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Length-based spawning potential ratio (LB-SPR) assessment of silver warehou (*Seriolella punctata*)

New Zealand Fisheries Assessment Report 2026/36

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PLAIN LANGUAGE SUMMARY

Silver warehou are found all around New Zealand and are relatively common around the South Island and on Chatham Rise at depths of 200–800 m. There has never been an accepted stock assessment for New Zealand silver warehou. We applied length-based spawning potential ratio (LB-SPR) analysis to the SWA 3 and 4 stock. LB-SPR uses length frequency data and biological parameters to estimate spawning potential ratio, a measure of the impact of fishing on the potential productivity of the stock. Length frequency data were collated from observer samples and resource surveys, but length frequencies from the resource surveys were too sparse and variable to be used. Observer length frequencies were acceptable, but SPR estimates were not considered plausible, primarily because the assumption of constant recruitment was likely to be violated. The method assumes that a relative reduction in large fish within the proportions at length is caused by mortality, but this could also occur if there had been recent strong recruitment, which was suspected for silver warehou. The hypothesis of recent strong recruitment should be tested through further fish ageing and age frequency analysis.

EXECUTIVE SUMMARY

Holmes, S.J.[1]; Dunn, M.R. (2026). Length-based spawning potential ratio (LB-SPR) assessment of silver warehou (*Seriolella punctata*).

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Silver warehou (*Seriolella punctata,* SWA) are a type of medusafish that in New Zealand waters are relatively common around the South Island and on Chatham Rise at depths of 200–800 m. Silver warehou in management areas SWA 3 and SWA 4 have been studied in several research projects since 2015, but these did not lead to an accepted quantitative stock assessment. Problems were encountered with options for monitoring relative abundance, composition of the stock, and highly uncertain parameter estimates generated by an integrated stock assessment model.

This report describes the application of another approach to obtain a stock assessment for SWA 3 and SWA 4, length-based spawning potential ratio (LB-SPR) analysis. LB-SPR uses length frequency data to estimate spawning potential ratio, a measure of the impact of fishing on the potential productivity of a stock. Biological input parameters from the most recent attempted assessments were adopted as best estimates, with estimates from other studies used to provide ranges of plausible values for sensitivity analyses and to establish input parameter distributions for use in a stochastic version of LB-SPR.

Length frequency data were available from observer data and resource surveys. Length frequency data from the resource surveys were too sparse and variable to be useable, with only intermittent representation of adult lengths. Observer coverage was good, especially after the year 2000, with numbers of tows sampled and fish measured that, in principle, should result in a good representation of the true length distribution of the stock. Observer length frequency data were restricted to those from fisheries targeting hoki and silver warehou, as these caught predominantly adult silver warehou. This mitigated a problem of intermittent modes at lower lengths associated with juvenile fish, which was found to bias LB-SPR results. Numbers of fish at lengths below 35 cm (approximating the minimum length expected for adult fish) were also set to zero to encourage the model to estimate a more appropriate selectivity ogive.

Although LB-SPR can be applied to a single year of data, for SWA it was applied to a time series of scaled length frequencies from 1990 to 2025. Problems with shallow selectivity gradients persisted, such that the length at 95% selection was often estimated to be greater than the asymptotic von Bertalanffy maximum fish length (i.e., an implausible result where even the biggest fish were not fully selected). This resulted in fishing mortality rates being estimated higher than was considered plausible. SPR results were more plausible than fishing mortality rates, but the SPR for the years when high recruitment was believed to have occurred, and also the final two years of data, were low. This described a shift in proportions at length to lower (adult) lengths, but that shift was likely to be not because of a reduction in fish at the largest lengths (i.e., mortality, consistent with declining stock health), but because of an increase in fish measured at the lower (adult) lengths (i.e., recruitment). The key methodological assumption of constant recruitment was therefore likely to have been violated. The SPR results were therefore rejected for defining stock status. Otoliths have been consistently collected for this stock, and the hypothesis of recent strong recruitment should be evaluated through fish ageing and age frequency analysis.

[1] Earth Sciences New Zealand.

1. INTRODUCTION

Silver warehou (*Seriolella punctata,* SWA) are a type of medusafish, a family that includes several other fishes that similarly feed on gelatinous zooplankton and small crustaceans (Horn et al. 2011). In New Zealand, silver warehou are relatively common around the South Island and on Chatham Rise at depths of 200–800 m, and they can be one of the most abundant species by weight caught by Chatham Rise trawl surveys (e.g., Stevens et al. 2024). Most of the commercial catch has been taken from the Chatham Rise, Canterbury Bight, southeast of Stewart Island, and off the west coast of the South Island (Fisheries New Zealand 2026). The management areas for SWA are shown in Figure 1.

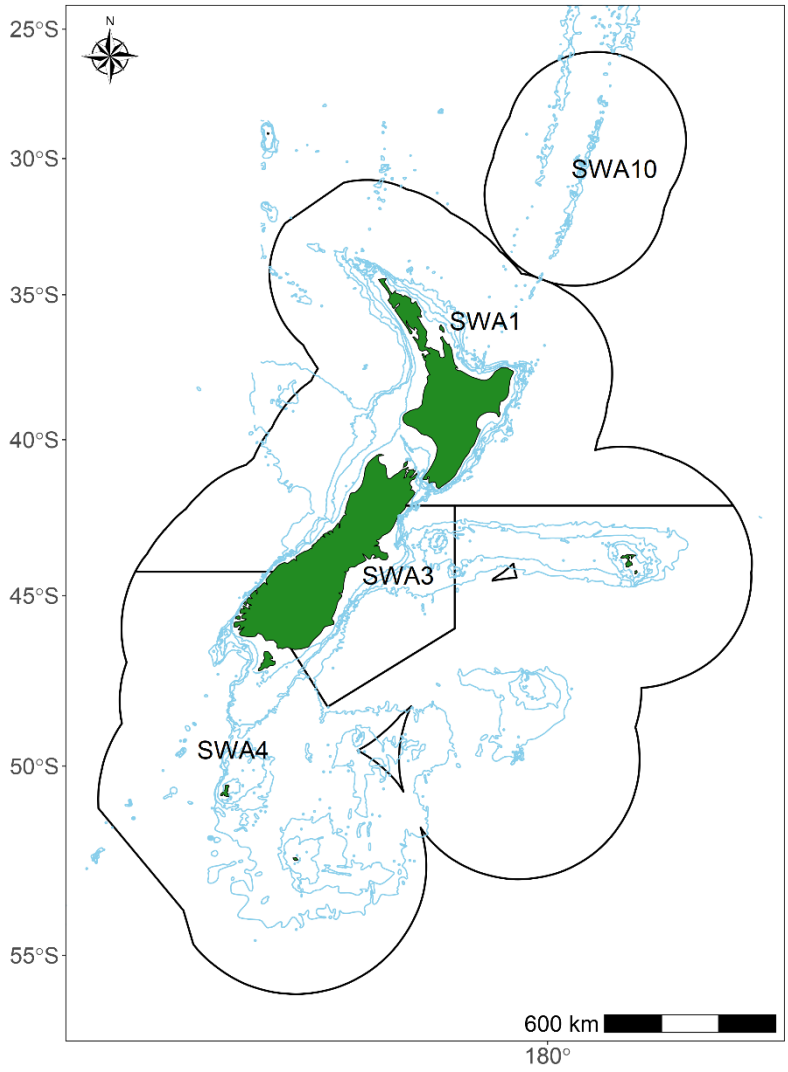


Figure 1: Management areas for silver warehou.

Silver warehou in management areas SWA 3 and SWA 4 have been studied in several research projects since 2015, but these did not lead to an accepted quantitative stock assessment (McGregor 2016; McGregor 2019a,b; Dutilloy & Dunn 2020; Dunn et al. 2020; Dunn & McGregor 2023). Problems were encountered with options for monitoring relative abundance, composition of the stock, and highly uncertain estimation of key parameters by the integrated stock assessment model.

1.1 Using CPUE to track biomass trends

Previous assessments have relied upon catch per unit effort (CPUE) as a relative biomass index. Dunn et al. (2020) reviewed silver warehou CPUE analyses, which was followed by further analyses (Dunn & McGregor, 2023). The schooling behavior and occurrence in midwater of silver warehou makes catches in bottom trawls inherently variable. CPUE trends were also often different for different fisheries and analyses. For some fisheries, it was suspected that a step to lower CPUE seen in 2007–08 was caused by a change in fisher behavior, with fishers deliberately avoiding silver warehou because of insufficient Annual Catch Entitlement (ACE) due to a low Total Allowable Commercial Catch (TACC), and an increase in deemed values (fines for exceeding the TAC) in 2007–08. The most credible CPUE series was agreed by the Fisheries New Zealand Deepwater Working Group (DWWG) to be that derived exclusively from MPI-observed events (following Dunn & McGregor 2023), and this CPUE was updated to the 2024–25 fishing year (Holmes et al. 2026). However, it is considered that any assessment that relies heavily upon CPUE could be misleading because the CPUE cannot be corrected for poorly known or unquantifiable changes in fisher behavior.

1.2 Integrated stock assessment models

An integrated assessment of a stock including all of Chatham Rise and Southland (SWA 3 and SWA 4) was attempted in 2023 (Dunn & McGregor 2023). The combined SWA 3 and SWA 4 stock hypothesis was an alternative to a previous assessment, which assumed a western Chatham Rise and east coast South Island stock (McGregor 2019a,b). Both assessments were rejected, primarily because of concerns about the veracity of the CPUE series, and the CPUE series had little contrast over time relative to the catch history, leading to a poorly defined stock biomass. The assessments used the available age frequency data. Age data were available for thirteen years between 1993 and 2016, but modes suggestive of relatively large year classes often did not track correctly across years, indicating that the age frequency data had substantial observation error. Ultimately, the age frequency data were found to add little information to the assessment; this was unsurprising given the inconsistencies and variability in these data.

Resource surveys were not included in the integrated assessments because the occasional large catch produced some years with very high CVs, making the biomass trend uninformative. Analyses by Dunn et al. (2020) could not find a pattern in these large catches that allowed their influence to be reduced.

An integrated stock assessment of silver warehou in Australian waters was also rejected because of poor fits to inconsistent length compositions, retrospective patterns in recruitment (suggesting a biased model), poor model fits to CPUE, and estimated recruitments patterns that appear driven by changes in fishery discard rates (Tuck et al. 2024).

1.3 Other options for stock assessment of silver warehou

Dunn & McGregor (2023) considered but rejected the following alternatives to the attempted integrated assessment models:

- Using only fishery-independent data, i.e., research trawl surveys: These series have not been accepted for silver warehou because of the intermittent large catches and high CVs, such that any trends are obscured by ‘noise’.
- Using only age data, e.g., estimating total mortality rate from catch curve analyses, with fishing mortality estimated given an assumed natural mortality M. The main problem is that no age data more recent than 2016 are available.
- Methods using catch data only may not be reliable given market and management pressures and are not considered credible in New Zealand (Holmes et al. 2020).
- Biomass dynamic (surplus production) models. These models use CPUE and catch. The problems in producing a standardised CPUE series described above would therefore be encountered if

attempting to apply biomass dynamic models, and exacerbated compared to integrated models where multiple data sources can be used.
- Delay-difference models. These models again need to make use of CPUE indices and seem to offer little benefit over integrated assessment models.
- Swept-area methods. This includes methods that estimate fishing mortality based on the area of overlap between species distribution and fishing effort. This approach was applied during the Low Information Stock Status Assessment projects, but the method was not adopted further (Holmes et al. 2022) because the Deepwater Working Group was not yet confident enough in the methodology.

In addition, silver warehou lack an air-filled swim bladder making the species a poor candidate for estimation of absolute biomass from acoustic surveys.

An approach not previously considered for this stock is the use of length frequency data and known biological parameters for growth and maturity to perform a length-based spawning potential ratio (LB-SPR) analysis, which provides a measure of the impact of fishing on the potential productivity of a stock. This approach has an established theoretical basis (Hordyk et al. 2015a, 2015b, 2016), has been used in U.S. fisheries (Froese et al. 2018), to assess crustaceans (Chakraborty et al. 2024), and recently in New Zealand for pāua (Neubauer et al. 2025). Length data from MPI-observed events are plentiful for silver warehou and length data are also available from resource surveys.

This report describes the application of LB-SPR to silver warehou in SWA 3 and SWA 4. The work was funded by Fisheries New Zealand project SWA2025–01 with the overall objective: "To develop an assessment of biomass in relation to management targets for silver warehou (*Seriolella punctata*) in SWA 3 and 4". This report describes the work completed towards specific objective 2: "To review all options and approaches to providing stock status advice and attempt a Level 1 fully quantitative stock assessment for the stock". Work against objective 1 "To update the descriptive analysis of the commercial catch and effort data for silver warehou on the Chatham Rise and Southland and update standardised catch and effort analyses" is reported in Holmes et al. (2026) and this report should be read in conjunction with that report.

2. METHODS

SWA 3 and 4 are managed as separate quota management areas but there is a lack of evidence that the two areas contain independent stocks. McGregor (2016) concluded "The current consensus is that despite the knowledge of several spawning areas (some with different timing than others), and that largely distinct adult distributions exist, the overall distribution of silver warehou is continuous within their preferred depth range." This study therefore followed Dunn & McGregor (2023) in treating all SWA 3 and SWA 4 as containing a single stock. The New Zealand fishing year for silver warehou is 1 October to 30 September. In this report a single year refers to the year ending, i.e., "2025" refers to 1 October 2024 – 30 September 2025.

2.1 LB-SPR model

The LB-SPR model was first developed using an adapted age-based model assuming a distribution for lengths at age (Hordyk et al. 2015a) and then as a fully length-based model where a cohort is divided into 'growth type groups' (GTG), with a common von Bertalanffy growth parameter k but different asymptotic lengths (L_∞) (Hordyk et al. 2016). The latter allows the model to better reflect faster growing individuals being selected at younger age by fishing gear, and was the version of LB-SPR used in this study. Alongside length frequencies the LB-SPR method requires as input:
- The M/k ratio where M is natural mortality and k the von Bertalanffy growth parameter.
- Asymptotic length L_∞.
- The coefficient of variation in asymptotic length L_∞, CV(L_∞).
- Size-at-maturity L_{50} and L_{95}.

The method produces as output:

- Estimated selectivity parameters S_{L50} and S_{L95}.
- The *F/M* ratio where *F* is fishing mortality.
- SPR as a proportion.

To estimate the SPR and *F*/*M* outputs, the method is essentially comparing a fit of the supplied length frequency data, to an expected unfished length frequency. Key assumptions underlying the methodology are that:

- The stock is in a steady state;
- Growth patterns are static, adequately described by the von Bertalanffy equation, and a single growth curve can be used to describe both sexes which have equal catchability;
- *M* is constant across size classes;
- Fishing selectivity is asymptotic. Therefore, if adult lengths are missing or underrepresented these lengths are assumed to be fished down (or out), and the SPR estimate will be biased low (*F* biased high).

All data analyses were completed using R 4.3.3 (R Core Team 2024) and specifically the LBSPR R library (https://adrianhordyk.github.io/LBSPR/articles/LBSPR.html).

The default number of growth type groups (GTG) used in the LBSPR function is 13. From Hordyk et al. (2016), the quality (smoothness) of the unfished length distribution (against which the fitted length distribution is compared) is expected to degrade as the number of GTG is reduced. Sensitivity analyses were conducted using 5, 13, 26, 52 and 104 GTG to test the difference in *F/M* and SPR results. As the number of GTG increased both *F/M* and SPR results converged to a given answer but the difference in result between the highest number of GTG tested and the default was small. During sensitivity analyses 100 GTG were used for maximum precision of results, but for computational time considerations, when performing a stochastic run (see Section 2.2) the default number of GTG was considered adequate.

2.2 Biological parameters

Biological parameters of growth and mortality are considered known with some confidence for SWA. They were most recently examined by Dunn & McGregor (2023), and no changes were considered necessary to previous estimates. Dunn & McGregor (2023) estimated small differences in residuals between males and females, but used von Bertalanffy growth parameters estimated for combined sexes. The 'best estimate' biological parameters used in exploratory LB-SPR runs are given in Table 1. The reasoning underpinning the best estimate values, and the ranges of plausible values, are given in Appendix 1.

Sensitivity analyses were conducted varying each of L_∞, CV(L_∞), *M/k*, *M*, *k* and L_{50} over the range of their plausible values. The value of L_{95} was fixed to L_{50} + 4 cm. To take account of uncertainty in biological parameters, previous assessments have run a stochastic version of LB-SPR with values of the input parameters drawn from distributions (Coscino et al. 2024, Priatna et al. 2021, Konoyima et al. 2024). For this study, a stochastic run based on the final scaled observer length frequency data was performed following Cope (2020). L_∞ and *k* values were drawn from a multivariate-normal distribution, *M* values from a separate normal distribution. L_{50} and L_{95} values were input as fixed values, the ratios of L_{50}:L_∞ and L_{95}:L_∞ recorded and then for each sampled L_∞, the L_{50} and L_{95} values were adjusted to maintain the same ratios. LB-SPR was calculated over 1000 resamples. Scatter plots of the L_∞ and *k* value pairs and L_∞ and *M/k* value pairs are given in Appendix 1.

The range of values used in sensitivity analyses and distributions used for the stochastic run are given in Table 1.

Table 1: Parameter inputs to the LB-SPR model. Length parameters (L_∞, L_{50} and L_{95}) are for fork length in cm. k: von Bertalanffy growth coefficient; M: natural mortality.

Parameter	Best estimate	Range (sensitivity analyses)	Distribution (stochastic run)
L_∞ (cm)	50	49–59	N(μ=53.2, σ =2.88)
CV(L_∞)	0.1	0.05–0.3	Kept at 0.1
M/k	0.65	0.524–0.785	na
M (yr^{-1})	0.25	0.2–0.3	N(μ= 0.25, σ = 0.025)
k (yr^{-1})	0.382	0.32–0.42	N(μ= 0.35, σ = 0.056)
L_{50} (cm)	44	35–45	Same ratio to L_∞ as best estimate
L_{95} (cm)	48	39–49 (L_{95} fixed to L_{50} + 4)	Same ratio to L_∞ as best estimate

2.3 Length frequencies

For simulated data using a similar M value to that of SWA, Miranda (2007) estimated that 425 to 1200 fish measurements (depending on L_∞ and k values) were required for 1-cm length frequency distributions to differ by 10% (or less) from the true distribution 80% of the time (from 1000 bootstraps). Hordyk et al. (2015b) simulated sampling from a 'true' length distribution using sample sizes of 100, 500, 1000, 5000, and 10 000 individuals, and found that variation in the estimated SPR reduced with sample size, but was "reduced greatly when [once] 1000 measurements were taken".

Hordyk et al. (2015b) also emphasised that the length samples need to be an unbiased sample of the length structure of the stock. Data lacking representation of larger (older) fish through domed selectivity cannot be distinguished from larger fish being fished out. The method assumes logistic selectivity, therefore domed selectivity will result in a downward bias of SPR (see Derhy et al. 2024 for a suspected real-world case). Data lacking representation of smaller (younger) fish can lead to F being estimated too low, and/or length at selectivity (S_{L50}) estimated too high, and SPR results biased high. These outcomes were demonstrated through simulation-estimation by Dai et al. (2021).

Another known pitfall for the LB-SPR method is multimodal length compositions. The assumptions of a stock at equilibrium and an M value constant over ages results in the model expecting a unimodal length composition curve. Multimodal length compositions can cause a poor fit to the right-hand side of the length frequencies (Hordyk et al. 2015b), from which the method estimates the fishing mortality F. Hordyk et al. (2015b) recommended that if there are multiple fleets targeting a stock, then the LB-SPR method should be applied to data from the fleet or fleets targeting the adult portion of the stock. If the multimodal data are within the range of adult fish lengths and result from limited sampling coverage then, because of the stock at equilibrium assumption, it is possible to aggregate (sum) length frequencies over multiple years to "smooth" the length distributions (Prince 2021). Prince (2021) also recommended truncating the length frequency data to start just before the mature fish lengths if data contained one or more additional modes of smaller and juvenile fish.

To obtain an indication for whether distinct length modes might be expected at juvenile ages for silver warehou the von Bertalannfy growth parameters used in the assessments of McGregor (2019b) and Dunn & McGregor (2023) were used to calculate expected length distributions at age. Assuming normally distributed lengths at age with CV = 0.1, distinct modes of fish aged one to three could be distinguished if the fishing gear was selecting those lengths (Figure 2). The maturity at age ogive used by McGregor (2019b) and Dunn & McGregor (2023) gave proportions mature of 0.3 at age 3, 0.7 at age 4, 0.95 at age 5, and 1 from age 6. By age 6, the theoretical length distributions overlap and cannot be distinguished. Figure 2 also indicates that removing lengths below 35 cm would still sample the overall length distribution of fish from about age 5 (i.e., mature fish).

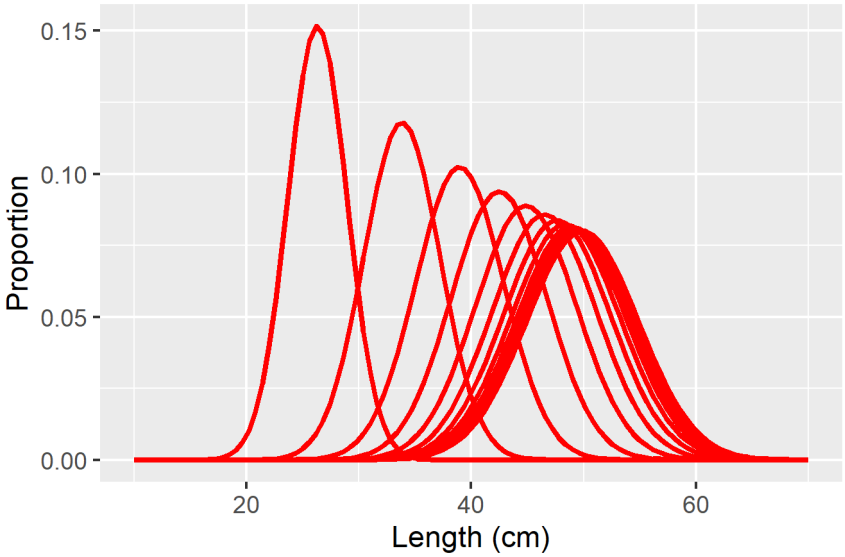


Figure 2: Theoretical distributions of length at age (ages 1 to 15) for SWA based on mean lengths from the von Bertalanffy growth equation with parameters L_∞ = 49.8 cm k = 0.382 and t_0 = -0.954, and lengths normally distributed around the mean length with CV = 1.

Resource surveys

Length frequencies were available from the Chatham Rise (CHAT), East Coast South Island (ECSI) and sub-Antarctic (SUBA) resource surveys. The length frequencies of the resource surveys were downloaded from the Earth Sciences New Zealand Trawl Survey Information Portal (Trawl Survey Information Portal). Resource survey length frequencies were already scaled according to the stratification of each survey, so no further scaling was conducted.

The number of length measurements from the surveys were considered in comparison to the results from Miranda (2007) and Hordyk et al. (2015b). The length frequencies were plotted to consider whether the adult portion of the population was being adequately represented.

Observer sampling

Length data from observer sampling was downloaded from the Fisheries New Zealand 'COD' database. Data was available for the years 1987–2025. Representativeness of the sampling was evaluated following Middleton (2026).

The raw LF data were partitioned for the main fisheries for SWA by target species (Holmes et al. 2026). For each fishery, the raw length frequencies were plotted, and the number of length measurements from the selected fisheries were evaluated relative to the results from Miranda (2007) and Hordyk et al. (2015b).

Strata for scaling the length frequencies were determined from assumed stock structure from previous studies using a classification tree approach (Dutilloy & Dunn 2020). The analyses were repeated in 2026 using an updated data set with almost identical results and are therefore only briefly described here.

Scaling the length frequencies from sample weight to tow catch weight, and from tow catch weight to stratum catch weight, was performed using the R package 'catchatage' and made use of catch-effort data supplied by Fisheries New Zealand (Replog 17212). The catch-effort data were groomed as described in Holmes et al. (2026).

3. RESULTS

3.1 Resource surveys

Table 2 shows the number of length measurements available from the CHAT, ECSI and SUBA resource surveys. The number of measurements from the SUBA survey was considered insufficient and this survey was not considered further.

Table 2: Number of length measurements available from research trawl surveys conducted within the SWA 3 and SWA 4 management areas. CHAT: Chatham Rise; ECSI: east coast South Island; SUBA: Sub-Antarctic. ns: no survey. Years are calendar years.

Year	Survey			Year	Survey		
	CHAT	ECSI	SUBA		CHAT	ECSI	SUBA
1991	ns	243	260	2008	1 843	1 350	415
1992	1 065	291	57	2009	1 828	652	257
1993	1 321	535	10	2010	2 509	ns	ns
1994	2 001	502	ns	2011	2 136	ns	75
1995	909	ns	ns	2012	1 284	1 096	8
1996	488	1 348	ns	2013	1 094	ns	ns
1997	525	ns	ns	2014	320	526	10
1998	796	ns	ns	2015	ns	ns	ns
1999	1 491	ns	ns	2016	2 065	1 329	20
2000	1 559	ns	8	2017	ns	ns	ns
2001	1 317	ns	350	2018	1 555	605	204
2002	561	ns	84	2019	ns	ns	ns
2003	722	ns	20	2020	1 390	ns	131
2004	1 598	ns	23	2021	ns	644	ns
2005	1 635	ns	77	2022	2 380	1 231	7
2006	1 111	ns	12	2023	ns	ns	ns
2007	1 619	1 112	202	2024	3 252	516	205

The raised length frequencies from the ECSI survey are shown in Figure 3. Larger individuals (40+ cm) were often absent, or in much smaller numbers than smaller fish, in contrast to the CHAT survey or scaled observer LFs. Exploratory LB-SPR runs on the ECSI data gave SPR close to zero. The ECSI survey data was therefore not considered suitable for LB-SPR analyses.

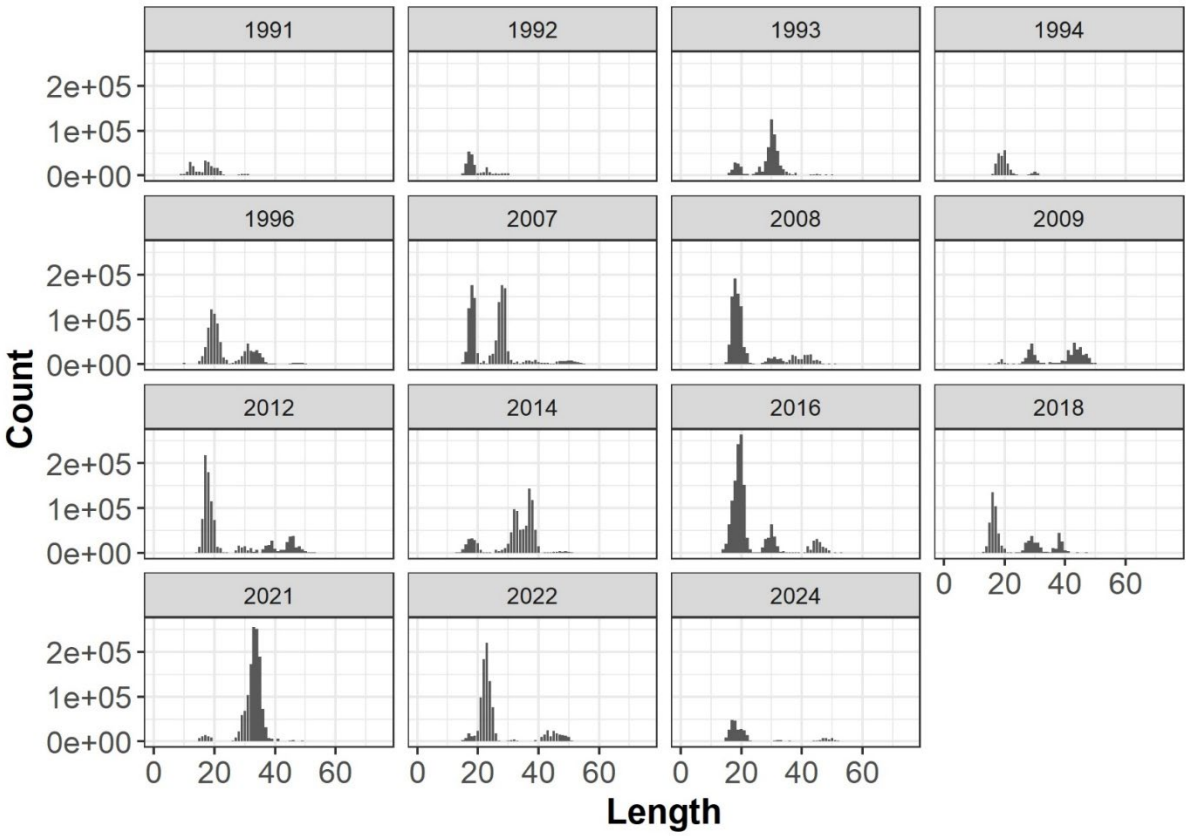


Figure 3: Scaled length frequency data for SWA from the east coast South Island (ECSI) research trawl survey. Lengths are fork lengths.

For the Chatham Rise survey, much higher numbers of fish measured in 2010 and 2011 relative to other years (and over a relatively narrow spread of lengths) meant a figure comparable to Figure 3 was uninformative because it was dominated by these two years. Figure 4 therefore shows the Chatham Rise data as proportions at length. On Chatham Rise, samples of fish at adult lengths were present in some years (e.g., 1994, 1995, 1997, 2000) but reduced or absent in others (e.g., 2002, 2008–13, 2024). The apparently sporadic sampling of adult fish meant that the Chatham Rise survey was not considered a reliable data source for the LB-SPR method. The LB-SPR method therefore focused on observer length frequency data.

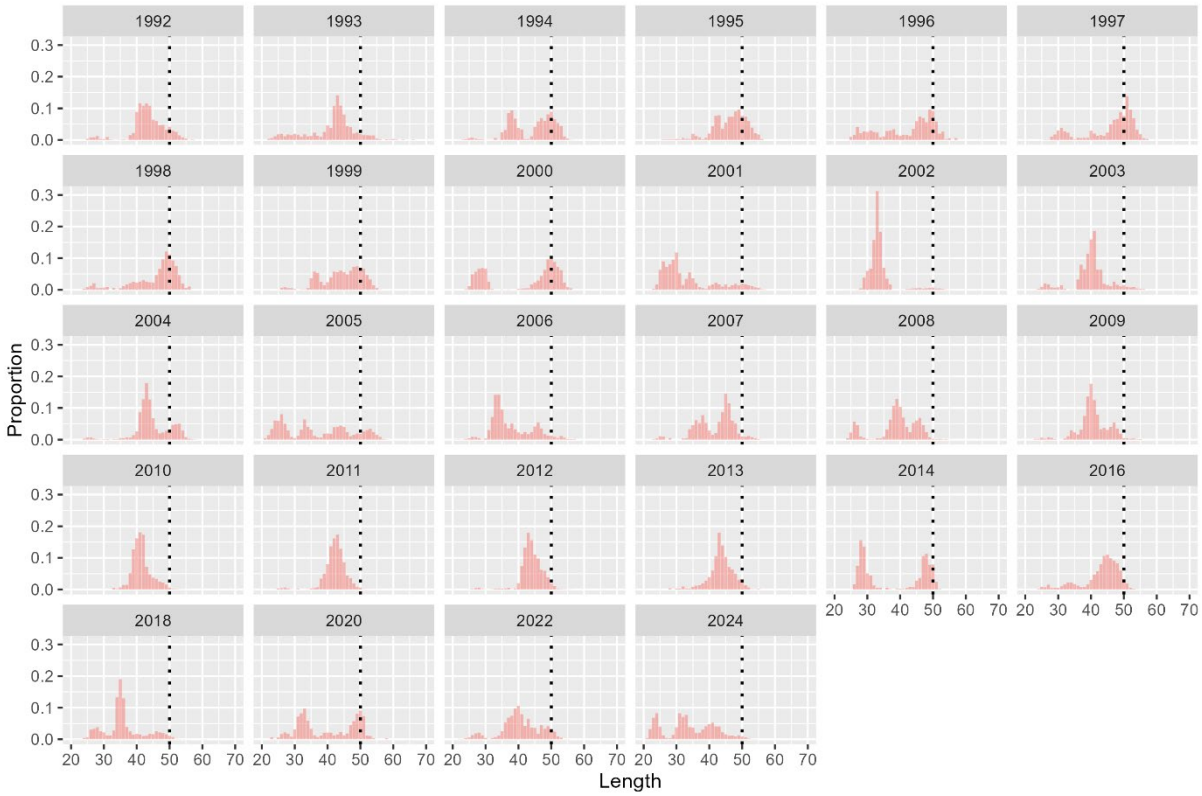


Figure 4: Scaled length frequency data for SWA from the Chatham Rise (CHAT) research trawl survey, shown as proportions at length. The vertical dashed line at 50 cm marks the 'best estimate' value for L_∞ supplied to the LB-SPR method. Lengths are fork lengths.

3.2 Selection and stratification of observer length frequency data

The unscaled length frequencies from all observer data in the SWA 3 and 4 areas are shown in Figure 5. The increase in the number of lengths measured after 1998 is clear. There were two or more length modes present in most years, with the modes of smaller fish consistent with the expected lengths for juvenile fish. A test application of LB-SPR to the unscaled length frequencies confirmed that the length modes from juvenile fish biased the approach, with the SPR estimated at one for multiple years. Figure 6 illustrates the problem, showing length distributions for four selected years and the fits to those distributions from LB-SPR. The year 2011 had a simple unimodal length distribution and there was a good fit to the length distribution. The data for the other years showed poor fits to the multimodal length distributions, and in particular, poor fits to the right-hand side of the adult fish length mode (the terminal mode), from which the LB-SPR is estimated.

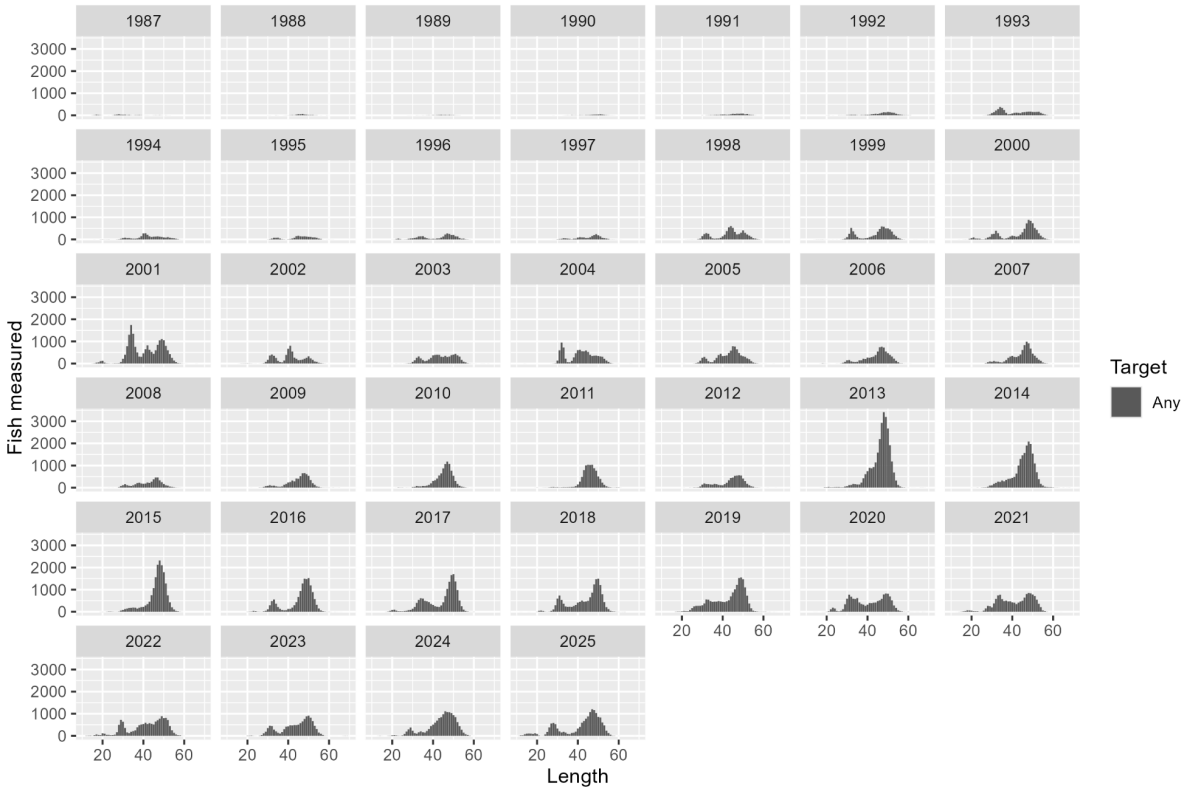


Figure 5: SWA 3 and 4, Unscaled length frequency data for SWA from all observer data in SWA 3 and 4. Lengths are fork lengths.

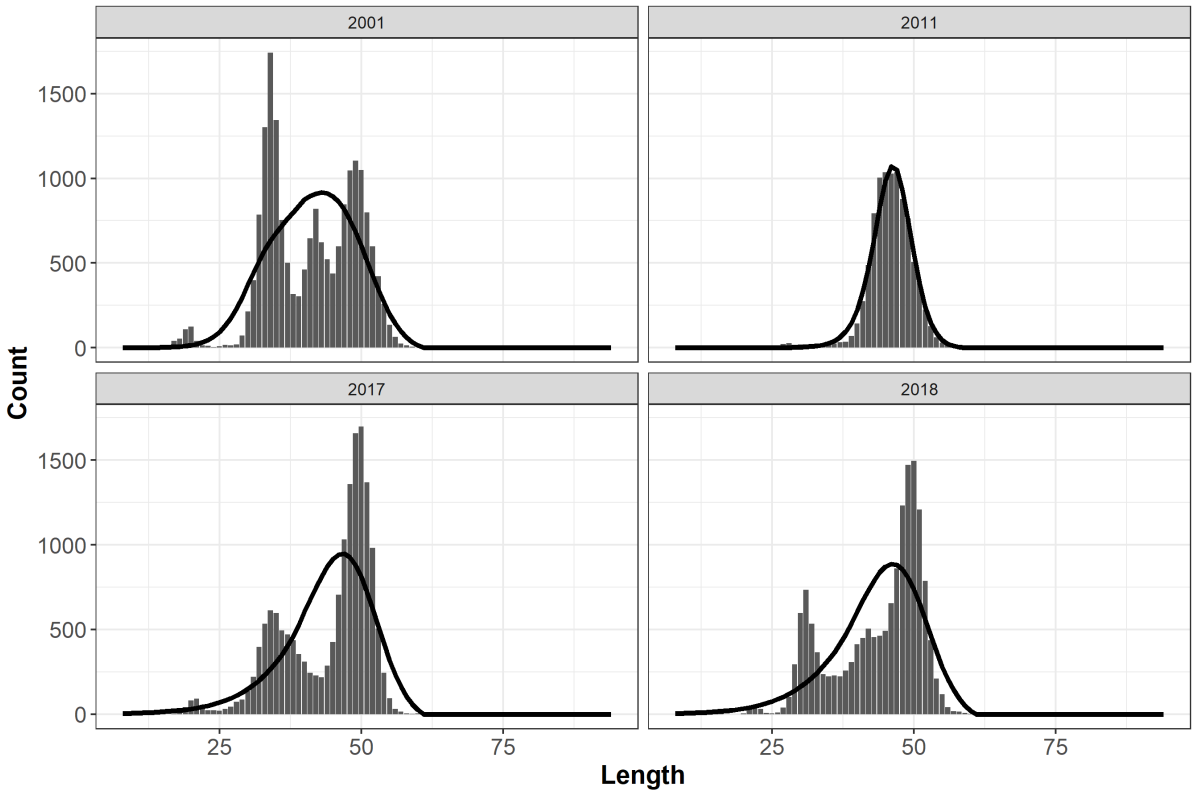


Figure 6: SWA 3 and 4, Unscaled length frequency data for SWA from all observer data for selected years. Solid line is the fit to the length frequency data by the LBSPR package. Lengths are fork lengths.

The characterisation of the silver warehou fisheries (Holmes et al. 2026) identified three primary target species fisheries catching SWA, targeting: hoki (*Macruronus novaeze*, HOK); arrow squid (*Nototodarus gouldi, N. sloanii*, SQU); and silver warehou. Filtering the length frequency data by target species showed that juvenile silver warehou were often caught by the SQU target fishery, whereas fish at juvenile lengths were absent from the HOK target fishery data, and rare in the SWA target fishery data (Figures A2.1 to A2.3 in Appendix 2). Data for LB-SPR analyses were therefore restricted to those from HOK and SWA target fisheries.

Table 3 shows the number of tows sampled and number of silver warehou measured in SWA 3 and 4 by hoki and silver warehou target fisheries individually and combined. For the combined HOK and SWA target fisheries, the number of fish measured to 1991 was less than indicated acceptable by Miranda (2007). The number of fish measured was consistently above 1000 from 1999. Scaled length frequencies were therefore expected to be less reliable before 2000, but all years from 1990 (also the first year for which landings data were available) were retained.

The result from the classification tree analyses following Dutilloy & Dunn (2020) on median length by tow from HOK and SWA target fisheries data and using 0.1° cells as a factor is shown in Figure 7. The analyses identified four clusters, with the mean of median lengths varying from 31.2 cm to 48.5 cm. Most of the smaller fish clusters occurred shallower than 250 m, either inshore or on offshore banks. The larger size clusters were predominantly offshore. Replacing the 0.1° cells with variables including latitude, longitude, and depth, identified first a split by longitude at 171.9° east. For the SWA 3 & 4 region this effectively split the grounds south of the Otago peninsula from those to the north and east. For the Chatham Rise region, the analysis separated 2024 and 2025 from earlier data (2024 and 2025 had a lower mean length), with a split in the earlier data by depth, at 299.5 m (shallower fish were smaller). In the Sub-Antarctic and west coast South Island region, the next split was by depth, at 281 m (shallower fish were smaller). Strata for scaling SWA 3 and 4 management area length frequencies were therefore set as:

- North of 46° south, and less than 300 m bottom depth;
- North of 46° south, and greater or equal to 300 m bottom depth;
- At or south of 46° south, and less than 300 m bottom depth;
- At or south of 46° south, and greater or equal to 300 m bottom depth.

The final scaled length frequencies are shown in Figure 8.

Table 3: Number of tows sampled (ntows) and length measurements (nfish) available from observer sampling conducted within the SWA 3 and SWA 4 management areas. All: all observer data; HOK: tows recorded as hoki target; SWA: tows recorded as silver warehou target; HOK+SWA: the sum of the HOK and SWA records.

Year	All		HOK		SWA		HOK+SWA	
	ntows	nfish	ntows	nfish	ntows	nfish	ntows	nfish
1987	5	368	0	0	1	31	1	31
1988	3	360	0	0	1	150	1	150
1989	22	184	12	60	6	89	18	149
1990	18	346	10	90	7	164	17	254
1991	40	889	14	353	3	76	17	429
1992	117	1 568	40	315	15	496	55	811
1993	209	4 112	37	581	10	471	47	1 052
1994	172	2 873	12	282	7	91	19	373
1995	123	1 913	11	118	3	150	14	268
1996	134	2 914	62	1 185	1	20	63	1 205
1997	68	2 024	28	1 126	0	0	28	1 126
1998	222	6 234	60	464	0	0	60	464
1999	364	6 787	106	1 423	3	40	109	1 463
2000	472	8 565	185	2 714	0	0	185	2 714
2001	809	18 671	228	3 720	10	663	238	4 383
2002	356	6 880	45	481	14	889	59	1 370
2003	387	7 267	69	795	13	1 047	82	1 842
2004	557	9 941	98	1 369	6	337	104	1 706
2005	491	8 844	112	913	4	359	116	1 272
2006	478	7 903	96	1 285	32	1 329	128	2 614
2007	503	8 614	65	1 248	28	1 285	93	2 533
2008	259	4 917	92	1 734	9	527	101	2 261
2009	237	6 659	23	405	44	2 930	67	3 335
2010	315	9 191	77	1 676	44	3 952	121	5 628
2011	240	9 174	63	1 508	79	5 377	142	6 885
2012	190	6 565	37	900	36	2 346	73	3 246
2013	734	27 293	151	3 550	181	12 990	332	16 540
2014	474	19 924	43	825	203	12 988	246	13 813
2015	440	17 557	811	1 812	151	9 598	232	11 410
2016	400	14 323	29	774	81	5 259	110	6 033
2017	468	16 248	19	590	106	6 267	125	6 857
2018	495	15 640	88	2 371	73	5 086	161	7 457
2019	705	18 656	148	3 322	61	4 204	209	7 526
2020	471	13 936	97	2 326	37	2 172	134	4 498
2021	478	14 540	75	1 631	61	4 235	136	5 866
2022	423	14 804	51	1 378	64	4 101	115	5 479
2023	362	12 535	121	2 567	46	3 451	167	6 018
2024	436	15 297	118	2 671	82	5 614	200	8 285
2025	356	16 028	57	1 475	60	4 409	117	5 884

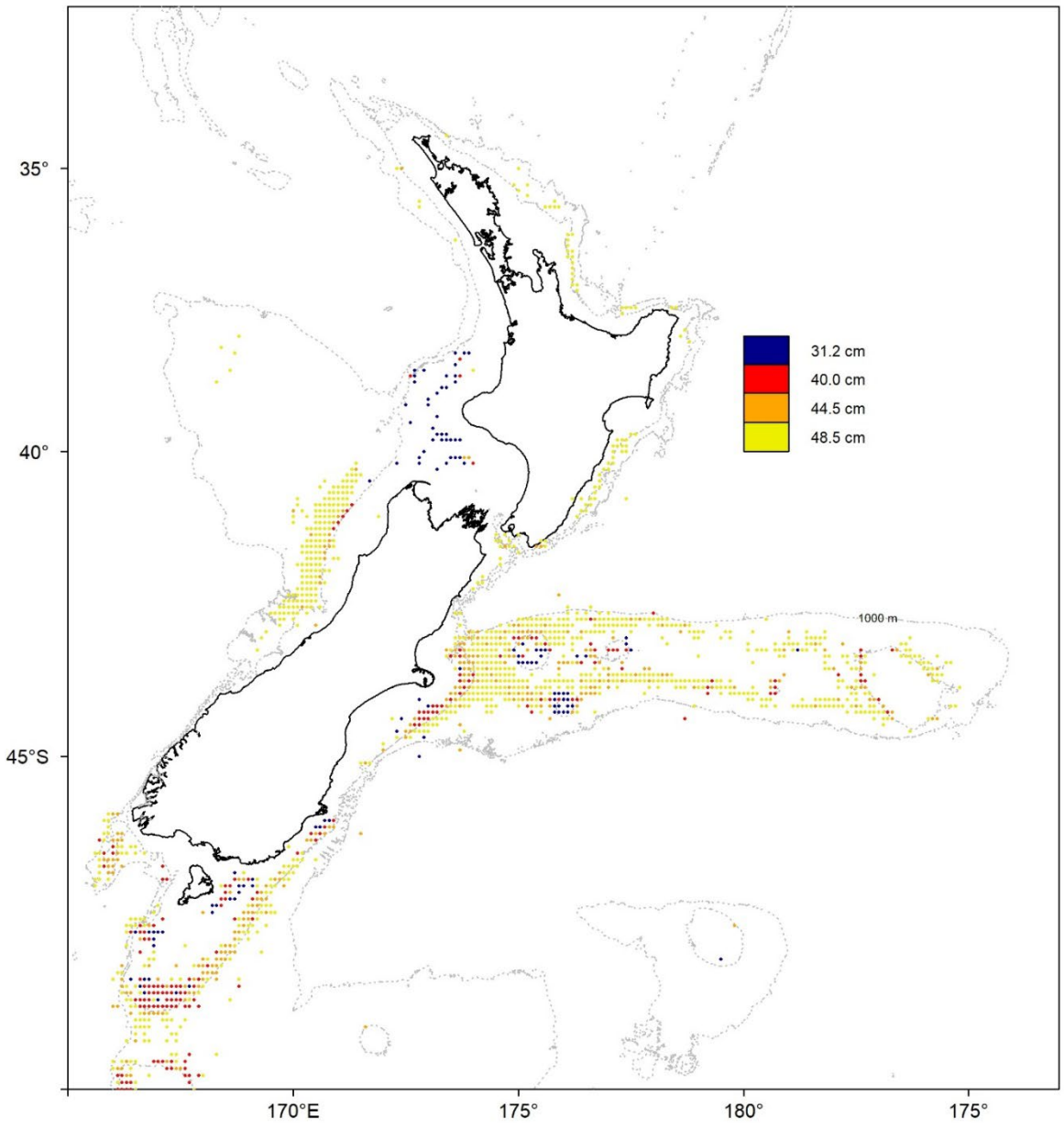


Figure 7: Location of terminal clusters from classification tree analysis using observer length frequency data for silver warehou from the hoki and silver warehou target fisheries, with tow median lengths as the response variable, and using 0.1° cells as a factor. Colour legend shows the mean of the tow median length for each cluster. Grey dashed lines are the 250 and 1000 m isobaths.

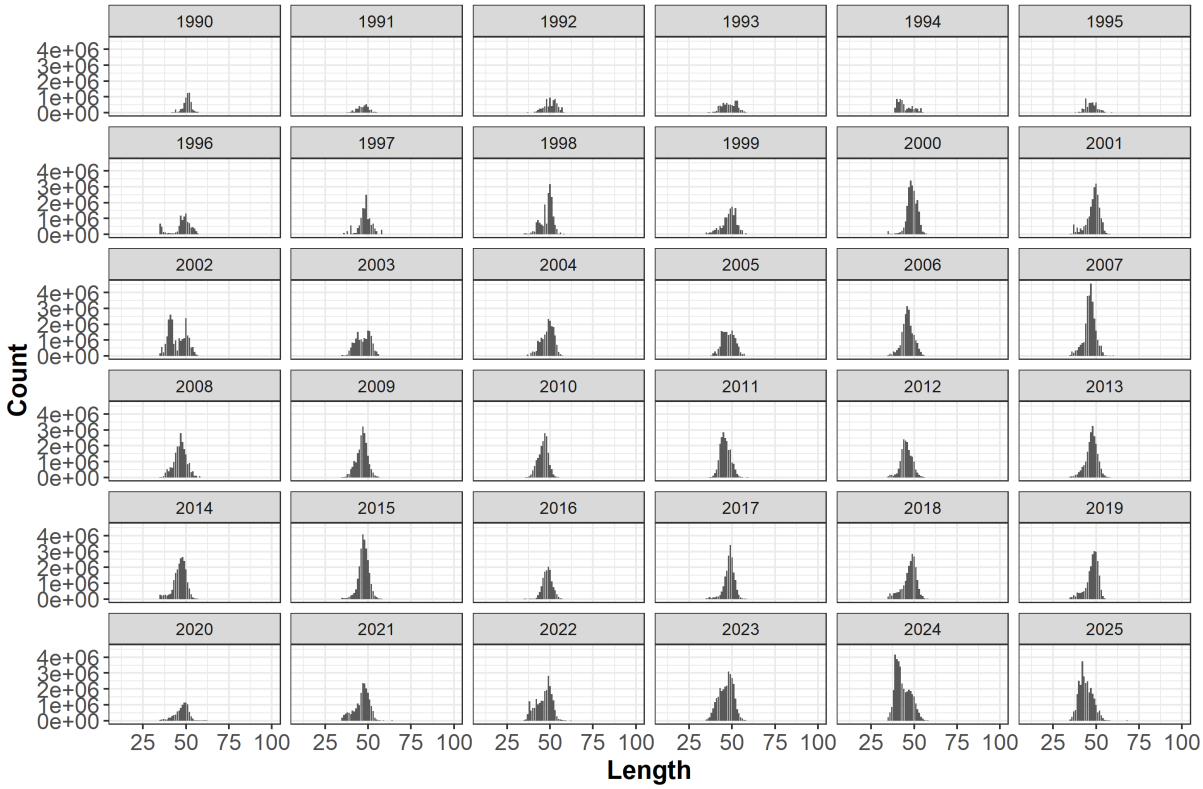


Figure 8: SWA 3 and 4, scaled length frequencies from observer data filtered to management areas SWA 3 and 4 and to include only data from hoki and silver warehou target fisheries. Lengths are fork lengths.

3.3 LB-SPR applied to scaled observer length frequencies

Initial applications of LB-SPR to both unscaled and scaled observer length frequencies resulted in shallow estimated selectivity slopes, such that the S_{L95} value could be greater than the supplied L_∞ value, and this was considered implausible. To achieve a steeper and more plausible estimated selectivity, the length frequencies less than 35 cm were set to zero. Results following this 'correction' to observer length frequencies, filtered and scaled as described in Section 3.2, and using the 'best estimate' biological parameters given in Table 1, are shown in Figure 9. The S_{L95} values were still mostly above the L_∞ value of 50 cm. Results for SPR from the 1990s were very variable, and in three years prior to 2004 SPR was estimated at 1 (and F at 0). Despite this, temporal trends were apparent, with F/M increasing in the mid to late 2000s, followed by a subsequent decline. Over the same period, there was a decrease in SPR, followed by a subsequent increase, but the SPR results for the last two years in the series were relatively low, with 2025 the lowest in the series.

Figure 10 shows the length frequency data for the last four years of the series expressed as proportions and the LB-SPR fits to those length frequencies. Also shown are the expected proportions at length from an unfished population (based on the biological parameters used in the model fit). The model fits to the length frequencies were reasonable in all four years. The modal length was relatively low in 2024 and 2025 with a large increase in proportions of fish smaller than about 45 cm and proportions at lengths greater than 45 cm reduced compared to both the earlier two years and the theoretical unfished population.

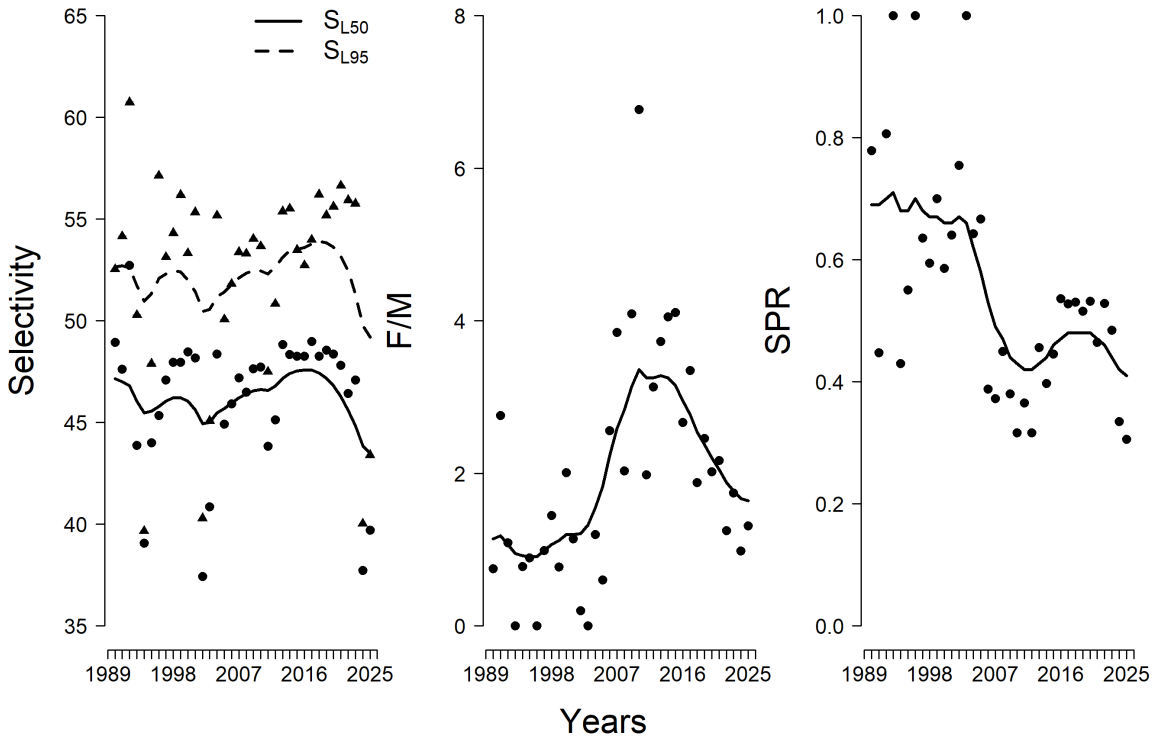


Figure 9: **SWA 3 and 4, result of applying LBSPR package to observer length frequency data filtered to include only data from hoki and silver warehou target fisheries, scaled as described in Section 3.2 and with all length frequencies less than 35 cm set to zero. Results for individual years (1990–2025) are given as points (triangles for SL95) and lines are the result of a smoother.**

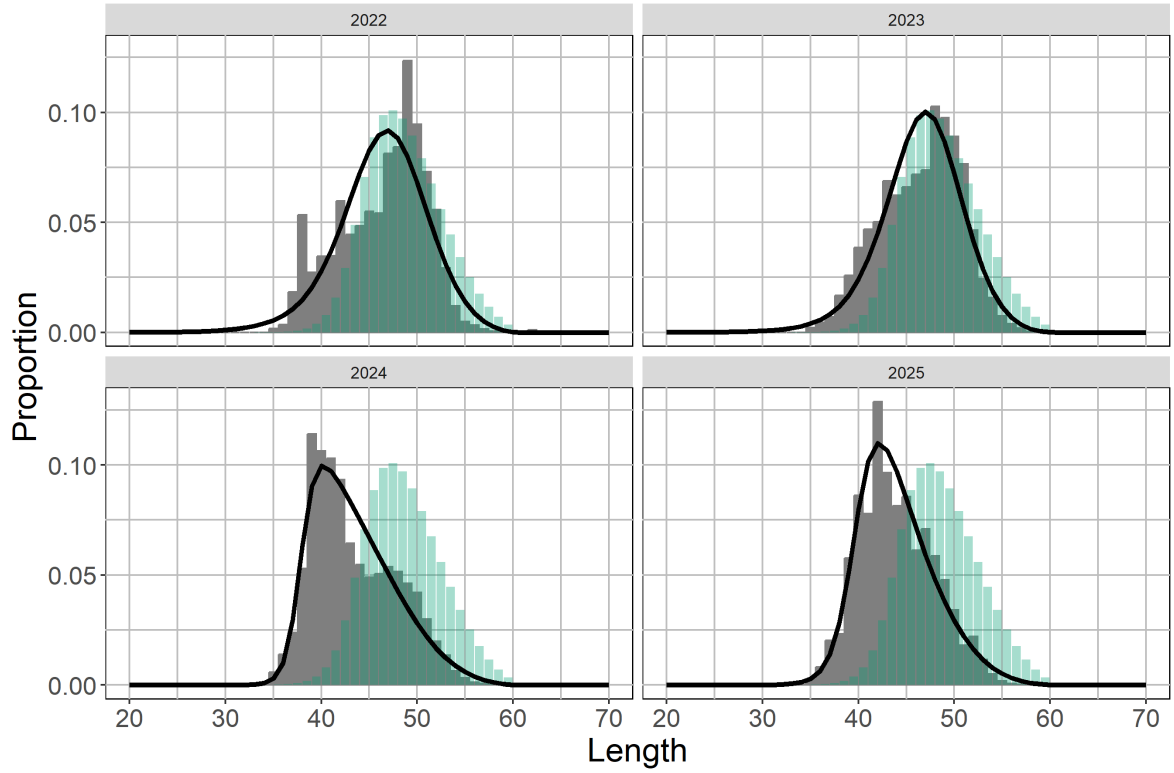


Figure 10: **SWA 3 and 4, scaled observer length frequency data for 2022–2025 shown as proportions at fork length (grey bars), LBSPR fits to the length frequency data (solid black lines) and length frequency distribution for an unfished population with the same L_∞, M/k, L_{50} and L_{95} parameter values as supplied to the LBSPR package (green bars).**

3.3.1 Sensitivity analyses

Sensitivity analyses were conducted by applying the model to the same data but with each of the biological input parameters altered in turn through a range of values (see Table 1).

L_∞ and CV(L_∞)
Increasing the assumed L_∞ lowered the estimated SPR in all years and reduced the variability in SPR estimates (Figure 11). Estimated *F/M* values increased with increasing L_∞ (Figure 12). Even at the lower values of L_∞, many of the *F/M* values were considered implausible by the DWWG. Keeping L_∞ fixed at 50 cm, increasing CV(L_∞) produced a similar effect to increasing L_∞ (see Appendix 3, Figure A3.1 and A3.2); this is because as CV(L_∞) is increased (or L_∞ increased) the proportion of fish at larger lengths increases, and there is therefore a greater difference between the expected and observed frequencies at these larger lengths, which is attributed as being the result of mortality, and hence results in a lower SPR.

M, k and *M/k*
From Hordyk et al. (2016), it is expected that values of *M* and *k* that result in the same value of *M/k* will result in the same SPR value (all else being equal). Here, this was confirmed by applying six combinations of *M* and *k* values that gave the same *M/k* value, which all gave the same SPR. Because, with respect to *M* and *k*, the *M/k* ratio controls the SPR estimate, increasing *M* while holding *k* (and all other input parameters) constant has the opposite effect on estimated SPR to increasing *k* while holding *M* constant. SPR increased with increasing *M/k*. Over ranges of plausible values for silver warehou, the changes in SPR estimates were much less than when changing L_∞, (Figures 13 and 14). *F/M* decreased with increasing *M/k* (Figure A3.3 and A3.4). *F/M* results were much less sensitive to changes in *M/k* value than to changes in assumed L_∞.

L_{50} and L_{95}
To test sensitivity to assumed length at maturity, the L_{50} was varied over a range considered reasonable for silver warehou, with L_{95} set to L_{50} + 4 cm. Increases in L_{50} resulted in decreases in SPR (Figure 15). Model estimates for S_{L50}, S_{L95} and *F/M* remained the same between runs. The high estimates of S_{L95} for this stock resulted in unselected (cryptic) mature biomass contributing to SPR. As L_{50} (and L_{95}) values were increased, the amount of this cryptic biomass was reduced.

All sensitivity tests estimated SPR for 2024 and 2025 as the lowest (or near to lowest) in the time series, with *F/M* also low in these years compared to the previous two decades.

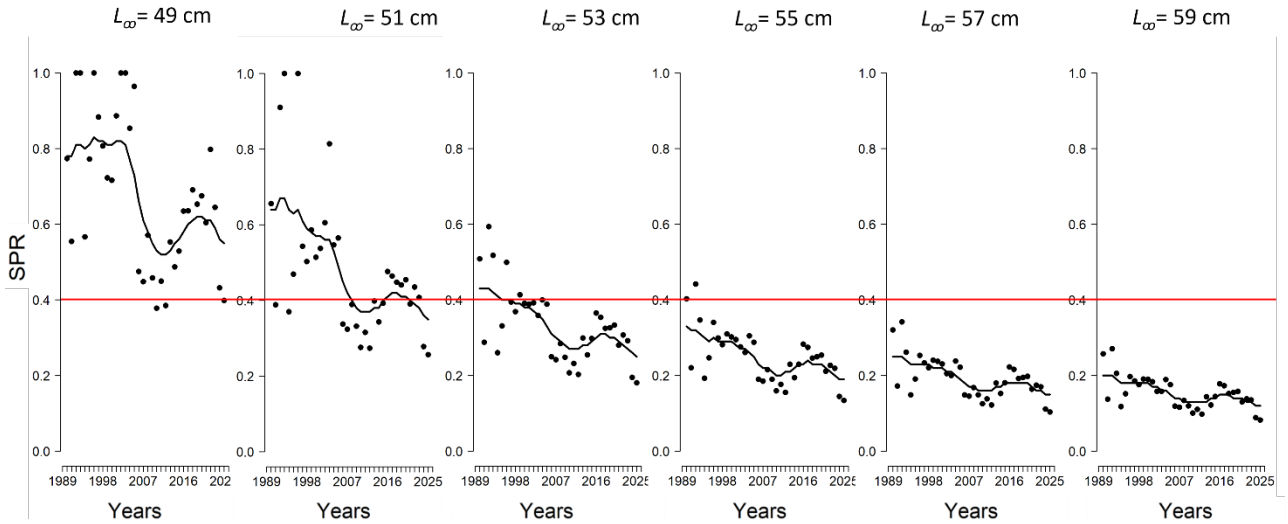


Figure 11: SWA 3 and 4, estimated SPR (vertical axis) over the years 1990–2025 from LB-SPR method applied to scaled observer length frequencies with L_∞ values supplied as indicated above each panel and all other parameters held at 'best estimate' value (see Table 1). Horizontal line is to aid comparison between panels.

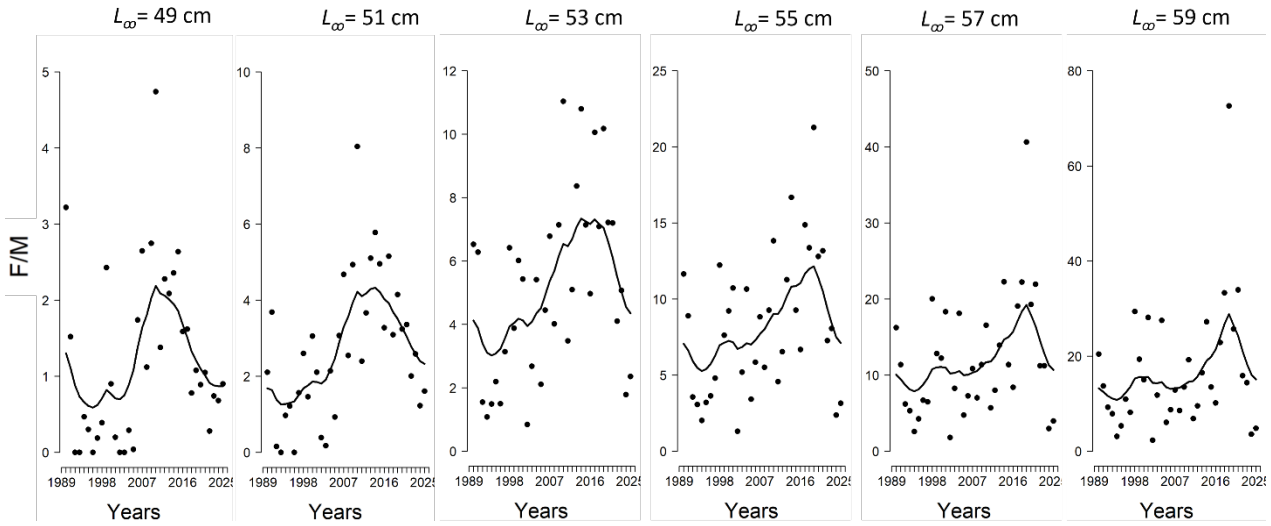


Figure 12: SWA 3 and 4, estimated *F/M* (vertical axis) over the years 1990–2025 from LB-SPR method applied to scaled observer length frequencies with L_∞ values supplied as indicated above each panel and all other parameters held at 'best estimate' value (see Table 1). Note different vertical axis scale for each panel.

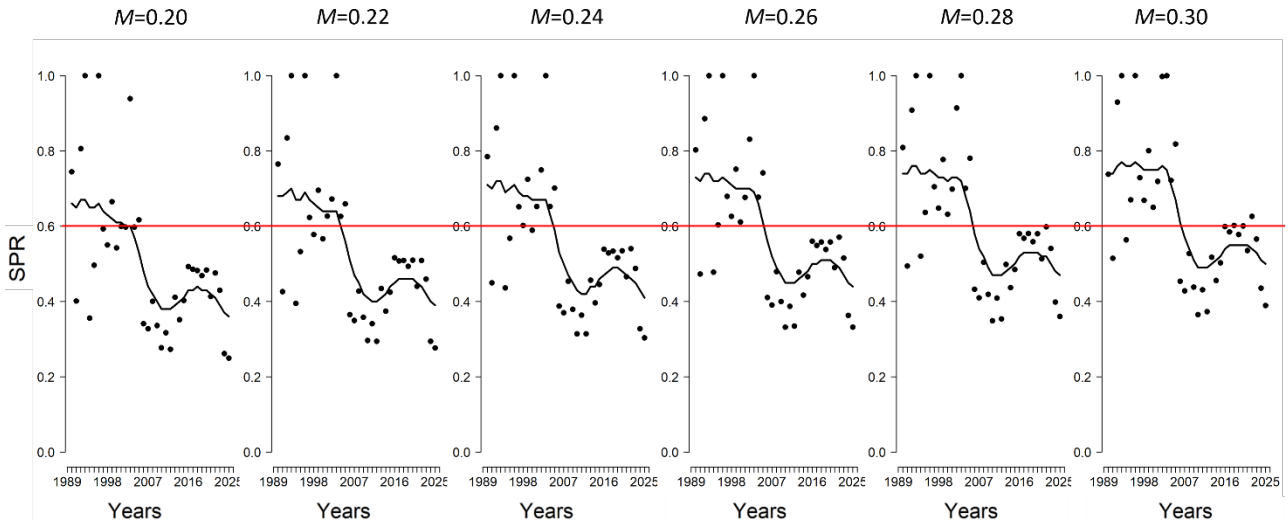


Figure 13: SWA 3 and 4, estimated SPR (vertical axis) over the years 1990–2025 from LB-SPR method applied to scaled observer length frequencies with *M* values supplied as indicated above each panel and all other parameters held at 'best estimate' value (see Table 1). Horizontal line is to aid comparison between panels.

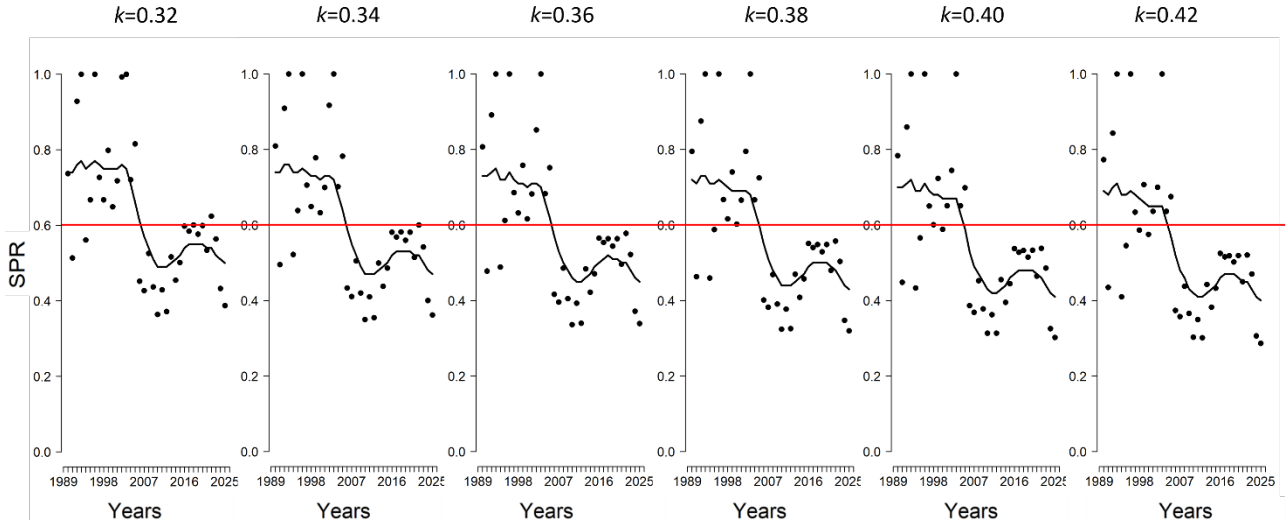


Figure 14: SWA 3 and 4, estimated SPR (vertical axis) over the years 1990–2025 from LB-SPR method applied to scaled observer length frequencies with *k* values supplied as indicated above each panel and all other parameters held at 'best estimate' value (see Table 1). Horizontal line is to aid comparison between panels.

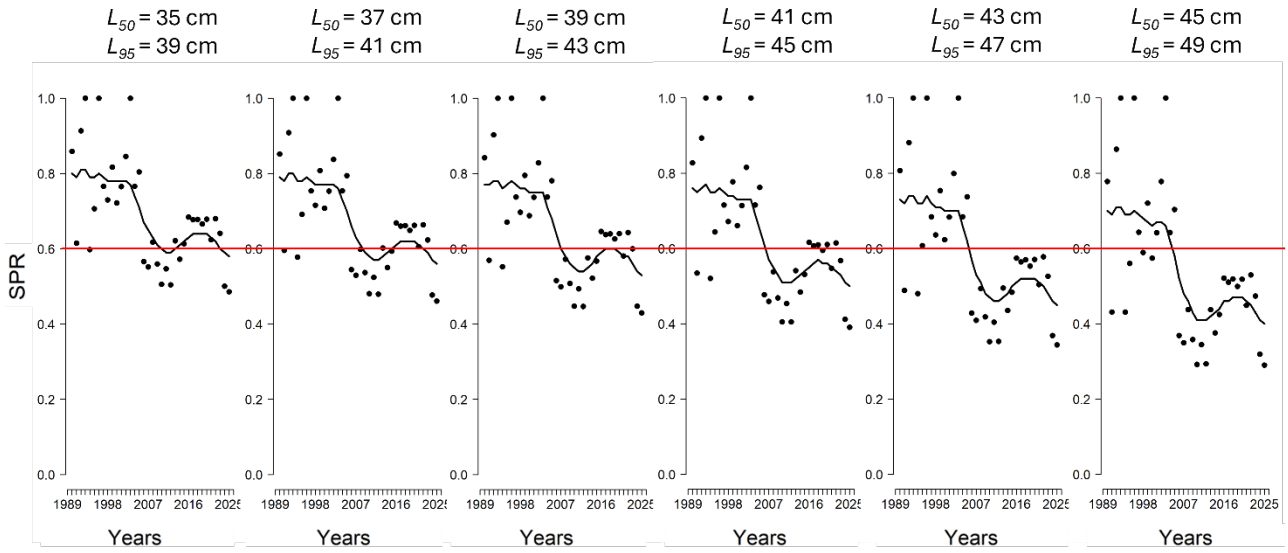


Figure 15: SWA 3 and 4, estimated SPR (vertical axis) over the years 1990–2025 from LB-SPR method applied to scaled observer length frequencies with L_{50} and L_{95} values supplied as indicated above each panel and all other parameters held at 'best estimate' value (see Table 1). Horizontal line is to aid comparison between panels.

3.3.2 Stochastic LB-SPR

Figure 16 shows SPR estimates from applying the stochastic version of LB-SPR. Almost all possible values for SPR were represented in each year (i.e., from just above zero, to one), but the inter-quartile range followed a year trend similar to that from the 'best estimate' run (Figure 9). The median SPR for 2025 was the lowest in the time series.

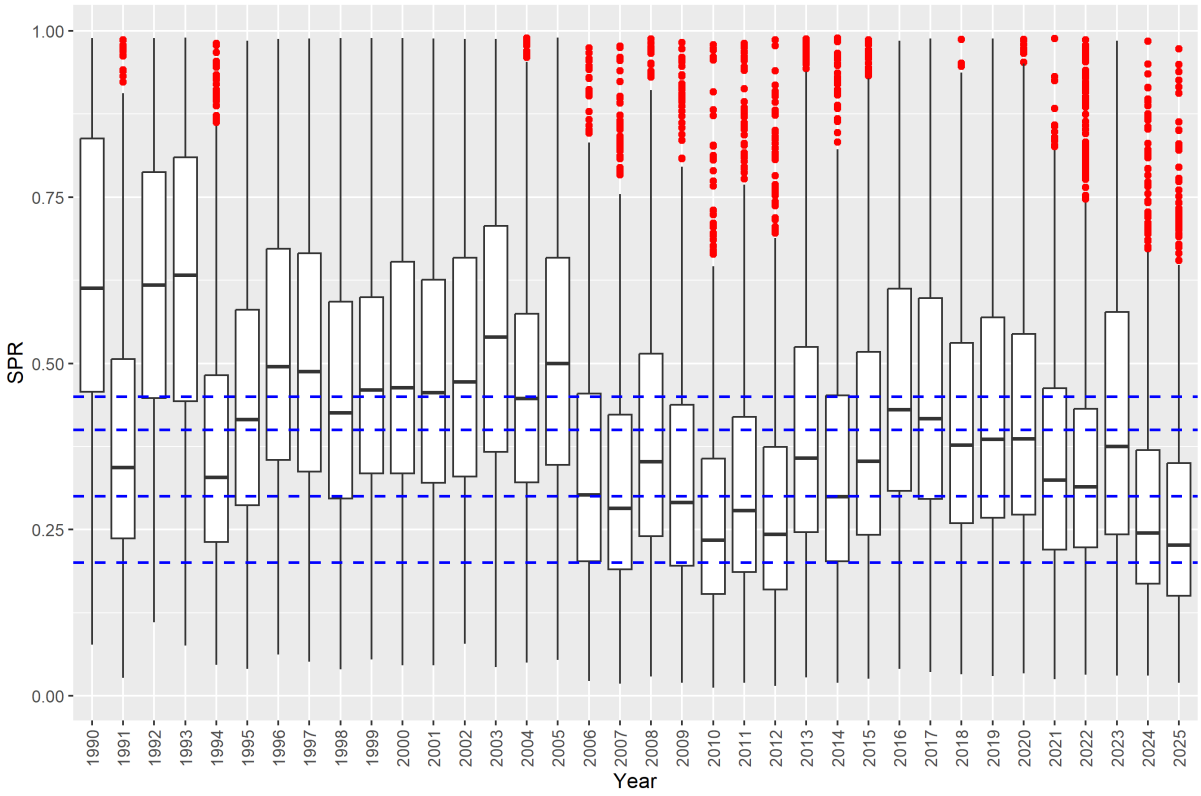


Figure 16: SWA 3 and 4, estimated SPR over the years 1990–2025 from stochastic LB-SPR method applied to scaled observer length frequencies. 1000 repetitions with values for L_∞, M and k drawn from distributions as shown in Table 1. Correlation between L_∞ and k was -0.59, based on a covariance of -0.095 and the respective sd values. Boxes extend between the 25th and 75th percentiles with bold line marking the median. Whiskers extend to 1.5 times the inter-quartile range. Outliers are shown as individual red dots. Horizontal dashed lines are at SPR values of 0.2, 0.3, 0.4 and 0.45.

4. DISCUSSION

Use of the LB-SPR method on the research trawl survey length data for SWA was rejected for all three candidate surveys. The SUBA survey had sample sizes that were too small, the ECSI survey had limited coverage of adults, and the Chatham Rise inconsistently captured mature fish.

By contrast, the length frequency data from observer sampling appeared adequate. Representation of the fishery appeared good from the mid-2000s (Middleton 2026), and after filtering to appropriate target fisheries it was possible to both adequately represent lengths of mature fish, whilst excluding modes of immature fish. The number of fish sampled for the selected fisheries would be adequate following Miranda (2007) and Hordyk et al. (2015b).

Simulation-estimation analyses (Chong et al. 2020, Wang et al. 2025) found LB-SPR to perform well for 'medium-lived' species relative to short-lived species. Silver warehou is a 'medium-lived' species. Short-lived species tend to display rapid growth and/or strong cohort effects resulting in highly multimodal length compositions. The length frequencies for short lived species are also likely over a relatively narrow size range and differences in length composition between lightly and heavily fished populations may be small.

The DWWG rejected LB-SPR being used for SWA management advice because of the sharp decrease in SPR seen in 2024, which conflicted with results from CPUE analyses which suggested stability (Holmes et al. 2026), and the interpretation of stock status from the scaled LFs. The latter suggested no

change in the slope of the right-hand side of the adult fish mode, and a relative abundance of smaller fish at the lower (adult) lengths (Figure 8), suggesting a strong 'recruitment' into the adult population. Strong recruitment would be an opposite interpretation of stock status compared to that from the SPR estimates, which suggest overfishing. The LB-SPR methodology deals in relative length frequencies, and assumes steady state conditions such, that the shift in relative length frequencies is interpreted as a reduction in the abundance of larger fish and therefore lower SPR. The DWWG concluded that a strong recruitment may have violated the equilibrium assumption of the LB-SPR method, and the SPR results would therefore be misleading. Using a time series of data, not just the most recent year, was important to highlight this problem. The reduction in SPR estimated between the early 2000s and 2006 coincides with results from CPUE indices that show an increase in abundance during 2003–04 to 2006–07, and it is suspected that one or more strong year class(es) entered the adult population from 2006 (Fisheries New Zealand 2026). The SPR estimates also reduced at this time.

Adequate observer length frequency data is considered to go back at least as far as 1999 and the representativeness of observer coverage was found to be good from about the same time (Middleton 2026), suggesting that the higher SPR results from the earlier years were not just an artifact of inadequate sampling.

Dai et al. (2021) found that length data biased towards smaller fish had a greater impact on the estimation of SPR than length data that were biased towards larger fish. This may contribute to the relatively large reductions in SPR seen in 2024 and 2025. Silver warehou also had a relatively low value of M/k (0.65 was used as the best estimate value), and simulation studies by Hordyk et al. (2015b) found that lower values of M/k corresponded to greater sensitivity to misspecification of input biological parameters.

The results of the regression tree analysis were consistent with past results considering lengths and ages of silver warehou, and a transition in length composition at about 300 m (Dutilloy & Dunn 2020). McGregor (2019a), using data for the western Chatham Rise, showed that catches at depths less than 300 m contained both adult and juvenile (3-year-old and under) fish whereas catches at depths 300 m and greater almost exclusively contained adult fish. Holmes et al. (2026) showed that the mode in effort for the arrow squid target fishery was shallower than 300 m, and the length frequencies for that fishery had modes for both juvenile and adult fish (Figure A2.1). The modes for effort for the hoki and silver warehou targeted fisheries were deeper, and the length frequencies were primarily of adult fish (Figures A2.2 and A2.3). Filtering by target species proved a convenient and effective way to obtain length frequencies focused on adult fish. The regression tree analysis split of the 2024–25 data from the Chatham Rise region from previous years was also supporting evidence for a change in length distribution in 2024.

Sensitivity analyses corroborated Hordyk et al. (2015b) in demonstrating that the LB-SPR results were most sensitive to the input value of L_∞ with changes in M, k or maturity at length having a lesser impact. Results for F/M, even at values for L_∞ considered at or close to a lower credible value for silver warehou, were often too high to be considered credible. The high values for F were linked to the shallow fishing fleet selectivity curves estimated. A problem with selectivity estimation was also encountered with the most recent attempted integrated assessment (Dunn & McGregor 2023), where selectivity at age was estimated too high. That assessment eventually ran models with selectivity fixed equal to maturity; altering the code base of the LB-SPR package to do the same was beyond the scope of this project. In addition, such changes to the LB-SPR assumptions would not have mitigated against the suspected recent strong recruitment and fall in SPR in 2024 and 2025 counter to expectations from CPUE analyses.

Even if problems with selectivity could be resolved, F/M may still prove highly sensitive to input parameters for species with relatively low M/k values. The method relies on detecting the signal of fishing mortality on the upper tail of the length composition. Species with low M/k are expected to have unfished length composition strongly skewed to the left, with the length composition consisting of adults of widely varying age but a similar (near asymptotic) size. Fishing is not expected to have an impact on the upper tail of the length composition until F is very high (Hordyk et al. 2015b). If F values

are judged over-estimated it might still be possible to base reference points on SPR for management advice. Hordyk et al. (2015a) demonstrated mathematically (based on the LB-SPR assumptions and knife-edge selectivity) that SPR declines rapidly with increasing *F/M* when all size classes are selected but that the decline in SPR with increasing *F/M* becomes much slower as the relative size at selection increases. At any given size at selection the rate of change in SPR also decreased as *F/M* values increased.

There is a generally accepted safe (target) level of SPR (Clark 1991, 1993), and Shertzer et al. (2024) found that SPR-reference points (including F40%) were generally robust to uncertainty in stock productivity induced by environmental variability. The default MSY target of Fmsy (F40%) has also been shown to be relatively robust to stock-recruitment steepness (M. Dunn, pers. comm.).

5. POTENTIAL RESEARCH

There are currently no age data available for silver warehou more recent than 2016. There are, however, many otoliths collected from all years since 2016 (across fisheries management areas 3, 4, 5 and 6 the minimum number of otoliths available from any year up to 2022 is just under 2000). Age data from recent years (starting from the 2020–21 fishing season) would cover all ages of the cohort reaching age four by the 2024–25 fishing season and could be used to evaluate the hypothesis of strong recent recruitment. Additional ageing from earlier years (a large number of otoliths have been collected each year since the late 1990s) could similarly provide a further test of the assumption of exceptionally strong recruitment in the early 2000s.

Ageing silver warehou would open the possibility for new types of future assessment. Catch-curve stock reduction analysis (CC-SRA) (Thorson & Cope 2015) requires as inputs age composition from the final year of catches, values for maturity at age (m_a) and weight at age (w_a), likelihood penalties for natural mortality (M) and Beverton-Holt recruitment steepness (h), and a value for the magnitude of the variability in recruitment σ^2_R. Like LB-SPR, CC-SRA assumes that selectivity follows a logistic ogive. Outputs from the model are final estimates for M and h, fishery selectivity estimates for age at 50% selection (S_{50}),, and rate of change of selectivity at age S_{50} (in logit-space) (S_{slope}), virgin recruitment R_0, and the recruitments and fully selected fishing mortalities for all fished years. A disadvantage of the method is the assumption that the population is in an unfished equilibrium in the initial year. A simpler approach could be to apply simple catch curve analyses to individual silver warehou cohorts.

An updated time series of age frequency data may also improve an integrated stock assessment. A future assessment could also include the fishery subsets, and length frequency distributions, estimated during this project (length frequencies were not used in the most recently attempted integrated assessment).

An alternative to using new age data is investigation of the Length-based Integrated Mixed Effects (LIME) method (Rudd & Thorson 2018). This method uses similar data inputs to LB-SPR but can base estimates of annual fishing mortality and SPR on multiple years of data. When multiple years of data are available, annual recruitments are treated as random effects, where the mean and standard deviation of a distribution for recruitment are estimated as fixed effects. Additionally, Rudd & Thorson (2018) describe a 'data rich' use of LIME where, in addition to length frequencies, the method makes use of total catch estimates and an abundance index. Both these additional data are available for silver warehou. LB-SPR was chosen over LIME for this study because it is a simpler method to implement and because simulation studies comparing methods found LB-SPR could give less biased results than LIME (Chong et al. 2020, Rudd & Thorson 2018); however, this was under equilibrium conditions.

6. FULFILMENT OF BROADER OUTCOMES

As required under Government Procurement rules[2], Fisheries New Zealand considered broader outcomes (secondary benefits such as environmental, social, economic or cultural benefits) that would be generated by this project. This project delivered against two aspects of broader outcomes.

Building capacity and capability in the research sector
Within this project Earth Sciences NZ used a team approach that brought together one of our most experienced researchers, including experience from the most recent SWA stock assessment research, with a less experienced but complementary researcher.

Supporting and partnering with Māori
While the work undertaken in this project did not involve direct interactions with Māori, iwi entities own quota in most fisheries stocks, and the work undertaken here will help support the fish stocks that underpin these Māori owned resources.

7. ACKNOWLEDGEMENTS

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APPENDIX 1: BIOLOGICAL PARAMETERS

Sources of values for asymptotic length L_∞, von Bertalanffy growth parameter k, natural mortality M, and lengths at 50 and 95% mature (L_{50}, L_{95}) are outlined below. A summary of the values and sources is given in Table A1.

Asymptotic length (L_∞)

McGregor (2019b) estimated a combined sex value of L_∞ = 49.8 cm. A best estimate of 50 cm was chosen on this basis.
Dunn & McGregor (2023) estimated a combined sex value of L_∞ = 50.8 cm with 95% confidence intervals of 50.6–51.0 cm, but in the attempted assessment retained the value from McGregor (2019b).
Horn & Sutton (1996) used data from silver warehou off the south-east coast of the South Island and estimated L_∞ = 54.5 cm (with 95% confidence intervals of 54.0–55.0 cm) for females and 51.8 cm (with 95% confidence intervals of 51.3–52.3 cm) for males.
Gavrilov (1979) estimated L_∞ = 58.4 cm.
Assessments of the Australian stock of silver warehou (Tuck 2022) used L_∞ = 51.3 cm.
Estimates for a Chilean stock (Aguayo & Chong, 1991) gave L_∞ = 55.2 cm.

For stochastic LBSPR
Offering a normal distribution to the above L_∞ values resulted in a distribution with mean 53.2 cm and standard deviation (σ) 2.88 cm, i.e., N(53.2,2.88).

Von Bertalanffy growth parameter (k)

McGregor (2019b) estimated a combined sex value of k = 0.382 yr^{-1}. This was chosen as the best estimate value.
Dunn & McGregor (2023) estimated a combined sex value of k = 0.36 with 95% confidence intervals of 0.35–0.37 yr^{-1} but in the attempted assessment retained the value from McGregor (2019b).
The same Horn & Sutton (1996) study used to estimate L_∞ gave k estimates of 0.33 yr^{-1} (0.31–0.35 yr^{-1}) for females and 0.41 yr^{-1} (0.38–0.43 yr^{-1}) for males.
Gavrilov (1979) estimated a combined sex value of 0.36 yr^{-1}.
Aguayo & Chong (1991) estimated a combined sex value of 0.23 yr^{-1}.

For stochastic LBSPR
Offering a normal distribution to the above k values resulted in a distribution with mean 0.35 yr^{-1} and standard deviation (σ) 0.056 yr^{-1}, i.e., N(0.35,0.056).

Natural mortality (M)

The most recent attempted assessment for SWA (Dunn & McGregor 2023) used an M value of 0.25 yr^{-1}. This was chosen as the best estimate value.
Horn & Sutton (1995) reported a maximum observed age of 23 for females and 19 for males. From M = ln100/$Amax$, where $Amax$ is age reached by 1% of individuals (19 for females and 17 for males) they obtained M estimates of 0.24 and 0.27 yr^{-1}. The samples were not from an unfished population. They recommended M should be considered in the range 0.2–0.3.
Assessments of the Australian stock of silver warehou (Tuck 2022) used 0.3 yr^{-1} with sensitivity trials at 0.25 and 0.35 yr^{-1}.

For stochastic LBSPR
For the stochastic LBSPR application a normal distribution was assumed with mean 0.25 yr^{-1} and standard deviation (σ) 0.025 yr^{-1}, i.e., N(0.25,0.025).

Lengths at 50 and 95% mature (L_{50} and L_{95})

Considering length-maturity information from all available New Zealand survey and commercial data McGregor (2016) concluded "It is likely that 47 cm is close to the size at 100% maturity, with the size

at 50% maturity closer to 44 cm". Best estimate values of L_{50} = 44 cm, L_{95} = 48 cm were chosen on this basis.
From Fisheries New Zealand (2026) "fish reach sexual maturity at around 45 cm fork length in 4 years".
Gavrilov (1979) indicated an age of maturity of 3–4 years based on histological analysis, corresponding to a length of 46–48 cm.
Assessments of the Australian stock of silver warehou (Tuck 2022) assumed 50% mature at 37 cm (with sensitivity trials at 34 cm and 40 cm).
Estimates for a Chilean stock (Chong et al. 2019) gave 50% mature at 37.2 cm (95% confidence limits of 35.9–37.9 cm), at age 5.

Table A1: Sources of values for asymptotic length L_∞, von Bertalanffy growth parameter k, natural mortality M, and lengths at 50 and 95% mature (L_{50}, L_{95}).

Parameter	Best estimate	Source	Other values	Source
L_∞ (cm)	49.8 (rounded to 50)	McGregor (2019b)	50.8	Dunn & McGregor (2023)
			54.5 (females)	Horn & Sutton (1996)
			51.8 (males)	
			58.4	Gavrilov (1979)
			51.3	Tuck (2022)
			55.2	Aguayo & Chong (1991)
k (yr^{-1})	0.382	McGregor (2019b)	0.36	Dunn & McGregor (2023)
			0.33 (females)	Horn & Sutton (1996)
			0.41 (males)	
			0.36	Gavrilov (1979)
			0.23	Aguayo & Chong (1991)
M (yr^{-1})	0.25	Dunn & McGregor (2023)	0.24 (females)	Horn & Sutton (1995)
			0.27 (males)	
			0.3	Tuck (2022)
L_{50} (cm)	44	McGregor (2016)	45	Fisheries New Zealand (2026)
			46–48	Gavrilov (1979)
			37	Tuck (2022)
			37.2	Chong et al. (2019)
L_{95} (cm)	48	McGregor (2016)		

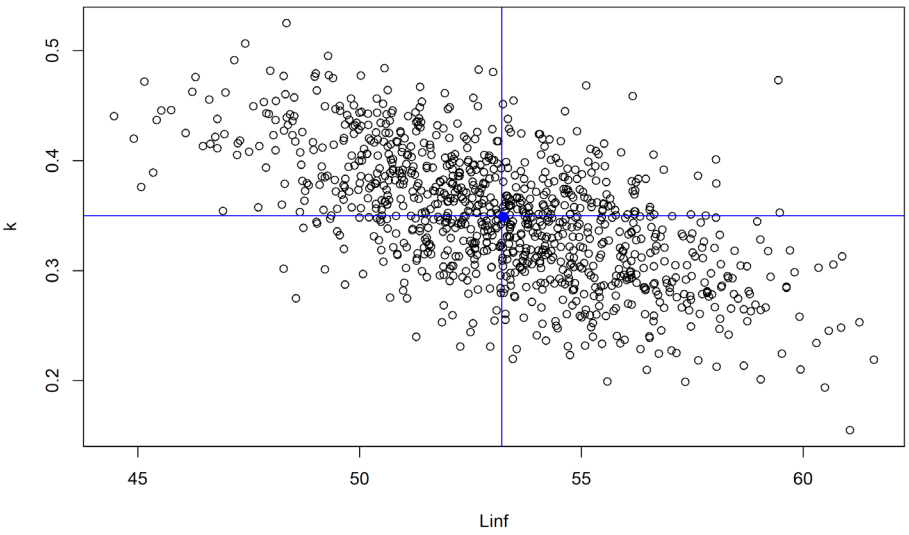


Figure A1.1: L_∞ and k value pairs used in the stochastic implementation of LB-SPR. Values were drawn from a multivariate normal distribution where the distributions for L_∞ and k were as in Table 1 and the covariance between parameters was estimated at -0.095. Blue dot represents the median of the sampled L_∞ and k values and the vertical and horizontal blue lines the means of the L_∞ and k distributions.

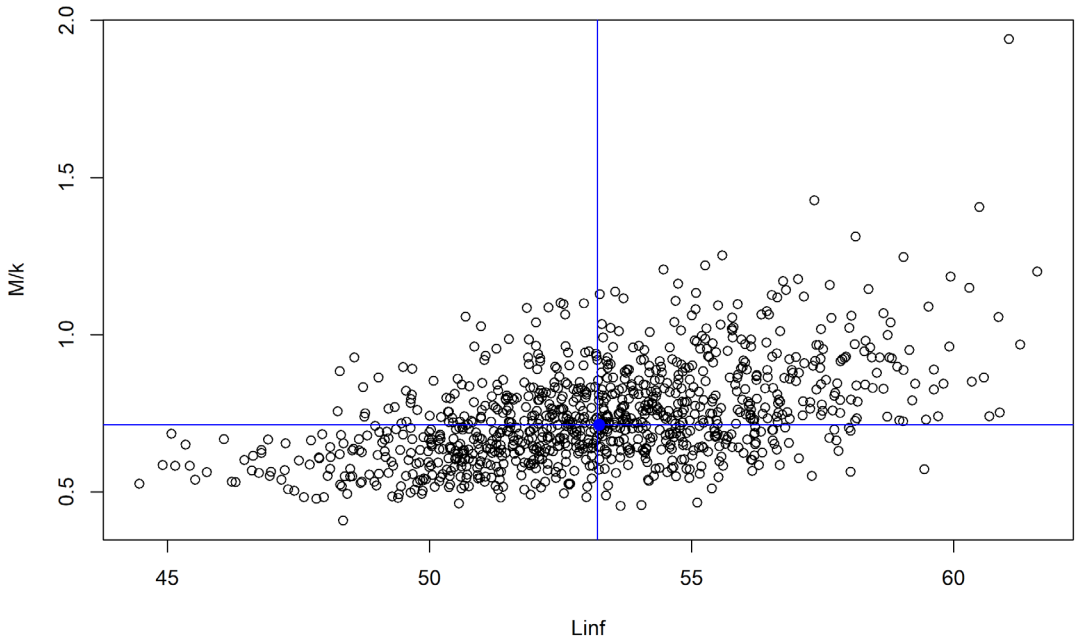


Figure A1.2: L_∞ **and** M/k **value pairs used in the stochastic implementation of LB-SPR. Values of** L_∞ **and** k **were drawn from a multivariate normal distribution where the distributions for** L_∞ **and** k **were as in Table 1 and the covariance between parameters was estimated at -0.095. Values of** M **were drawn independently from a separate normal distribution (Table 1). Blue dot represents the median of the sampled** L_∞ **values and median of the sampled** M **values divided by the mean of the** k **distribution. Vertical and horizontal blue lines are the means of the** L_∞ **distribution and median of the sampled** M **values divided by the mean of the** k **distribution.**

APPENDIX 2: UNSCALED OBSERVER LENGTH FREQUENCIES BY TARGET FLEET

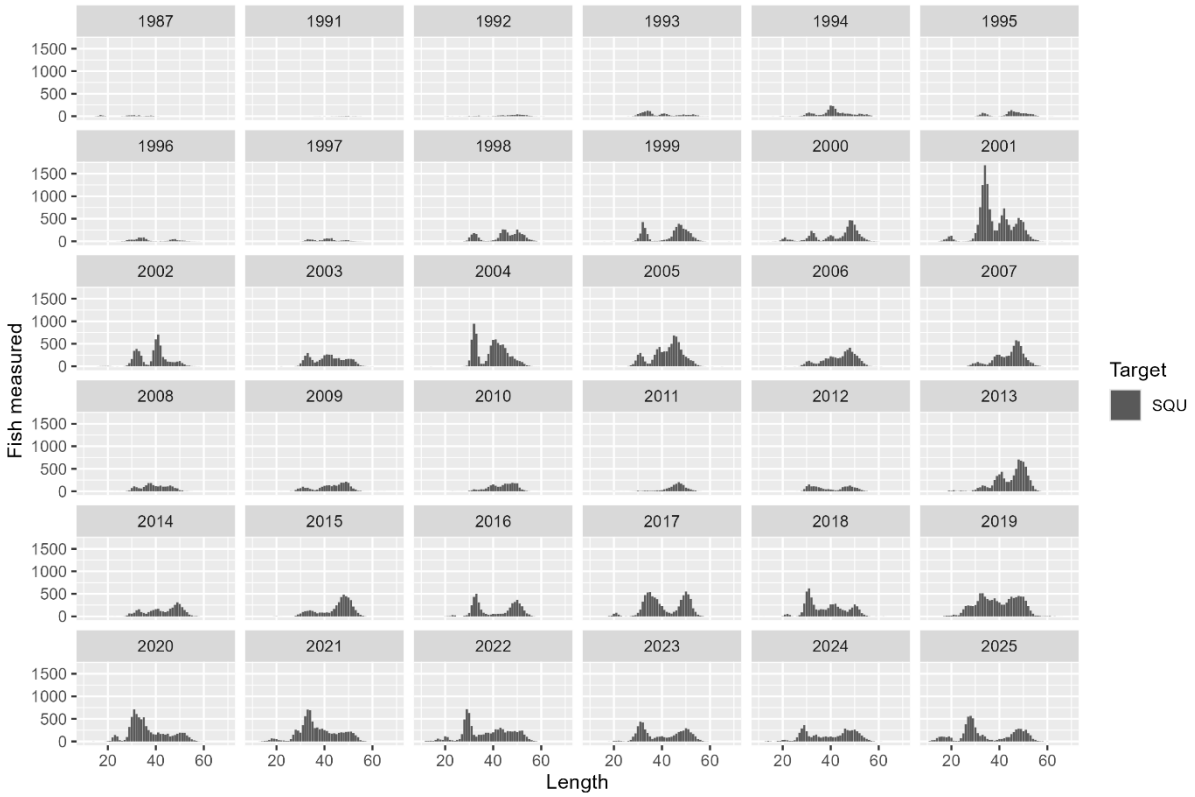


Figure A2.1: Unscaled length frequencies from observer data filtered to management areas SWA 3 and 4 and to include only data from arrow squid target tows.

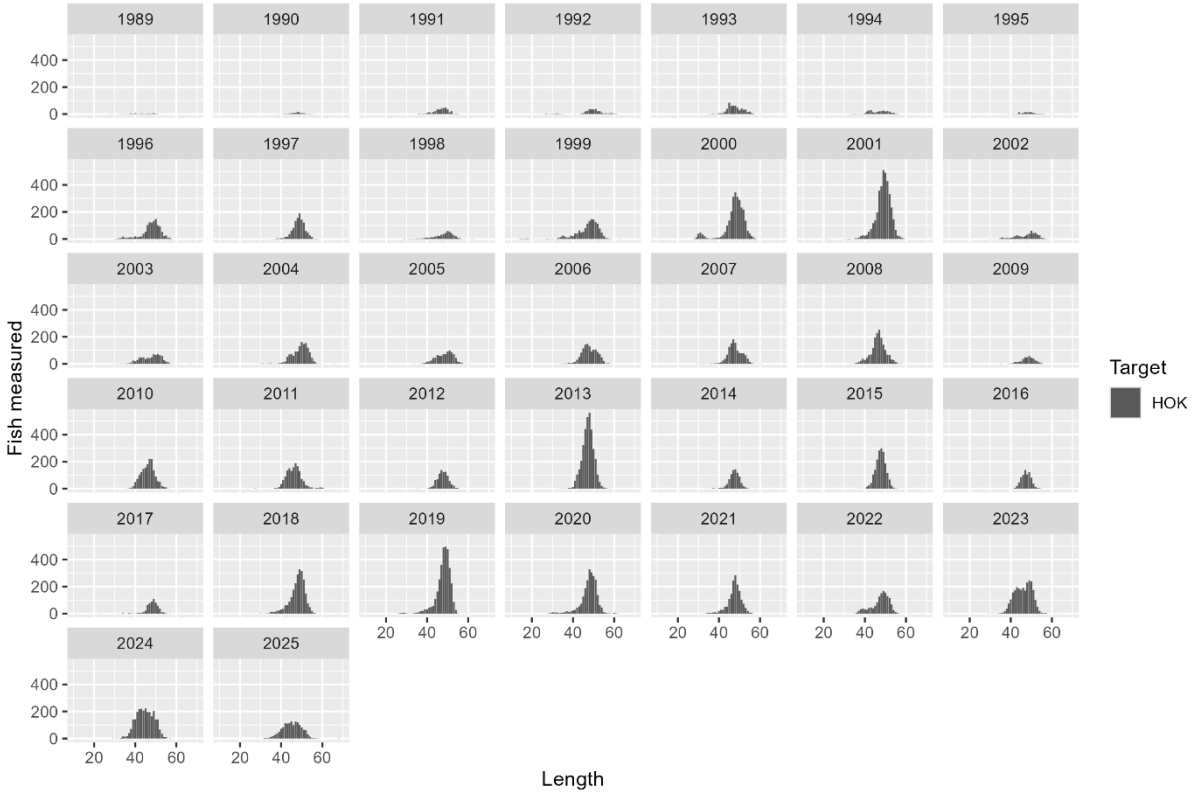


Figure A2.2: Unscaled length frequencies from observer data filtered to management areas SWA 3 and 4 and to include only data from hoki target tows.

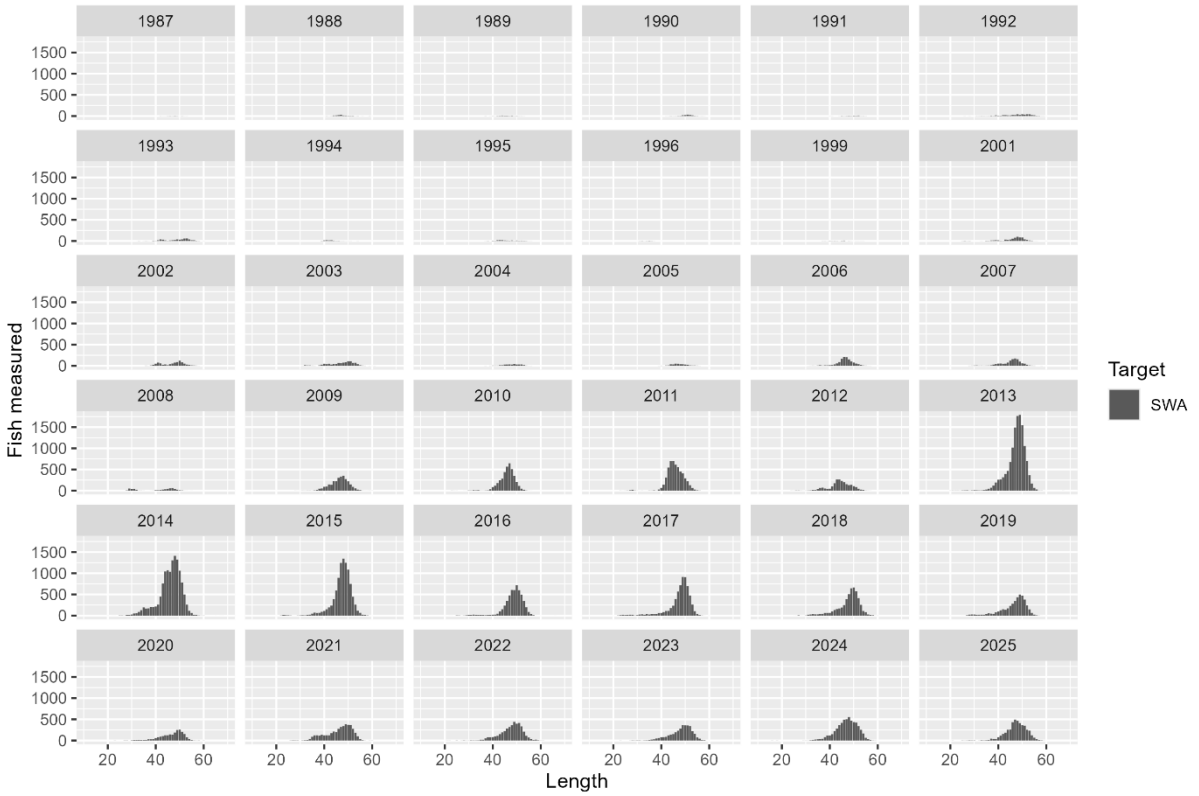


Figure A2.3: Unscaled length frequencies from observer data filtered to management areas SWA 3 and 4 and to include only data from silver warehou target tows.



Figure A2.4: Length frequencies (unscaled) expressed as proportions at length for SWA using hoki and silver warehou target fisheries data combined. Superimposed in red are the theoretical distributions of length at age (as seen in Figure 2) for ages 4 to 15.

APPENDIX 3: SENSITIVITY ANALYSES (LB-SPR APPLIED TO SCALED OBSERVER LENGTH FREQUENCIES)

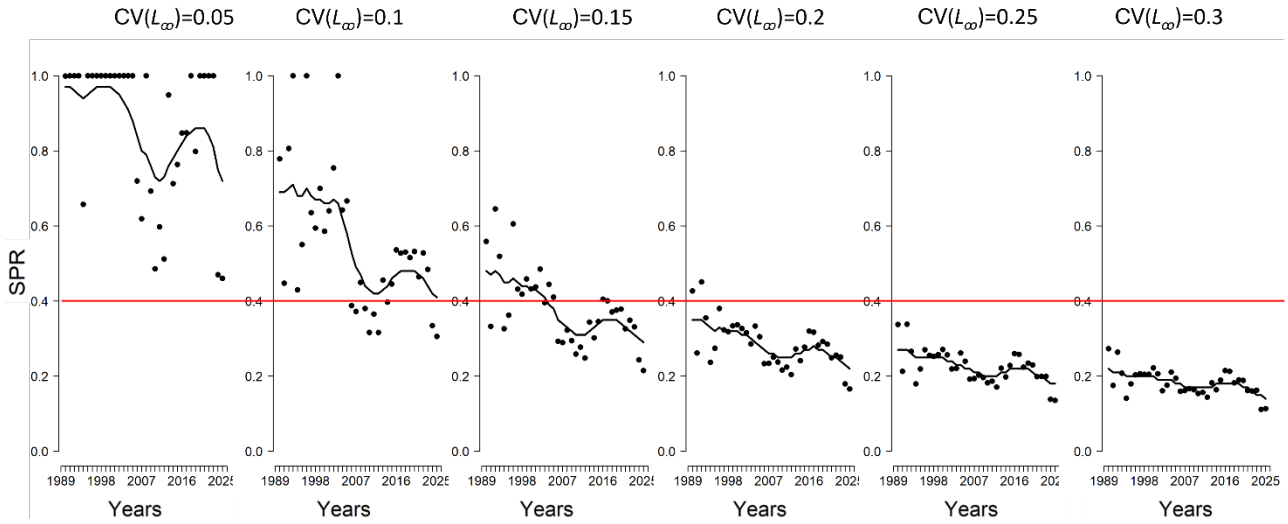


Figure A3.1: **Estimated SPR (vertical axis) over the years 1990–2025 from LB-SPR method applied to scaled observer length frequencies with CV(L_∞) values supplied as indicated above each panel and all other parameters held at 'best estimate' value (see Table 1). Horizontal line is to aid comparison between panels.**

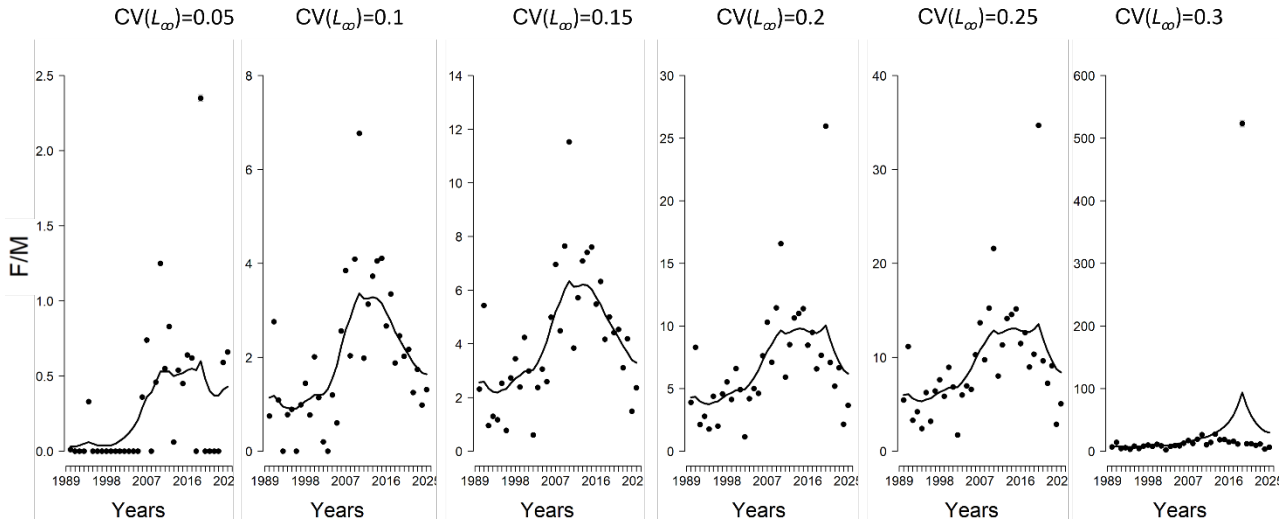


Figure A3.2: **Estimated *F/M* (vertical axis) over the years 1990–2025 from LB-SPR method applied to scaled observer length frequencies with CV(L_∞) values supplied as indicated above each panel and all other parameters held at 'best estimate' value (see Table 1). Note different vertical axis scale for each panel.**

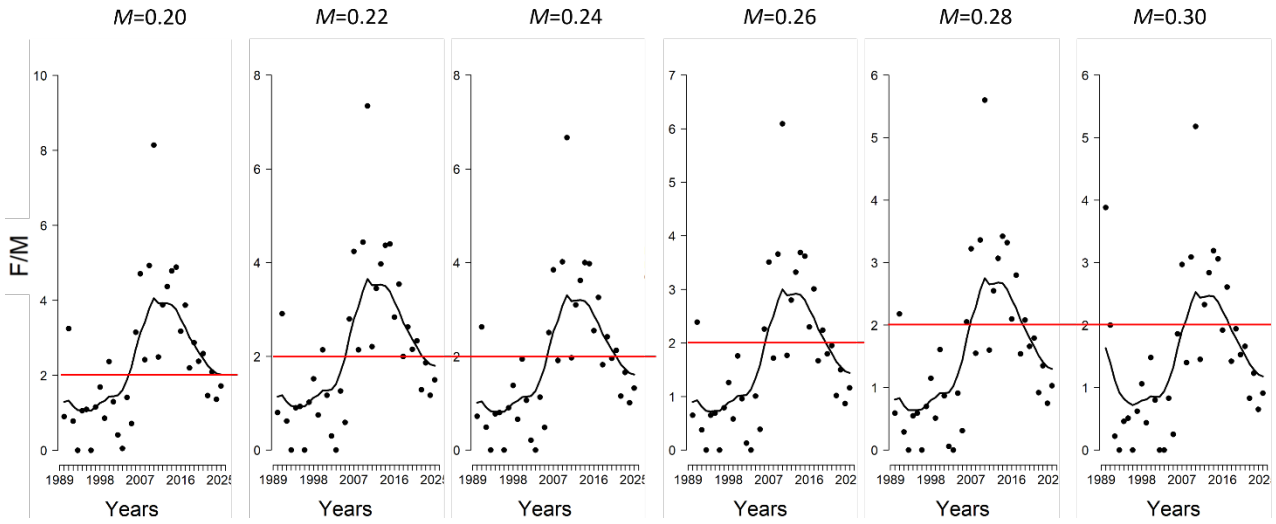


Figure A3.3: **Estimated *F/M* (vertical axis) over the years 1990–2025 from LB-SPR method applied to scaled observer length frequencies with *M* values supplied as indicated above each panel and all other parameters held at 'best estimate' value (see Table 1). Note different vertical axis scales. Horizontal lines are to aid comparison between panels.**

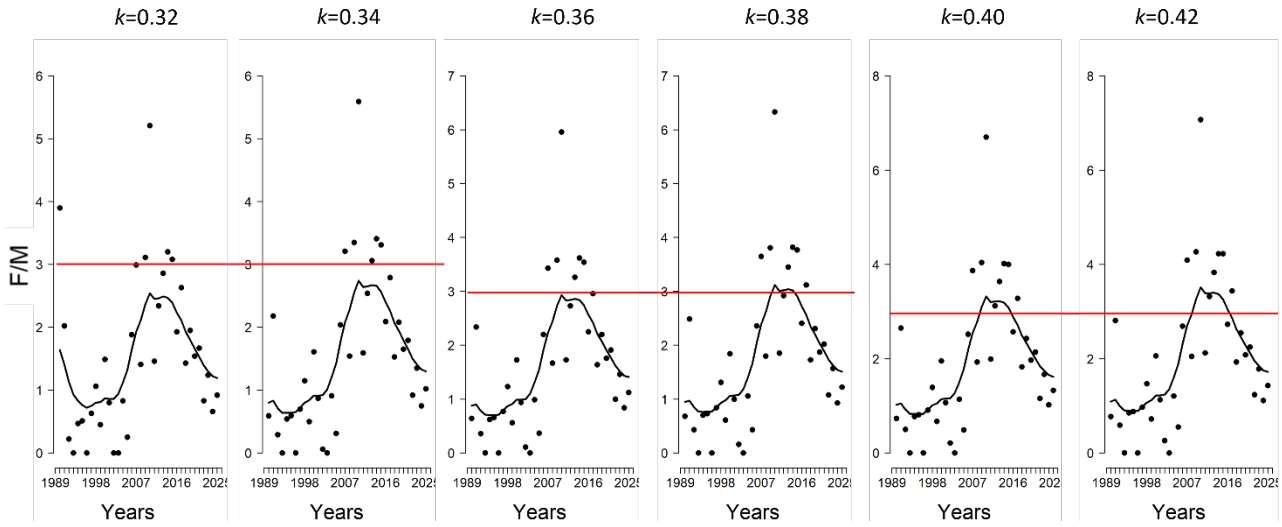


Figure A3.4: **Estimated *F/M* (vertical axis) over the years 1990–2025 from LB-SPR method applied to scaled observer length frequencies with *k* values supplied as indicated above each panel and all other parameters held at 'best estimate' value (see Table 1). Note different vertical axis scales. Horizontal lines are to aid comparison between panels.**