	0.959	0.030	2013	1.042	0.043
1997	1.039	0.034	2014	1.090	0.043
1998	1.083	0.035	2015	0.972	0.046
1999	1.025	0.033	2016	0.997	0.044
2000	1.128	0.032	2017	0.881	0.046
2001	1.235	0.031	2018	0.804	0.044
2002	1.313	0.033	2019	0.775	0.049
2003	1.293	0.035	2020	0.867	0.046
2004	1.251	0.034	2021	0.831	0.054
2005	1.401	0.034	2022	0.956	0.057
2006	1.322	0.034	2023	0.933	0.062

Table A3.2: 1986 pot mesh experiments, right-hand side to the LF for pot used in the pre-1994 pot fishery as used in the assessment, i.e., data past 33 cm were excluded. 1-cm wide bins, no plus-group.

Length (cm), lower bound of bin	Proportion
13	0
14	0
15	0
16	0
17	0
18	0
19	0
20	0
21	0
22	0
23	0
24	0
25	0.013699
26	0.022831
27	0.068493
28	0.150685
29	0.182648
30	0.232877
31	0.187215
32	0.141553

Table A3.3: Logbook data (assigned to 2010) length sample distribution for Statistical Areas 025. 1-cm wide bins, no plus-group.

Length (cm), lower bound of bin	Proportion
13	0
14	0
15	0
16	0
17	0
18	0
19	0
20	0
21	0
22	0
23	0
24	0
25	0
26	0.000289
27	0.002891
28	0.004626
29	0.011853
30	0.015322
31	0.022839
32	0.029777
33	0.076034
34	0.082972
35	0.100607
36	0.113328
37	0.091356
38	0.10292
39	0.077768
40	0.052616
41	0.043654
42	0.041631
43	0.022261
44	0.026886
45	0.014166
46	0.012142
47	0.015322
48	0.010408
49	0.00636
50	0.007517
51	0.003758
52	0.005204
53	0.002602
54	0.001156
55	0.000289
56	0.000867
57	0.000289
58	0.000289

Table A3.4: Shed length sample distribution (assigned to 2010 for Statistical Area 025). Not used, shown for completeness.

	Proportion	
Length (cm), lower bound of bin	Male	Female
27	0	0
28	0	0
29	0.002101	0.00042
30	0.001471	0.001471
31	0.015339	0.013658
32	0.058416	0.055684
33	0.111158	0.076487
34	0.113469	0.073335
35	0.091826	0.045388
36	0.083841	0.027107
37	0.057155	0.015339
38	0.040555	0.009456
39	0.028367	0.007354
40	0.014709	0.003362
41	0.010927	0.003152
42	0.009876	0.001681
43	0.008195	0.001681
44	0.005884	0.00063
45	0.002942	0.001261
46	0.002101	0
47	0.001471	0
48	0.002101	0
49	0	0
50	0.00021	0
51	0	0
52	0	0
53	0.00021	0
54	0	0
55	0.00021	0
56	0	0
57	0	0
58	0	0

Table A3.5: Statistical Area 025 scaled age compositions of the commercial catch that were used in the assessment. The data is truncated at age 3 for modelling purposes. Age 15 is a plus-group.

	2018		2019		2022		2023	
Age	Male	Female	Male	Female	Male	Female	Male	Female
3	0.000113	0.000113	0.000161	0.000161	0	0	0	0
4	0.000113	0.000113	0.000161	0.000161	0.002374	0	0	0
5	0.038653	0.000113	0.000161	0.000161	0.07311	0	0.013993	0
6	0.124204	0.021264	0.082464	0.000161	0.131592	0	0.047479	0
7	0.080877	0.037513	0.132357	0.000161	0.202807	0.003775	0.160222	0.002579
8	0.227785	0.132566	0.115831	0.013732	0.215385	0.009433	0.304132	0.013356
9	0.020334	0.046826	0.277357	0.034168	0.148086	0.019996	0.189153	0.002082
10	0.055132	0.01954	0.027463	0.009529	0.072242	0.013336	0.144689	0.002891
11	0.012131	0.031885	0.066926	0.000161	0.035893	0.011792	0.063313	0.000242
12	0.000113	0.101808	0.053131	0.000161	0.012952	0.015558	0.023459	0.006949
13	0.000113	0.005715	0.025173	0.038904	0.003241	0.003243	0.01695	0
14	0.000113	0.013969	0.022882	0.000161	0.003241	0.003241	0	0
15	0.005352	0.023543	0.000161	0.098154	0.001587	0.017115	0	0.008512

Table A3.6: Scaled length sample distributions of the recreational catch for 2009–10 used in the assessments. The same LF was applied to each sub-area assessed. Length bins were 1-cm wide and there was no plus-group.

Length (cm), lower bound of bin	Proportion
13	0.009846
14	0.001532
15	0.008314
16	0.007727
17	0.003717
18	0.009047
19	0.003064
20	0.009713
21	0.001386
22	0.014361
23	0.004744
24	0.012976
25	0.019559
26	0.023261
27	0.016919
28	0.0267
29	0.023928
30	0.060393
31	0.036237
32	0.035731
33	0.067683
34	0.07409
36	0.077094
37	0.0634
38	0.088041
39	0.049778
40	0.070687
41	0.022917
42	0.031802
43	0.016692
44	0.009927
45	0.005543
46	0.011737
47	0.003504
48	0.005102
49	0
50	0
51	0
52	0
53	0
54	0
55	0
56	0
57	0

Pot mesh experiment, 2015

Pot 1 (pre-2018 standard pot) was a 50–52 mm galvanised mesh (3' 6" × 3' 6") and Pot 2 (proposed new pot) had 54–56 mm stainless steel mesh (3' 6" × 4'). These pots were set simultaneously 19 times at a total of six sites across four statistical areas (Table 3.10).

Table A3.7: Data design of the 2015 pot mesh experiments conducted by G. Carbines (pers. comm.).

Statistical	Number of			
Area	Sites	Sets	Pots	Blue cod
025	2	9	3	496
027	1	3	3	56
029	1	3	3	102
030	2	4	3	81
Total	6	19	51	735

The experiment was reviewed by the INSWG in November 2015 and the notes of the meeting found that:

1. "Limitations of the experimental design precluded meaningful comparison of size composition by statistical area, or area related differences in selectivity. The data did, nevertheless, enable a comparison of the relative selectivity of the three pot types.
2. Proportions of undersize (< 33cm TL) blue cod retained by the pots were: 11% for Pot 1, 2% for Pot 2, and 50% for Pot 3. Apart from retaining a larger proportion of undersized fish, Pot 3 also allowed a substantial portion of larger fish to pass through the escape gaps.
3. Almost all commercially caught undersized blue cod retained by pots are dead on return to the water."

Table A3.8: LHS length sample distribution from Pot 2 in the 2015 pot mesh experiments as used in the assessment. Data from 38 cm onwards were excluded.

Length bin lower limit (1 cm wide)	Proportion
29	0.012
30	0.016
31	0.028
32	0.024
33	0.113
34	0.140
35	0.272
36	0.227
37	0.168

APPENDIX 4: MCMC DIAGNOSTICS FOR STATISTICAL AREA 025

The non-YCS parameter codes (as generated automatically from Casal2) and their descriptions are shown in Table 4.1, and their median and 95% CIs shown in Table 4.2.

Table A4.1: Parameter codes used in this appendix and their descriptions.

Code	Parameter class	Parameter
process.Recruitment..b0		*B*$_0$, virgin biomass
selectivity.potSurveySel_male..a50	Pot survey selectivity, male	Age at 50% selection
selectivity.potSurveySel_male..ato95		Extra time from 50% to 95% selection
selectivity.potSurveySel_female..a50	Pot survey selectivity, female	Age at 50% selection
selectivity.potSurveySel_female..ato95		Extra time from 50% to 95% selection
time_varying.potFsel.L50..values.1900.	Pot fishery selectivity, 1900–1993	Length at 50% selection
time_varying.potFsel.Lto95..values.1900.	Note, the 1993 comes from the start year of the next time block minus 1 year	Extra length to go from 50% to 95% selection
time_varying.potFsel.L50..values.1994.	Pot fishery selectivity, 1994–2017	Length at 50% selection
time_varying.potFsel.Lto95..values.1994.		Extra length to go from 50% to 95% selection
time_varying.potFsel.L50..values.2018.	Pot fishery selectivity, 2017–2018	Length at 50% selection
time_varying.potFsel.Lto95..values.2018.		Extra length to go from 50% to 95% selection
selectivity.recFSel..L50	Recreational selectivity	Length at 50% selection
selectivity.recFSel..Lto95		Extra length to go from 50% to 95% selection

Table A4.2: Statistical Area 025 MCMC parameter estimates: median, 95% confidence level, and CV.

Name	Median	95% Confidence interval		CV (%)
process.Recruitment..b0	9815	10537	11781	5
selectivity.potSurveySel_male..a50	1.08	2.32	3.57	31
selectivity.potSurveySel_male..ato95	0.27	1.98	4.64	58
selectivity.potSurveySel_female..a50	1.21	2.93	4.09	28
selectivity.potSurveySel_female..ato95	0.28	2.13	4.78	58
time_varying.potFsel.L50..values.1900.	25.51	29.15	32.75	6
time_varying.potFsel.L50..values.1994.	33.18	34.77	37.3	3
time_varying.potFsel.L50..values.2018.	28.28	33.77	36.67	7
time_varying.potFsel.Lto95..values.1900.	0.5	0.5	0.5	0
time_varying.potFsel.Lto95..values.1994.	0.76	2.86	5.99	46
time_varying.potFsel.Lto95..values.2018.	0.84	5.24	30.98	93
selectivity.recFSel..L50	21.19	33.68	47.63	19
selectivity.recFSel..Lto95	7.34	15.05	19.55	23

Table A4.3: Rhat for parameters estimated for Statistical Area 025 MCMC, sorted by Rhat, and restricted to the top 8 values. Values under 1.05 are considered converged. The parameter names have the original "[]{}" included; these are converted into "." by R in some instances.

Parameter, sorted by Rhat	Rhat
process[Recruitment].recruitment_multipliers{2016}	1.003
process[Recruitment].recruitment_multipliers{2012}	1.002
time_varying[potFsel.a50].values{1994}	1.002
time_varying[potFsel.ato95].values{1994}	1.002
selectivity[recFSel].a50	1.002
process[Recruitment].b0	1.001
process[Recruitment].recruitment_multipliers{1981}	1.001
process[Recruitment].recruitment_multipliers{1986}	1.001

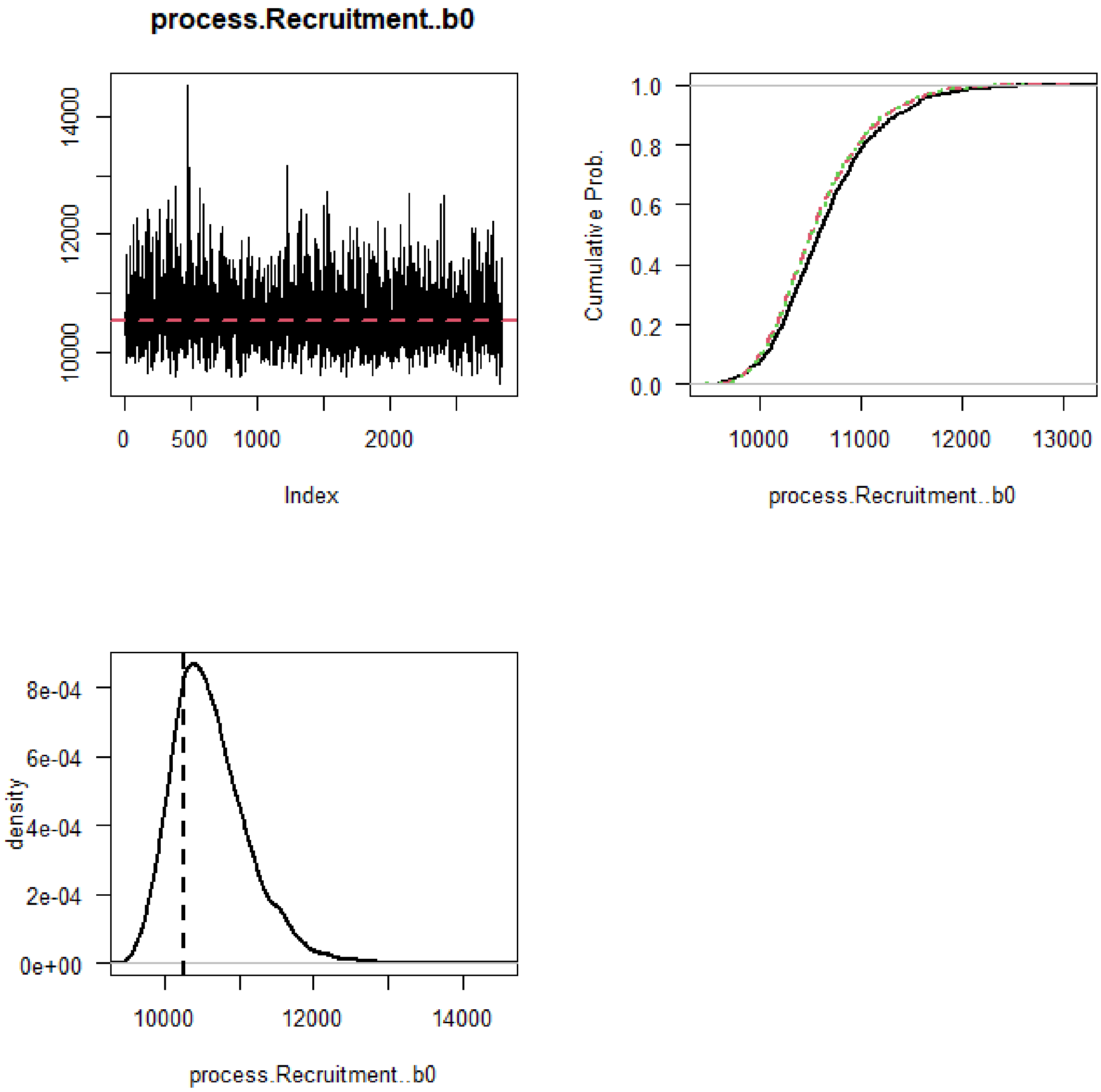

Figure A4.1: Statistical Area 025 virgin biomass, B_0, from top clockwise: MCMC trace, cumulative distribution from each chain (3), posterior distribution (dotted vertical line, MPD estimate).

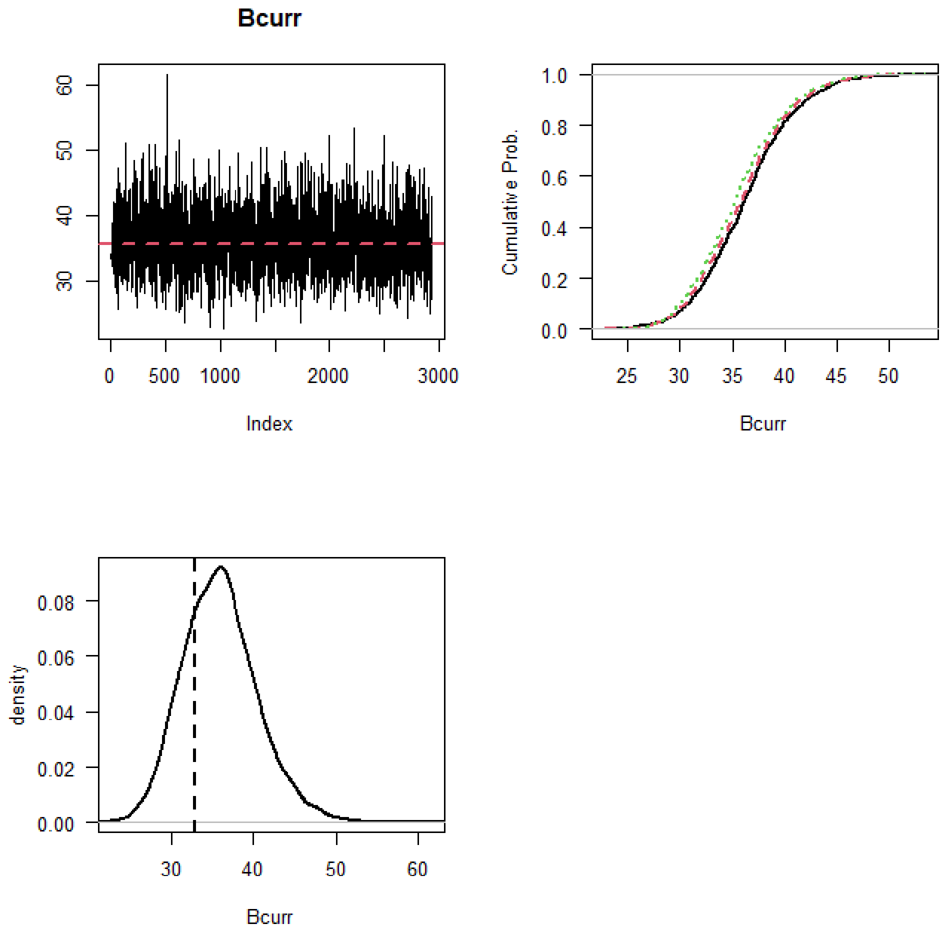

Figure A4.2: Statistical Area 025 $Bcurr = B_{2024}$ (%B_0) from top clockwise: MCMC trace, cumulative distribution from each chain (3), posterior distribution (dotted vertical line, MPD estimate).

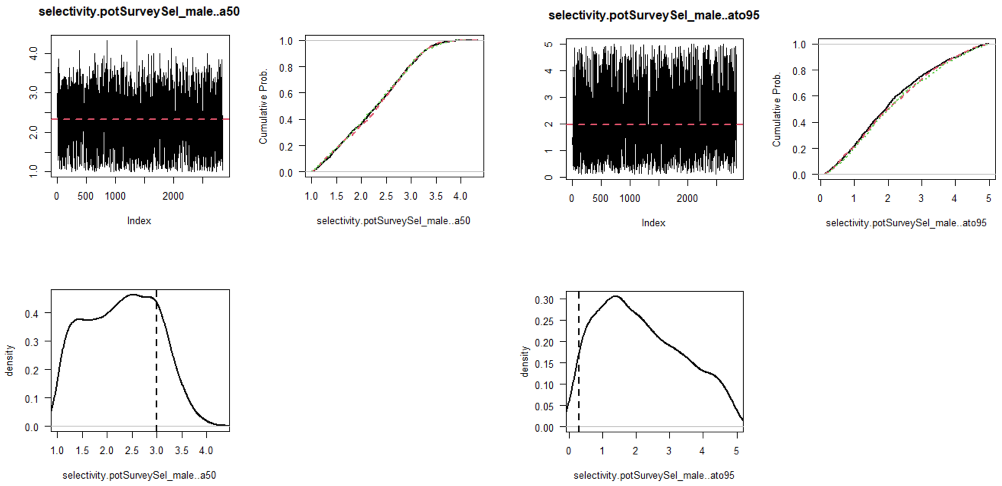

Figure A4.3: Statistical Area 025 pot survey male selectivity; left panel A_{50}, right panel A_{to95}. In each panel, from top clockwise: MCMC trace, cumulative distribution from each chain (3), posterior distribution (dotted vertical line, MPD estimate).

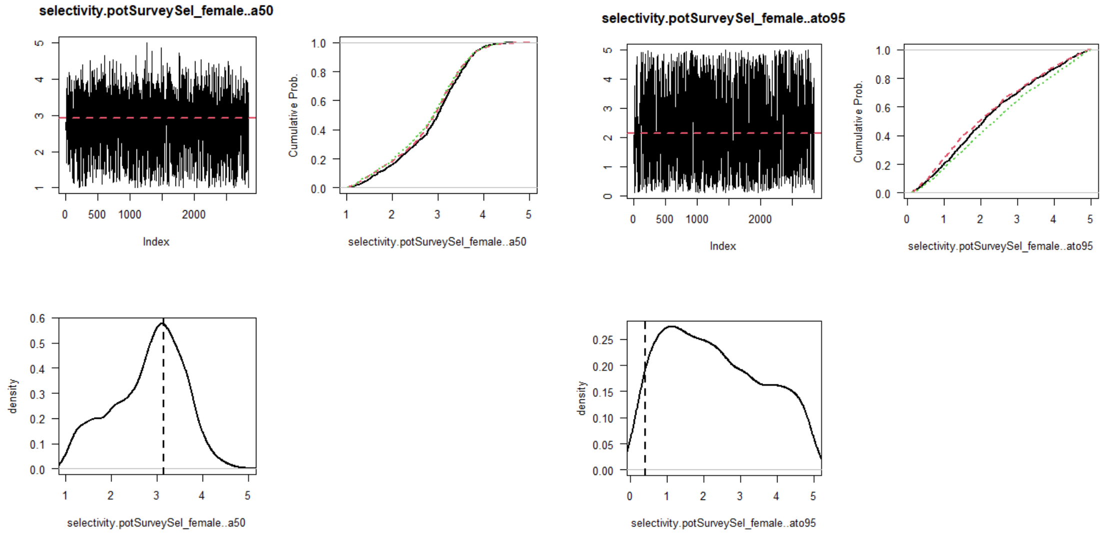

Figure A4.4: Statistical Area 025 pot survey female selectivity; left panel A_{50}, right panel A_{to95}. In each panel, from top clockwise: MCMC trace, cumulative distribution from each chain (3), posterior distribution (dotted vertical line, MPD estimate).

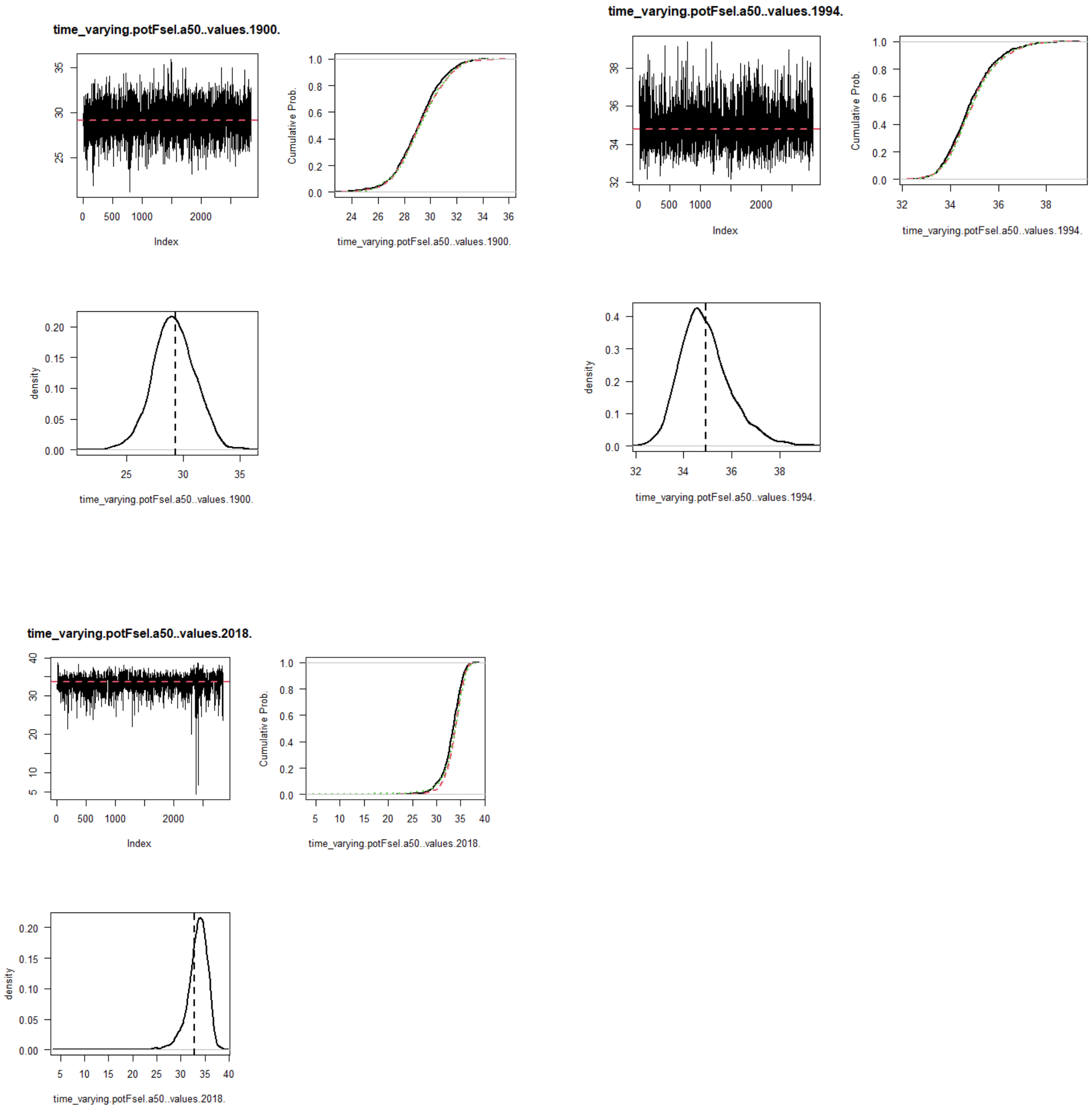

Figure A4.5: Statistical Area 025 pot fishery A_{50} for selectivity by time blocks; start years for time blocks are: 1900, 1994, 2018. Top left panel, 1900–1983; top right panel, 1983–2017; lower left panel, 2018–2024. In each panel, from top clockwise: MCMC trace, cumulative distribution from each chain (3), posterior distribution (dotted vertical line, MPD estimate).

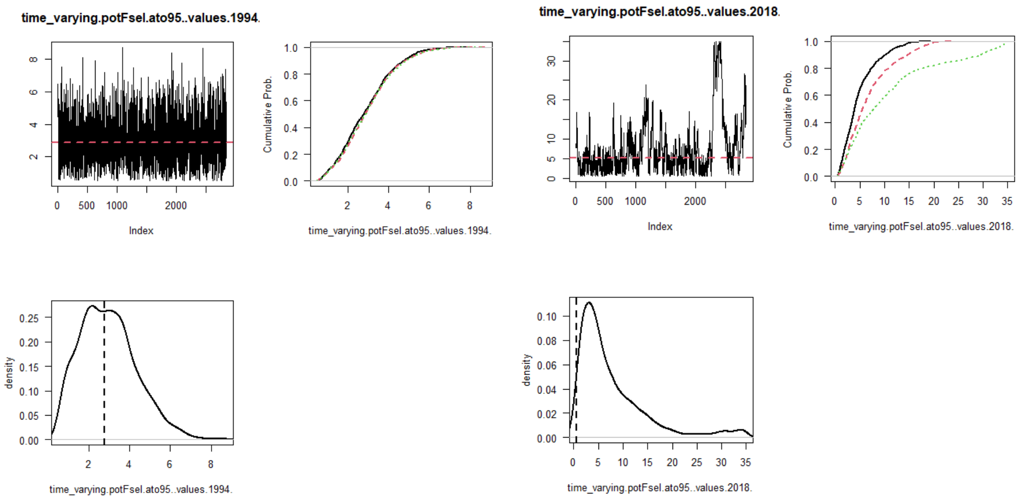

Figure A4.6: Statistical Area 025 pot fishery A_{to95} for selectivity by time blocks; start years for time blocks are: 1900, 1994, 2018. Parameter for time block for 1900–1983 kept at MPD value. Top left panel, 1983–2017; top left panel, 2018–2024. In each panel, from top clockwise: MCMC trace, cumulative distribution from each chain (3), posterior distribution (dotted vertical line, MPD estimate).

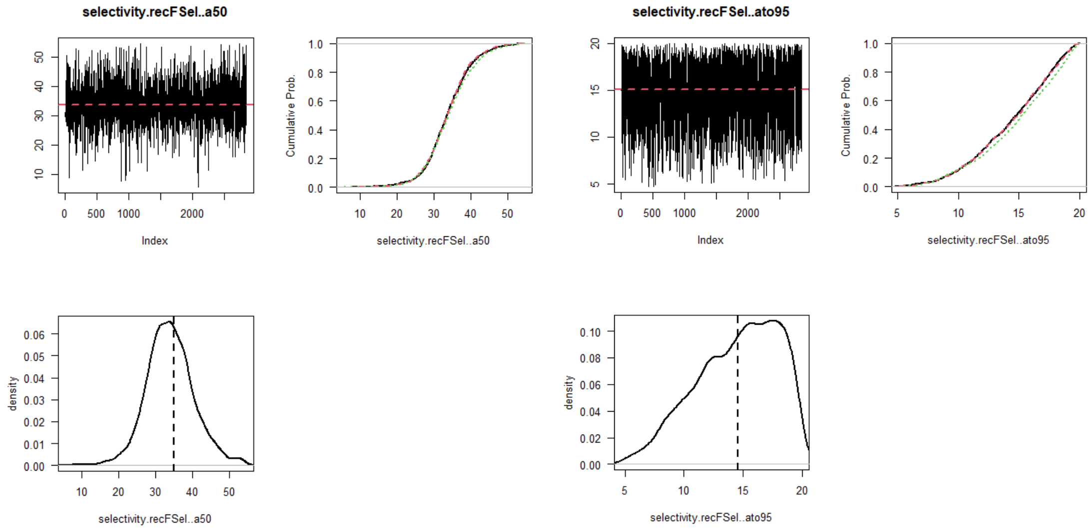

Figure A4.7: Statistical Area 025 recreational selectivity: left panel L_{50} parameter, right panel, L_{to95}. In each panel, from top clockwise: MCMC trace, cumulative distribution from each chain (3), posterior distribution (dotted vertical line, MPD estimate). [Note: the script that generated the plots used the L_{50} and L_{to95} parameters, not the age parameters given on the x-axis labels.]