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Fishery characterisation, CPUE analysis and preliminary modelling of gemfish in SKI 3 and SKI 7

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Gemfish (*Rexea solandri*) in SKI 3 and SKI 7 are considered to represent a single biological stock. Gemfish are caught in SKI 3 during spring–autumn, primarily as a bycatch of the Southland squid fishery. These fish are thought to migrate northwards to spawn in waters off the West Coast South Island (SKI 7) during August–September and are caught in association of the hoki trawl fishery at that time.

In recent years, annual catches from SKI 3 and SKI 7 have increased from low levels. For SKI 7, annual catches increased from 2015–16 and exceeded the TACC of 300 t in 2017–18 (by 94%). Similarly, annual catches from SKI 3 were well below the TACC of 300 t until 2017–18 when the catch exceeded the TACC by 55%. The recent increase in catch from SKI 3 was dominated by catches from the SQU 1T trawl fishery, while most of the increase in SKI 7 catch was associated with the WCSI hoki fishery.

A standardised CPUE analysis was conducted based on the gemfish catch and effort data from the WCSI hoki target trawl fishery. The definition of the fishery was restricted by area and season to encompass the portion of the fishery that accounted for most of the gemfish catch. The catch and effort data set was also restricted to the domestic trawl fleet due to concerns regarding the reliability of the reporting of gemfish catches by other sectors. These criteria restricted the CPUE data set to a small proportion of the catch and effort data from the entire WCSI hoki trawl fishery.

A Generalised Linear Modelling (GLM) approach was used to separately model the occurrence of gemfish catches (presence/absence) and the magnitude of positive gemfish catches. The final (delta-lognormal) CPUE indices combined the two sets of quite disparate indices from the lognormal and binomial models. The combined CPUE indices were very low during 1996/97–2002/03 and then increased in 2003/04. The combined indices remained relatively stable during 2003/04–2015/16 and then increased substantially in 2016/17–2017/18 (by approximately 300%), following the increase in the binomial CPUE indices. Overall, the precision of the combined CPUE indices was relatively low (CV 30–40% for most years).

Trends in abundance and length composition of gemfish from the time-series of WCSI *Kahaora* and *Tangaroa* trawl surveys were reviewed. Recent surveys have indicated the presence of relatively strong (2014–2016) year classes. These year classes were also present in the length compositions derived from the Observer sampling of commercial catches of gemfish from the summer squid trawl fishery and the WCSI hoki fishery.

An age structured population model was configured for the southern gemfish stock. The model provided a framework for investigating the trends in the various data sets available from SKI 3 and 7, specifically the time-series of annual catches, trawl survey biomass indices and age/length compositions, the WCSI CPUE indices, and fishery length composition data. The model was implemented in Stock Synthesis and incorporated data from 1975–2018.

The model is considered to provide a reasonable approximation of the SKI 3/7 stock dynamics from the late 1980s to the early 2010s. The stock is likely to have been at a relatively low level throughout this period, at least relative to the level of stock abundance in the early 1980s. However, the fits to the recent (2016–2018) length compositions from the trawl surveys and commercial fisheries are poor, indicating considerable conflict with the recent abundance indices, especially the CPUE indices. The estimates of recent recruitments are very poorly determined by the model. More critically, the magnitude of these recent recruitment estimates is implausibly large in comparison to the time-series of recruitments from the earlier period of the model. Consequently, estimates of the recent increase in

stock biomass are not considered reliable and the results are not considered appropriate for management purposes, particularly the determination of current stock status. The report provides recommendations for further development of the modeling towards providing a more comprehensive stock assessment.

1 INTRODUCTION

Gemfish (*Rexea solandri*) in SKI 3 and SKI 7 are considered to represent a single biological stock (Horn & Hurst 1999, Hurst 1988, Hurst & Bagley 1998). Gemfish are caught in SKI 3 during spring–autumn, primarily as a bycatch of the Southland squid fishery (Baird 2015). These fish are thought to migrate northwards to spawn in waters off the West Coast South Island (SKI 7) during August–September (Hurst & Bagley 1998) and are caught in association of the hoki trawl fishery at that time (Baird 2015).

The southern (SKI 3 and SKI 7) gemfish fishery developed in the late 1970s and annual catches increased rapidly over the subsequent years to reach a peak of 8253 t in 1985/86 (SKI 3 5446 t and SKI 7 1468 t) (Fisheries New Zealand 2019). At the introduction to the QMS, TACCs for SKI 3 and SKI 7 were initially set at the magnitude of the catches taken during the early 1980s (Hurst & Bagley 1998). During the late 1980s and early 1990s, the TACC for SKI 3 (about 3300 t) was substantially under caught. Annual catches declined considerably during the early 1990s and the SKI 3 TACC was subsequently reduced to 300 t in 1997/98. The SKI 3 TACC has remained at that level over the intervening period, while annual catches remained very low until recent years.

Annual catches from SKI 7 also declined considerably during the late 1980s and early 1990s and the SKI 7 TACC was also reduced to 300 t in 1997/98 and maintained at that level over the subsequent years. Annual catches remained well below the TACC until 2002/03, exceeded the TACC in 2003/04 and 2004/05, and then remained at or below the level of the TACC until 2015/16 (FNZ 2019).

In 1998, a preliminary stock assessment model was developed for the southern gemfish stock, although the model did not provide reliable estimates of biomass, depletion and yields (Hurst & Bagley 1998). The high level of uncertainty in the estimates of stock status was partly attributed to the high degree of variability in annual recruitment (Hurst & Bagley 1998). The variability in recruitment in the 1980s and 1990s has been linked to the prevailing environmental conditions (Renwick et al. 1998).

The most recent review of the southern gemfish fishery included a characterisation of the SKI 3 and SKI 7 commercial fisheries (to 2012/13) (Baird 2015). The study also included an analysis of gemfish Catch Per Unit Effort (CPUE) indices from the west coast South Island (WCSI) trawl fisheries. However, the resultant CPUE indices were not accepted as indices of stock abundance by the Deepwater Stock Assessment Working Group.

In more recent years, annual catches from SKI 3 and SKI 7 have increased from low levels. For SKI 7, annual catches increased from 2015–16 and exceeded the TACC of 300 t in 2017–18 (by 94%). Similarly, annual catches from SKI 3 were well below the TACC of 300 t until 2017–18 when the catch exceeded the TACC by 55% (Fisheries New Zealand 2019). There was also a recent increase in the gemfish biomass indices from the *Tangaroa* WCSI trawl survey (O'Driscoll & Ballara 2019). These trends are considered indicative of a recent increase in the abundance of the southern gemfish stock, although there is limited information to indicate the magnitude of the recent increase or, more particularly, the current level of biomass relative to historical levels. Hence, a more comprehensive review of recent trends from the southern gemfish fishery was initiated.

This report summarises recent trends in the SKI 3 and SKI 7 fisheries, including an updated analysis of CPUE from the main SKI 7 fishery. The study also compiled the time series of gemfish length composition data from the commercial fisheries and trawl surveys. The trends in abundance indices (trawl survey and CPUE) and length composition were evaluated within the framework of an age structured population model. The study was funded by the SKI 3 and SKI 7 commercial stakeholders (through Southern Inshore Fisheries Management Company and Deepwater Group) in conjunction with Fisheries New Zealand.

2 FISHERY CHARACTERISATION

Commercial catch and effort data from the SKI 3 and SKI 7 fisheries (Figure 1) were sourced from the Fisheries New Zealand combined *Warehou* and EDW databases. The scope of the study encompassed the SKI 3 and SKI 7 Fishstocks and the data extract included the catch and effort data from any fishing trip that recorded a catch of gemfish from either Fishstock. The extract was supplemented by data from the three main fisheries that catch SKI 7, as previously defined by Baird (2015), specifically: 1) trawls (bottom or midwater) targeting hoki in Statistical Areas 034 and 035 during June–September, 2) bottom trawls targeting BAR, HOK, HAK, SKI, SQU or SWA in Statistical Areas 034 and 035 during May–September, and 3) bottom trawls targeting LIN, SKI or TAR in Statistical Areas 033 and 034 during October–June.

For the qualifying trips, all effort data records were sourced, regardless of whether or not gemfish was landed. The estimated catches and landed catch records of all other finfish species were also sourced for the qualifying fishing trips. Data were complete to the end of the 2017/18 fishing year.

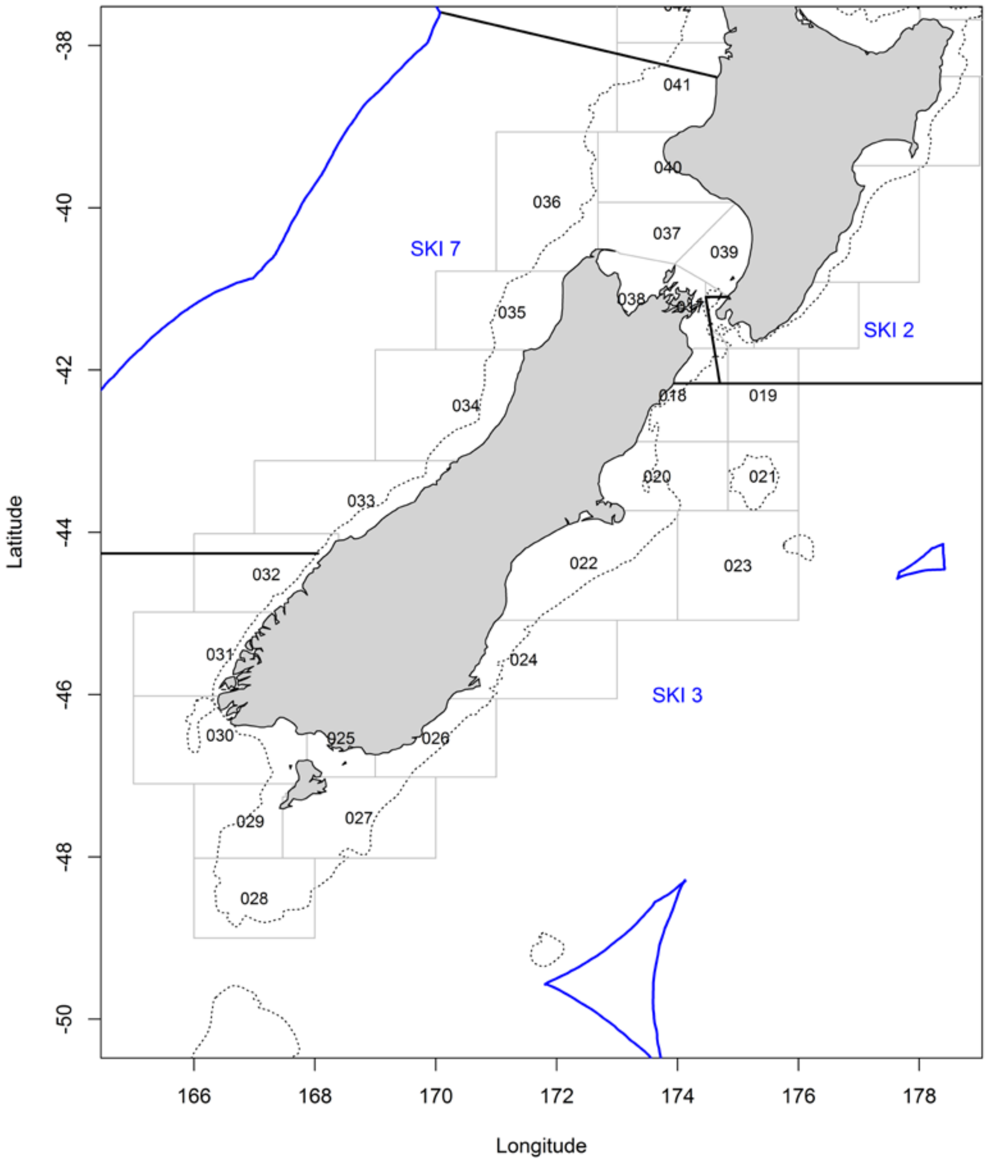

Figure 1: Map of SKI 3 and SKI 7 Fishstock areas and constituent inshore Statistical Areas. The dotted line represents the 200 m depth contour.

The catch and effort data sets were processed following the methodology described in Langley (2014). Two data sets were configured:

1) **Daily** aggregated catch and effort data set from 1989/90–2017/18. Gemfish catch and effort data were aggregated by vessel fishing day and fishing method to approximate the Catch Effort Landing Return (CELR) data format. The predominant Statistical Area and target species recorded during the fishing day were assigned to the daily aggregate record. For each trip, the landed catch of gemfish was apportioned amongst the daily fishing records in proportion to the estimated catches of gemfish (when included within the five main species caught in the day). Gemfish landed catches from trips without corresponding estimated catches were distributed amongst daily records in proportion to fishing effort (number of trawls).
2) **Trawl** based catch and effort data set from 1989/90–2017/18 derived from individual trawl records (reported via Trawl Catch Effort Processing Returns (TCEPR) and Trawl Catch Effort Returns (TCER) statutory forms or via the Electronic Reporting System). For each trip, the landed catch of gemfish was apportioned amongst the individual trawl records in proportion to the estimated catches of gemfish (amongst the top five species). Gemfish landed catches from trips without corresponding estimated catches were distributed equally amongst trawl records.

Total annual catches of SKI 3 and SKI 7 under the Quota Management System (QMS) are compiled from Monthly Harvest Returns (MHR) submitted by fishing permit holders (Fisheries New Zealand 2019). Since 1993/94, the total annual landed catches included in the SKI 3 and SKI 7 catch and effort data sets approximated the QMS annual catches (Figure 2 and Figure 3). Cumulative annual estimated catches associated with fishing effort data are considerably lower than the landed catches from both SKI 3 and SKI 7.

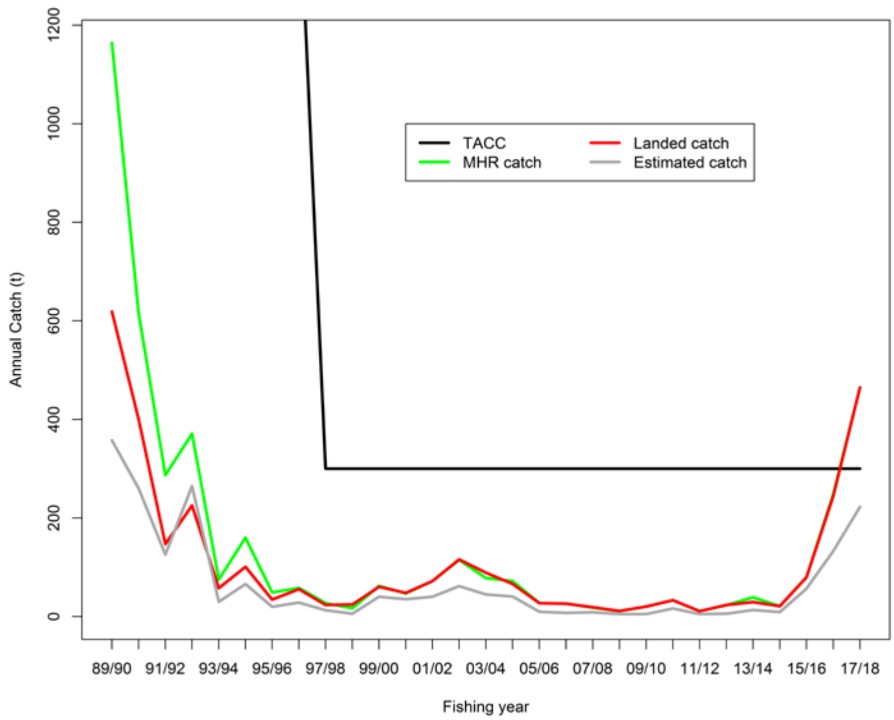

Figure 2: A comparison of total annual SKI 3 estimated and landed catches (t) by fishing year from the catch and effort returns and the total reported landings (t) to the QMS (MHR).

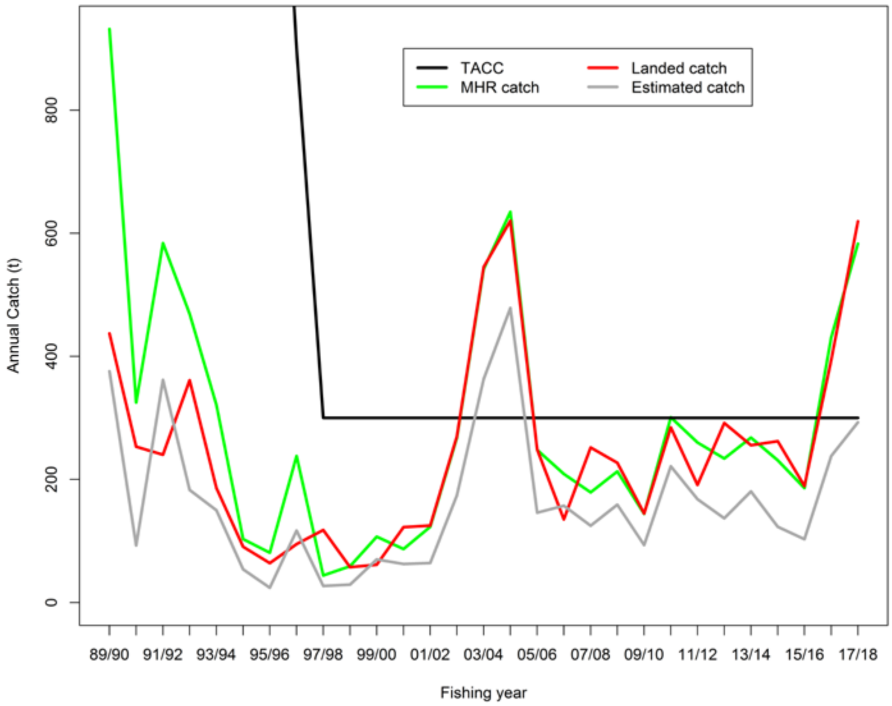

Figure 3: A comparison of total annual SKI 7 estimated and landed catches (t) by fishing year from the catch and effort returns and the total reported landings (t) to the QMS (MHR).

Annual catches from SKI 3 and SKI 7 have been primarily reported from inshore fleets via the CELR and TCER forms or from the deepwater trawl fleet via the TCEPR form. The Electronic Reporting System (ERS) was introduced to the deepwater trawl fleet in 2017/18 and accounted for a substantial proportion of the annual SKI 3 and SKI 7 catch (Figure 4).

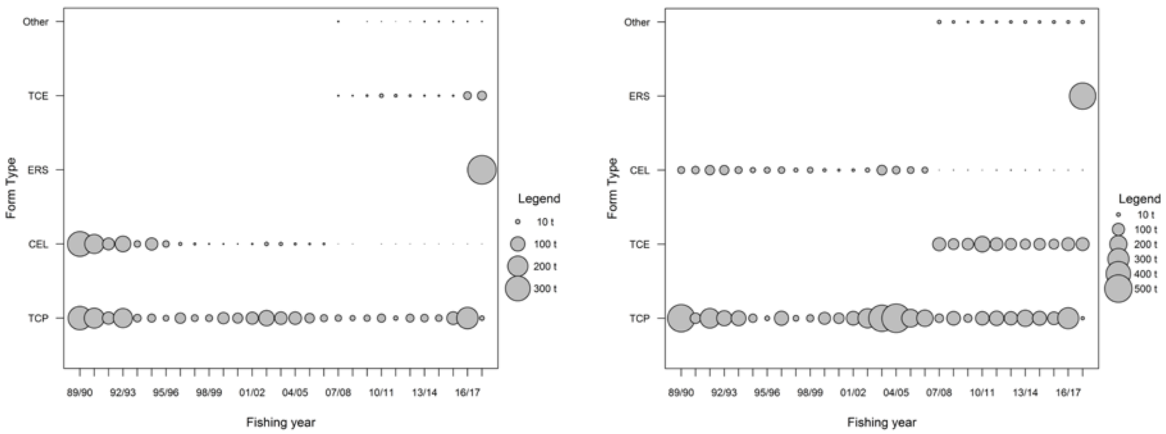

Figure 4. Annual catches of gemfish from SKI 3 (left panel) and SKI 7 (right panel) by reporting format (TCE, Trawl Catch Effort Return; CEL, Catch Effort Landing Return; TCP, Trawl Catch Effort Processing Return; ERS, Electronic Reporting System).

Gemfish catches from SKI 3 have been predominantly taken by bottom trawl gear. Catches were taken from a range of trawl fisheries, including a target trawl fishery that operated during the late 1980s – early 1990s. The recent increase in catch from SKI 3 was dominated by catches from the SQU 1T trawl fishery (Figure 5).

Annual catches from SKI 7 were dominated by the bycatch from the target hoki fishery, principally from bottom trawl gear. The remainder of the catch was distributed amongst the range of trawl fisheries operating within SKI 7, including a small gemfish target fishery (Figure 6).

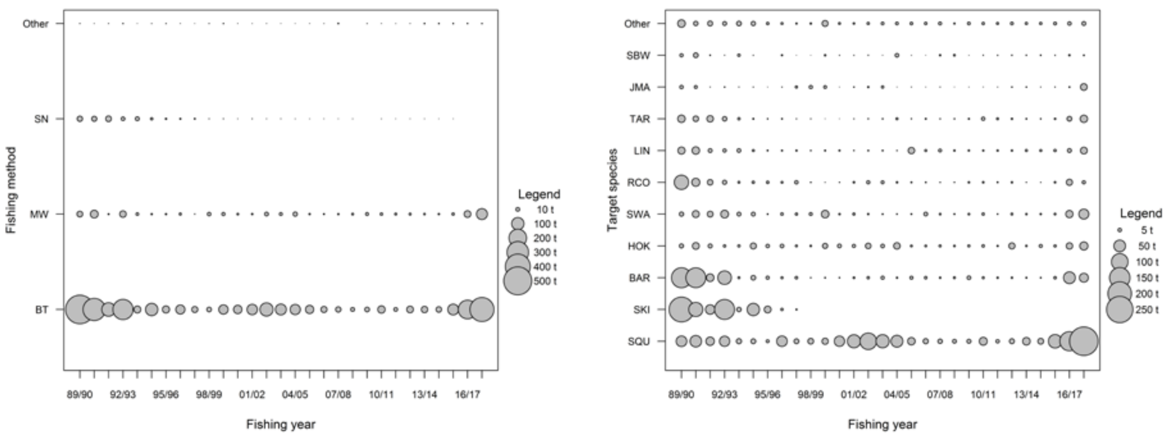

Figure 5: Annual landed catch of gemfish from SKI 3 by fishing method (left panel) and target species (right panel).

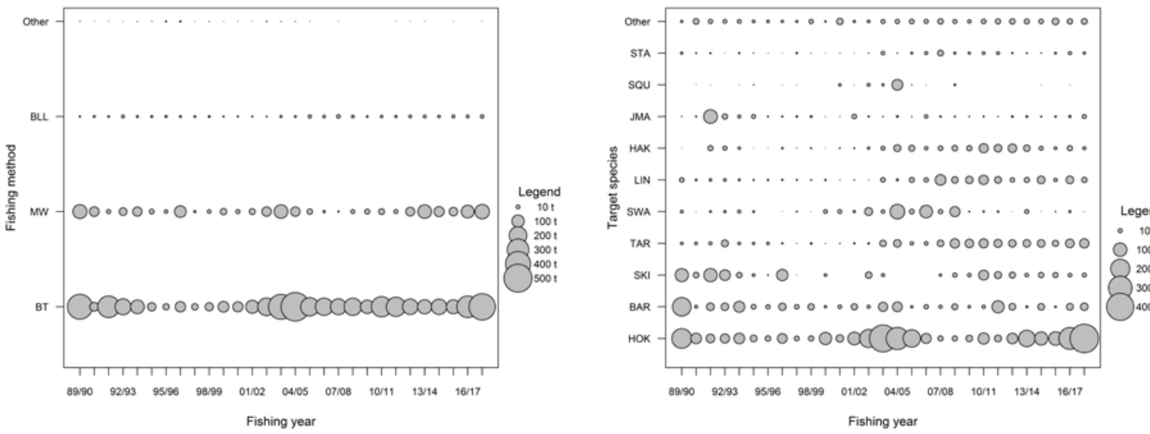

Figure 6: Annual landed catch of gemfish from SKI 7 by fishing method (left panel) and target species (right panel).

Most of the gemfish catch from SKI 3 was taken during summer (January–March), while catches from SKI 7 were predominantly taken during July–September (Figure 7).

Catches of gemfish from SKI 3 were predominantly taken around the Solander Corridor (Statistical Areas 030), the Stewart/Snares Shelf (028) and off Banks Peninsula (020 and 022) (Figure 8 and Figure 10). Most of the recent catch was taken by the squid trawl fishery within the 150–300 m depth range (Figure 9).

Catches from SKI 7 were predominantly taken off the northern west coast of the South Island (Statistical Areas 034 and 035) (Figure 8 and Figure 10). The hoki target trawl fishery predominantly catches gemfish within the 400–520 m depth range, while the other SKI 7 trawl fisheries (targeting TAR, BAR, LIN, or SKI) catch gemfish in shallower areas (130–370 m) (Figure 9).

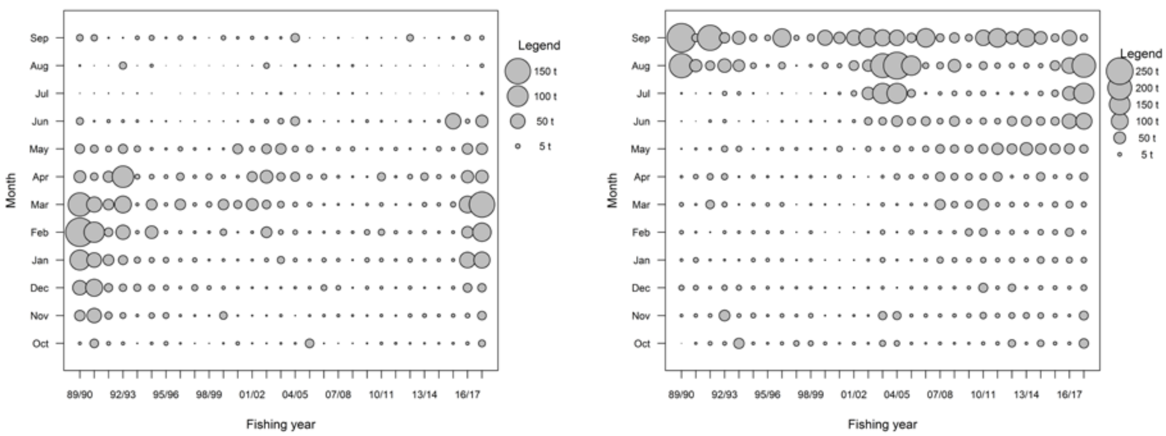

Figure 7: Annual landed catch of gemfish by month from SKI 3 (left panel) and SKI 7 (right panel).

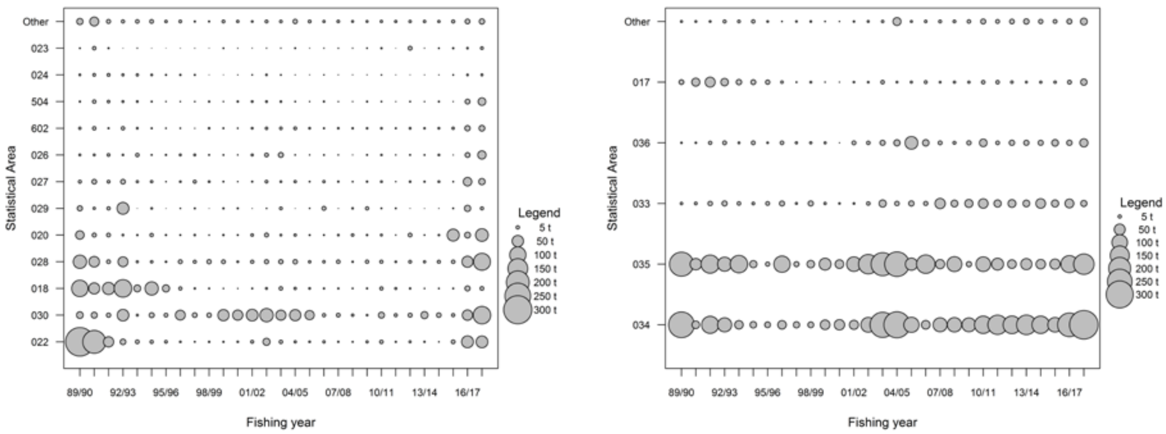

Figure 8: Annual landed catch of gemfish by Statistical Area from SKI 3 (left panel) and SKI 7 (right panel).

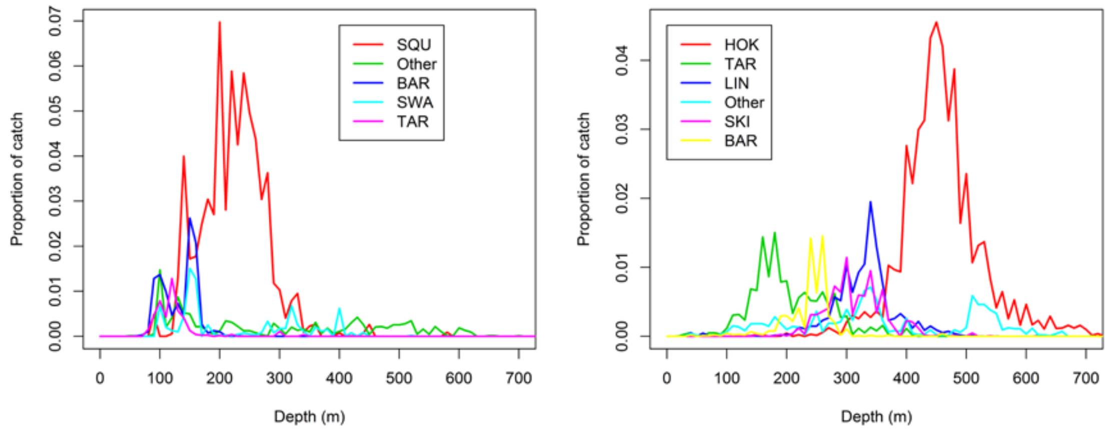

Figure 9: Depth (bottom) distribution of gemfish catch from SKI 3 (left panel) and SKI 7 (right panel) by target species from 2008/09–2017/18.

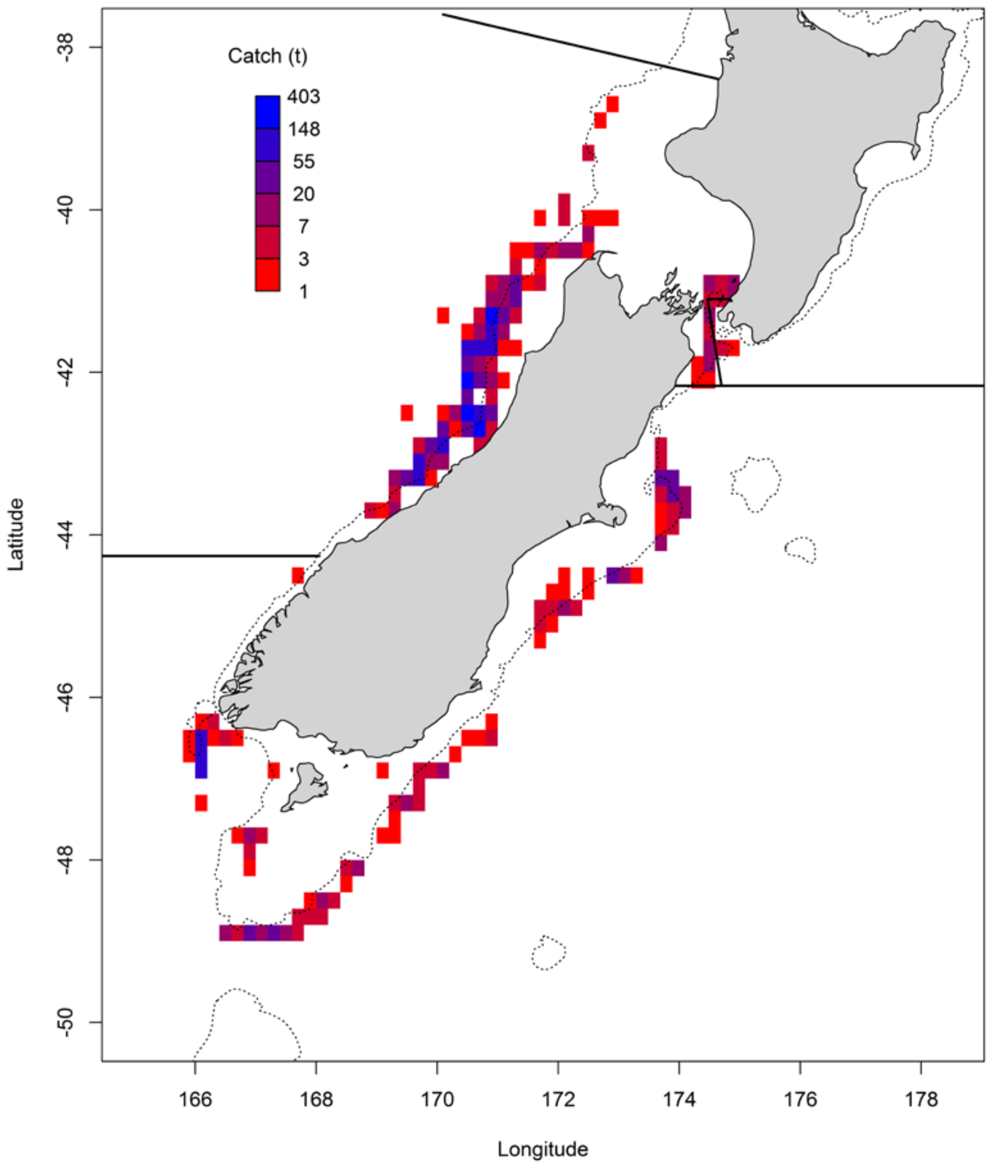

Figure 10: Total SKI 3 and SKI 7 gemfish trawl catch by 0.2 degree latitude/longitude, aggregated for 2008/09–2017/18 (logarithmic scale). The dashed line represents the 200 m depth contour.

3 CPUE ANALYSIS

The fishery characterisation identified that the WCSI hoki trawl fishery accounted for a substantial proportion of the total SKI 3 and SKI 7 gemfish catch during the 1989/90–2017/18 fishing years (typically 30–40% per annum). An examination of the length composition data from the fishery revealed that catches are comprised of a broad length range, including the mature portion of the stock (i.e. fish larger than about 70 cm fork length). Thus, the fishery was identified as the primary candidate for a more detailed analysis of catch and effort data, including the derivation of CPUE indices.

The initial data set was selected from the *trawl* data set (BT or MW gear) based on target species (HOK), location (WCSI, Statistical Areas 034 and 035) and fishing season (July–September). This data set was further restricted to trawls that occurred within the main depth range of gemfish catches (250–600 m) (Table 1).

Gemfish are more prevalent in the catches from the hoki fishery towards the end of the fishing season (from late August), corresponding to the main spawning period for gemfish (Fisheries New Zealand 2019). Trawl records were restricted to this period to ensure more consistent coverage of the adult portion of the stock (Table 1). These catches are predominantly taken in the northern area of the hoki fishery, i.e., north of the Hokitika Canyon.

Members of the Deepwater Working Group expressed some concern regarding the reliability of the reporting of the catches of gemfish by foreign charter vessels prior to the mid 2000s. On that basis, the data set was further restricted to domestic (New Zealand registered) vessels only (Table 1). Limited records were available from the domestic fleet prior to 1994/95 and, hence, the data set was further restricted to the subsequent period. Further selection criteria were applied to restrict the fleet to vessels that had operated in the fishery for at least five years (representing a core fleet of 23 vessels).

A subset of fishing trips were identified that landed gemfish but did not report an estimated catch of the species. For those trips, the data processing scheme apportioned the landed catch equally amongst all the associated fishing event records, generating numerous, small trawl catches of gemfish. Most of these records are likely to represent erroneous (“false positive”) catches. These records represented 12% of the trawl records in the qualifying data set (Table 1), predominantly from 1996/97–2001/02. These records were excluded from the final data set.

The final data set includes a small proportion of the total number of trawls from the WCSI hoki fishery, primarily due to the fishing season and fleet selection criteria. This limited the data set to about 150–300 trawls per annum, representing 2.2% of the trawl records from the initial data set and 19.5% of the total gemfish catch (Table 1).

Table 1: A summary of the selection criteria applied to derive the final data set for the standardised CPUE analysis.

		Trawls		SKI catch	
Criterion		**Number**	**Percent**	**Tonnes**	**Percent**
	Initial data set	139 841	100.0%	2 476.1	100.0%
1	Trawl bottom depth range 250–600m	125 503	89.7%	2 415.0	97.5%
2	Season day > 20 August	30 114	21.5%	1 356.7	54.8%
3	Latitude > -42.5 S	20 439	14.6%	1 268.7	51.2%
4	Vessel flag NZL	8 864	6.3%	722.9	29.2%
5	Fishing year >= 1994/95	8 204	5.9%	686.0	27.7%
6	Core Vessels	3 490	2.5%	488.6	19.7%
7	Catch allocation flag != 2	3 077	2.2%	482.7	19.5%

The final CPUE data set was further restricted to the 1996/97–2017/18 fishing years (Figure 11) as there were limited qualifying trawls by the core vessels during 1994/95 and 1995/96.

Annual catches of gemfish included in the final data set varied considerably amongst years with higher catches during 2003/04–2005/06 and 2013/14–2017/18 (Figure 11 and Appendix 1). In most years, a high (approximately 80%) proportion of trawls had no associated catch of gemfish (zero catch), although gemfish was caught in a substantially higher proportion of trawls in 2003/04–2005/06 and 2016/17–2017/18 (Figure 11).

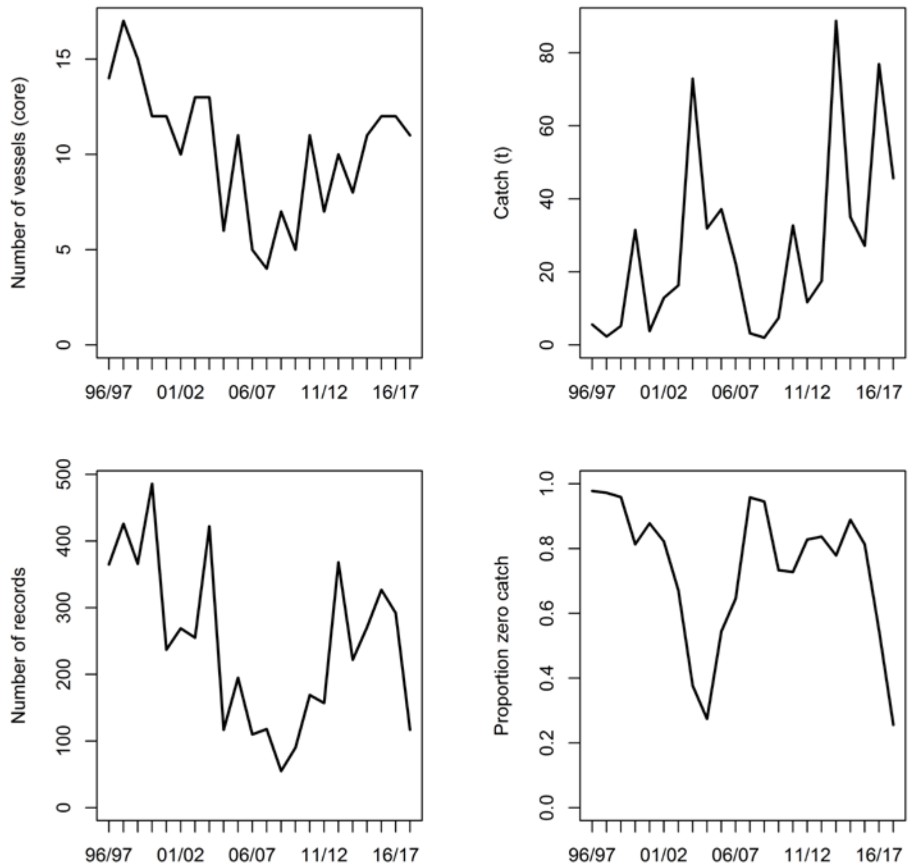

Figure 11: Summary of gemfish catch and effort records included in the final CPUE data set.

There was considerable inter-annual variability in distribution of the trawl records included in the final data set, with respect to fishing depth, location, fishing date and trawl duration (Figure 12). These changes are related to substantial changes in the operation of the WCSI hoki fishery during the study period.

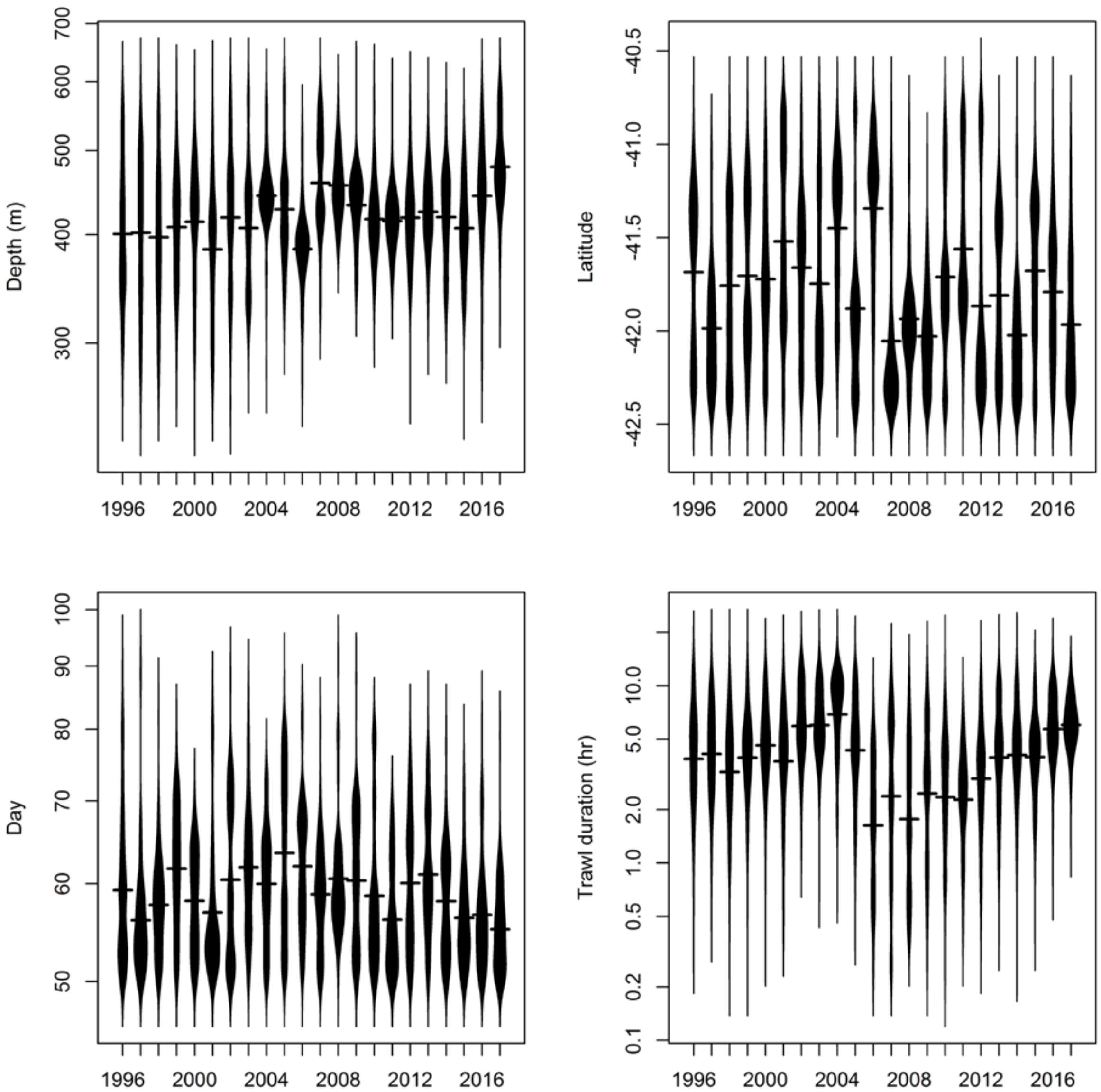

Figure 12: Beanplots of the distribution of key variables included in the CPUE data set by fishing year. The Day variable represents the day of the fishing season (from 1 July).

A Generalised Linear Modelling (GLM) approach was used to separately model the occurrence of gemfish catches (presence/absence) and the magnitude of positive gemfish catches. The dependent variable of the catch magnitude CPUE models was the natural logarithm of catch. For the positive catch CPUE models, a lognormal error structure was adopted, although alternative distributions (Weibull, Gamma) were also investigated.

A step-wise fitting procedure was implemented to configure each of the CPUE models. The fitting procedure considered the range of potential explanatory variables (Table 2) with the continuous variables parameterised as a third order polynomial function. The categorical variable *FishingYear* was included in the initial model and subsequent variables were included in the model based on the improvement in the AIC. Additional variables were included in the model until the improvement in the Nagelkerke pseudo-R^2 was less than 0.5%.

Table 2: The variables included in the CPUE data set.

Variable	Definition	Data type
Vessel	Fishing vessel	Categorical
FishingYear	Fishing year	Categorical
SeasonDay	Day of the season	Continuous
Latitude	Latitude at the start of the trawl	Continuous
Gear	Trawl gear type (BT, MB, MW)	Categorical (3)
Duration	Natural logarithm of trawl duration (hours)	Continuous
BottomDepth	Fishing depth (m)	Continuous
StartTime	Hour at the start of trawl	Continuous
Speed	Trawl speed (knots)	Continuous
GearWidth	Wingspread of trawl gear (m)	Continuous
GearHeight	Headline height of trawl gear (m)	Continuous
SKIcatch	Scaled estimated SKI trawl catch (kg)	Continuous
SKIbin	Presence (1) or absence (0) of SKI catch in trawl	Categorical

The influence of each of the main variables in the CPUE models was examined following the approach of Bentley et al. (2011). The final (combined) CPUE indices were determined from the product of the positive catch CPUE indices and the binomial indices following the approach of Stefansson (1996). The confidence intervals associated with the combined indices were determined using a bootstrapping approach.

The main predictor variables included in the positive catch CPUE model were *FishingYear*, *Gear*, *Vessel*, and *SeasonDay,* while additional variables were included related to the specifics of the fishing activity (*Duration, StartTime, BottomDepth, Latitude, Speed, GearWidth and GearHeight*) (Table 3). Overall, the model explained 47.9% of the variation in the positive catch of gemfish (Nagelkerke pseudo-R^2), with the *FishingYear* variable accounting for 17.5% of the total variation. The distribution of the CPUE model residuals is generally consistent with the assumption of normality (Figure 13).

Table 3: Summary of stepwise selection of variables in the positive catch CPUE model. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Term	**DF**	**Log likelihood**	**AIC**	**Nagelkerke pseudo-R^2 (% Improvement)**
intercept	1	-2 143	4 290	
FishingYear	21	-2 024	4 094	0.175 *
Gear	2	-1 952	3 953	0.267 *
Vessel	19	-1 843	3 774	0.386 *
SeasonDay	3	-1 817	3 728	0.412 *
Duration	3	-1 803	3 707	0.425 *
StartTime	3	-1 790	3 686	0.438 *
BottomDepth	3	-1 775	3 661	0.452 *
Latitude	3	-1 765	3 648	0.460 *
Speed	3	-1 758	3 640	0.467 *
GearWidth	3	-1 752	3 633	0.472 *
GearHeight	3	-1 745	3 625	0.479 *

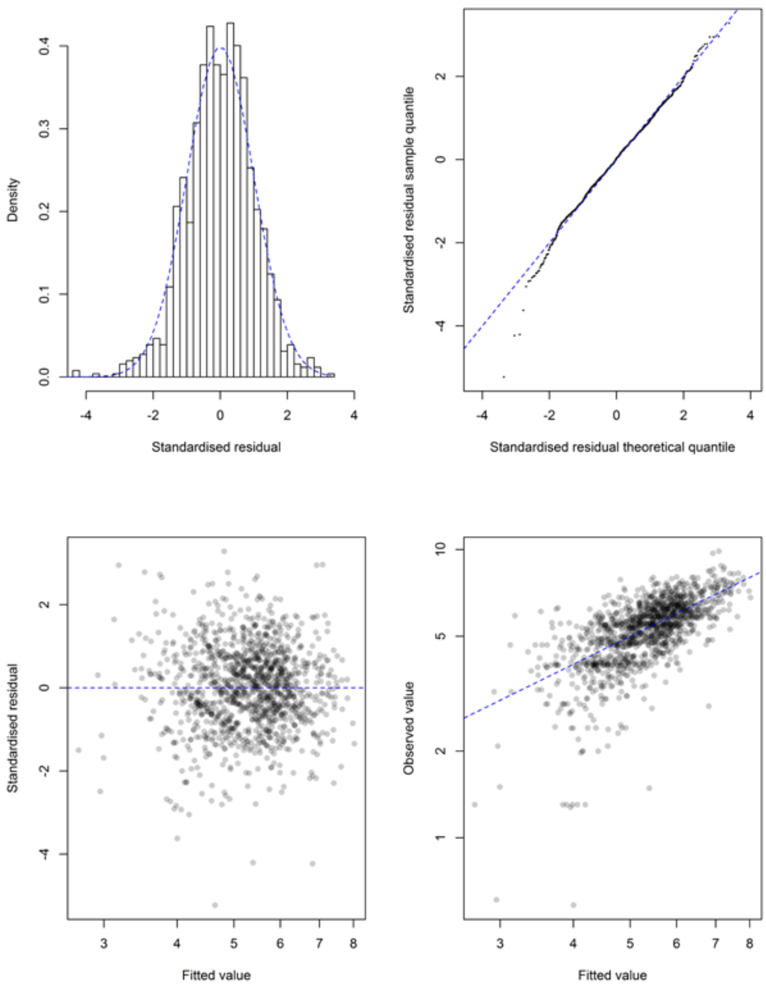

Figure 13: Residual diagnostics for the positive catch CPUE model. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

The lognormal CPUE indices are low for 1996/97–2004/05 (Figure 14). The indices generally increase from 2004/05 to 2017/18 with higher CPUE indices from 2007/08–2008/09 and 2013/14–2014/15. The lognormal CPUE indices are relatively imprecise, particularly for the two periods with higher CPUE. The time-series of CPUE indices is comparable to the unstandardised catch rate (geometric average) of gemfish, although the inter-annual variability in the standardised indices is lower during 2009/10–2017/18, primarily due to the inclusion of the *Vessel* variable within the model (Figure 15). The other main variables included in the model did not appreciably influence the annual indices.

The occurrence of gemfish in trawl catches was predicted by the binomial model which included the main explanatory variables *FishingYear, SeasonDay*, *BottomDepth*, *Vessel* and *Latitude* (Table 4). *FishingYear* accounted for a high proportion (64%) of the variation explained by the model. The annual indices derived from the binomial model were comparable to the annual proportion of positive catch records. The binomial indices varied considerably over the study period with a substantially higher probability of catching gemfish during 2002/03–2005/06 and 2016/17–2017/18 (Figure 14). The probability of catching gemfish was low in 2007/08–2008/09 (while the lognormal CPUE indices were high for those years).

The final (delta-lognormal) CPUE indices combine the two sets of quite disparate indices from the lognormal and binomial models. The combined CPUE indices are very low during 1996/97–2002/03 and then increase in 2003/04 due to the increase in the binomial indices (Figure 14). The combined indices remain relatively stable during 2003/04–2015/16 and then increase substantially in 2016/17–2017/18 (by approximately 300%) following the increase in the binomial CPUE indices. Overall, the precision of the combined CPUE indices is relatively low with coefficients of variation of 30–40% for most years.

Table 4: Summary of stepwise selection of variables in the catch occurrence CPUE model (binomial model). Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Term	DF	Log likelihood	AIC	Nagelkerke pseudo-R^2 (% Improvement)
intercept	1	-2 975	5 951	
FishingYear	21	-2 376	4 795	0.297 *
SeasonDay	3	-2 236	4 523	0.358 *
BottomDepth	3	-2 152	4 359	0.393 *
Vessel	22	-2 075	4 251	0.424 *
Latitude	3	-2 028	4 162	0.442 *
StartTime	3	-1 994	4 101	0.455 *
Duration	3	-1 978	4 075	0.461 *
Gear	2	-1 965	4 051	0.467 *

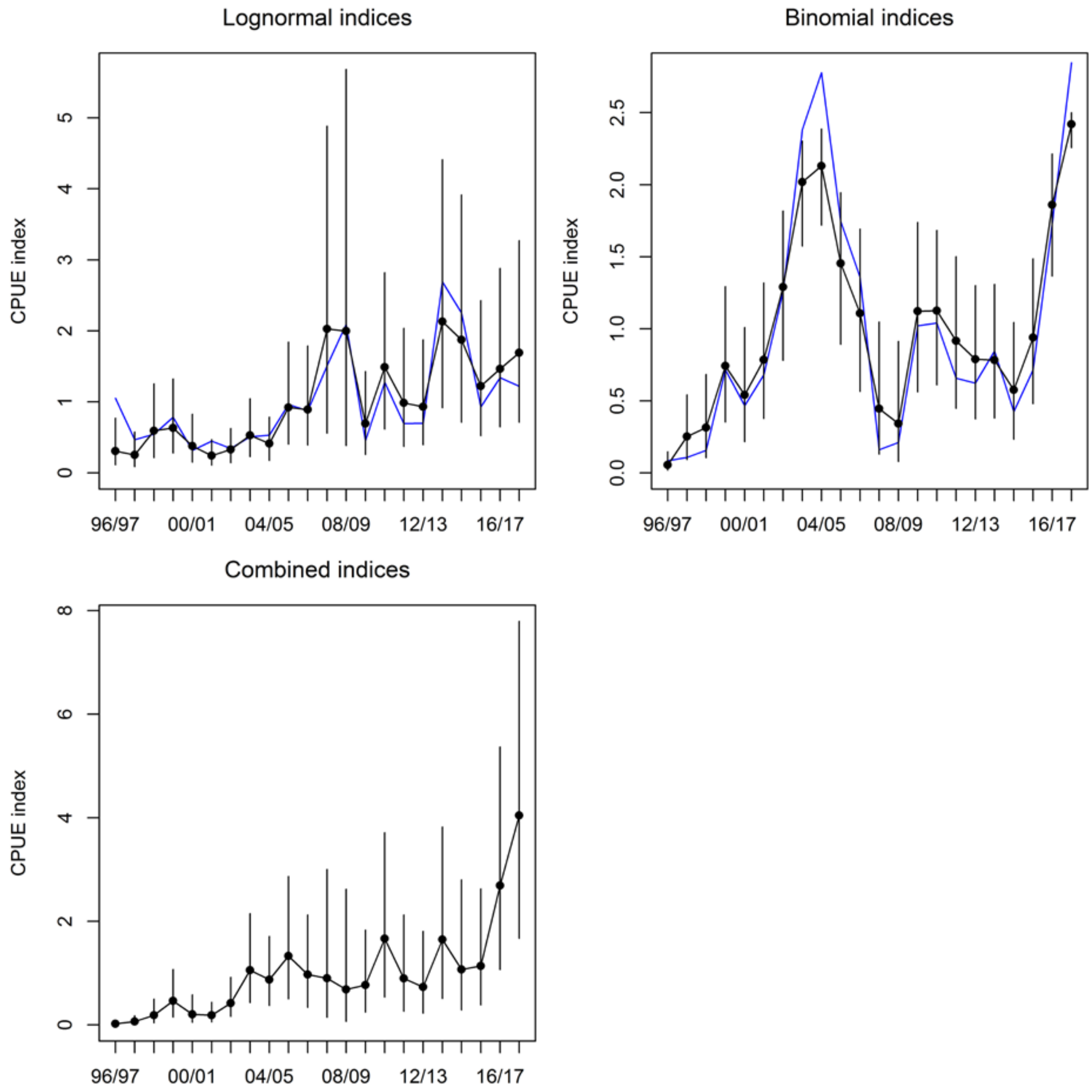

Figure 14: A comparison of the standardised CPUE indices and the normalised geometric mean of the annual catch per trawl (blue line) (top left panel), a comparison of the binomial indices and the normalised annual proportion of positive catch records (blue line) in the data set (top right panel) and the combined index (bottom panel) . The error bars represent the 95% confidence intervals associated with each index. The annual indices are provided in Table A2 (Appendix 1).

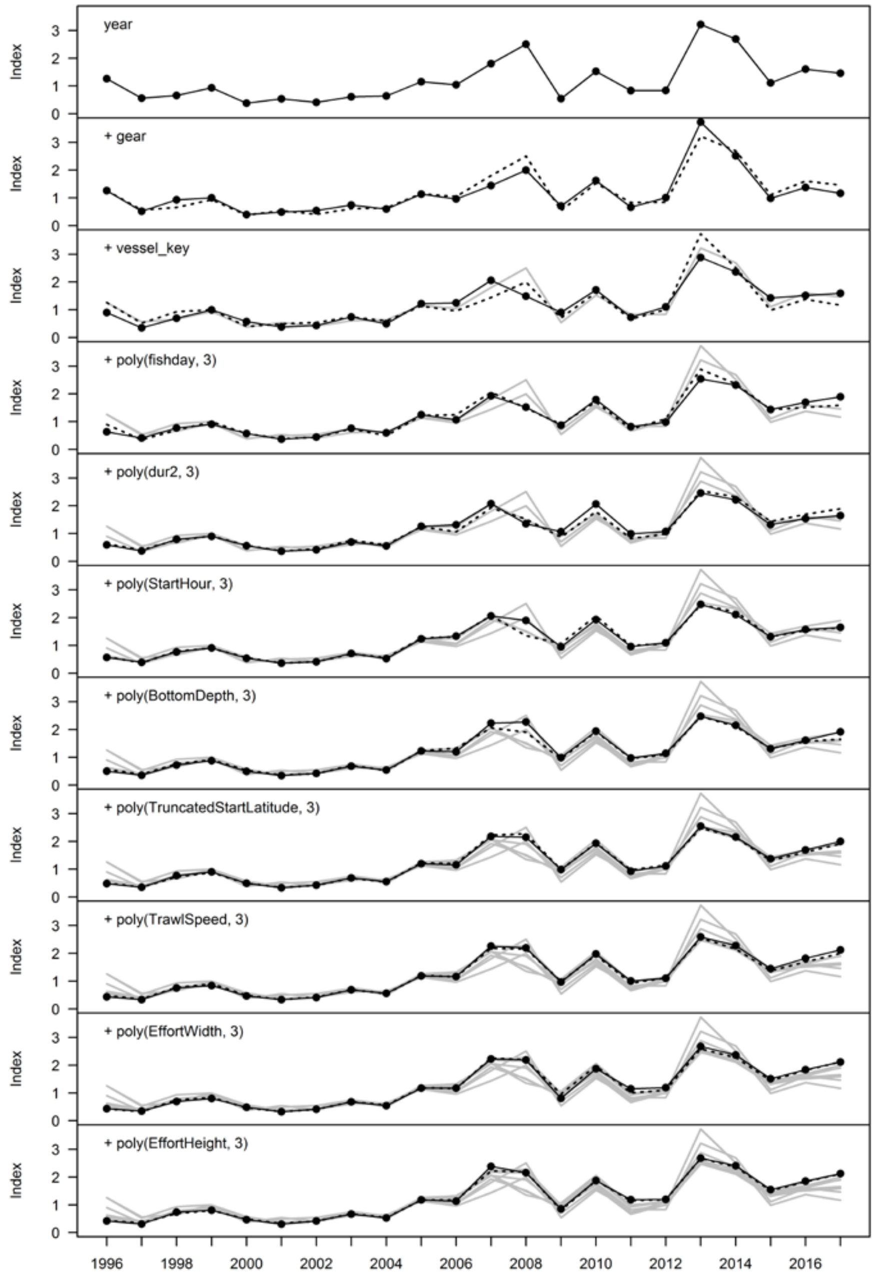

Figure 15: The change in the annual coefficients with the step-wise inclusion of each of the significant variables in the positive catch CPUE model (from top to bottom panel). The solid line and points represent the annual coefficients at each stage. The fishing year is denoted by the calendar year at the beginning of the fishing year (e.g. 1996 denotes the 1996/97 fishing year).

4 TRAWL SURVEYS

The relative abundance of gemfish in the Southland area (SKI 3) was monitored by trawl surveys conducted by *Shinkai Maru* (early 1980s) and *Tangaroa* (early 1990s) (Hurst & Bagley 1997). Since the early 1990s, a regular series of inshore trawl survey off the west coast South Island (SKI 7) has been conducted by *Kaharoa* during April–May (Stevenson & Hanchet 2000, Stevenson & MacGibbon 2018). The survey area encompasses the 20–400 m depth range (south of Cape Foulwind). Juvenile (age 0+ and 1+) gemfish are predominantly distributed within 200–400 m depth and the WCSI area appears to represent a main nursery area for gemfish in SKI 3 and 7 (Hurst et al. 2000). Gemfish is not considered to be a target species for the survey, although the consistency in the length composition and biomass estimates from the time-series of survey indicates that the survey is adequately monitoring the relative abundance of juvenile gemfish in the area.

The recent series of *Tangaroa* west coast South Island trawl surveys encompasses the 200–800 m depth range (O'Driscoll & Ballara 2019), overlapping the main spatial distribution of gemfish. The surveys were conducted during late July–early August, prior to the period considered to represent the main spawning period for gemfish (late August–September). The survey samples both juvenile and adult gemfish, although it is difficult to evaluate the utility of the survey for monitoring the gemfish stock because of the limited number of surveys completed to date (four).

From 2015/16, the biomass estimates for gemfish from the two sets of trawl surveys increased considerably (Figure 16), corresponding to the presence of strong length modes of small gemfish in the 2017 *Kaharoa* trawl survey and 2016 and 2018 *Tangaroa* trawl surveys (Figure 17).

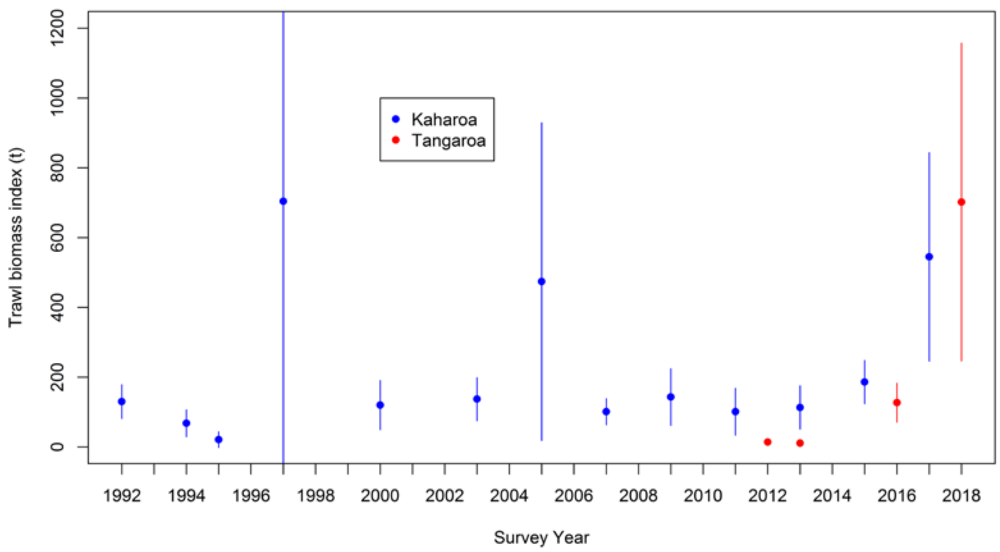

Figure 16: Trawl survey biomass indices (and 95% confidence intervals) from the time-series of west coast South Island *Kaharoa* and *Tangaroa* trawl surveys.

There is a general correspondence between the modal structure of the individual compositions and the mean length-at-age derived from the established growth function for SKI 3 (Horn & Hurst 1999) and an assumed "birthday" around August–September. The strong mode at about 42 cm in the length composition from the 2016 *Tangaroa* trawl survey probably represents the 2014 year class at two years of age (Figure 17). This year class is evident in the length composition of the 2017 *Kaharoa* trawl survey (age 2+ yr, length mode 50 cm) and in the 2018 *Tangaroa* trawl survey (age 4 yr, 60 cm length mode). The length composition of the 2017 *Kaharoa* trawl survey also indicates the presence of a strong mode at about 35 cm (FL) which is likely to represent the 2015 year class (sampled at age 1+ yr). This year class also appears to be present (at age 3 yr, about 50 cm) in the 2018 *Tangaroa* trawl survey length composition (Figure 17). A further strong length mode is evident in the 2018

Tangaroa trawl survey length composition at about 40 cm, assumed to represent the 2016 year class at age 2 yr.

Corresponding length compositions are also available from the Observer sampling of commercial catches of gemfish from the summer squid trawl fishery and the WCSI hoki fishery. The modal structure of the length composition from the 2018 squid fishery is comparable to the multi-modal structure of the 2018 *Tangaroa* trawl survey length composition, while the strong 2014 year class was also evident in the length composition from the 2017 squid fishery (Figure 17). The 2014 year class is present in the successive length compositions of gemfish sampled from the WCSI hoki fishery during 2016–2018 (length modes at about 40 cm, 52 cm and 62 cm, respectively). However, the younger year classes (2015 and 2016) were not present in the samples from the 2018 hoki fishery (Figure 17).

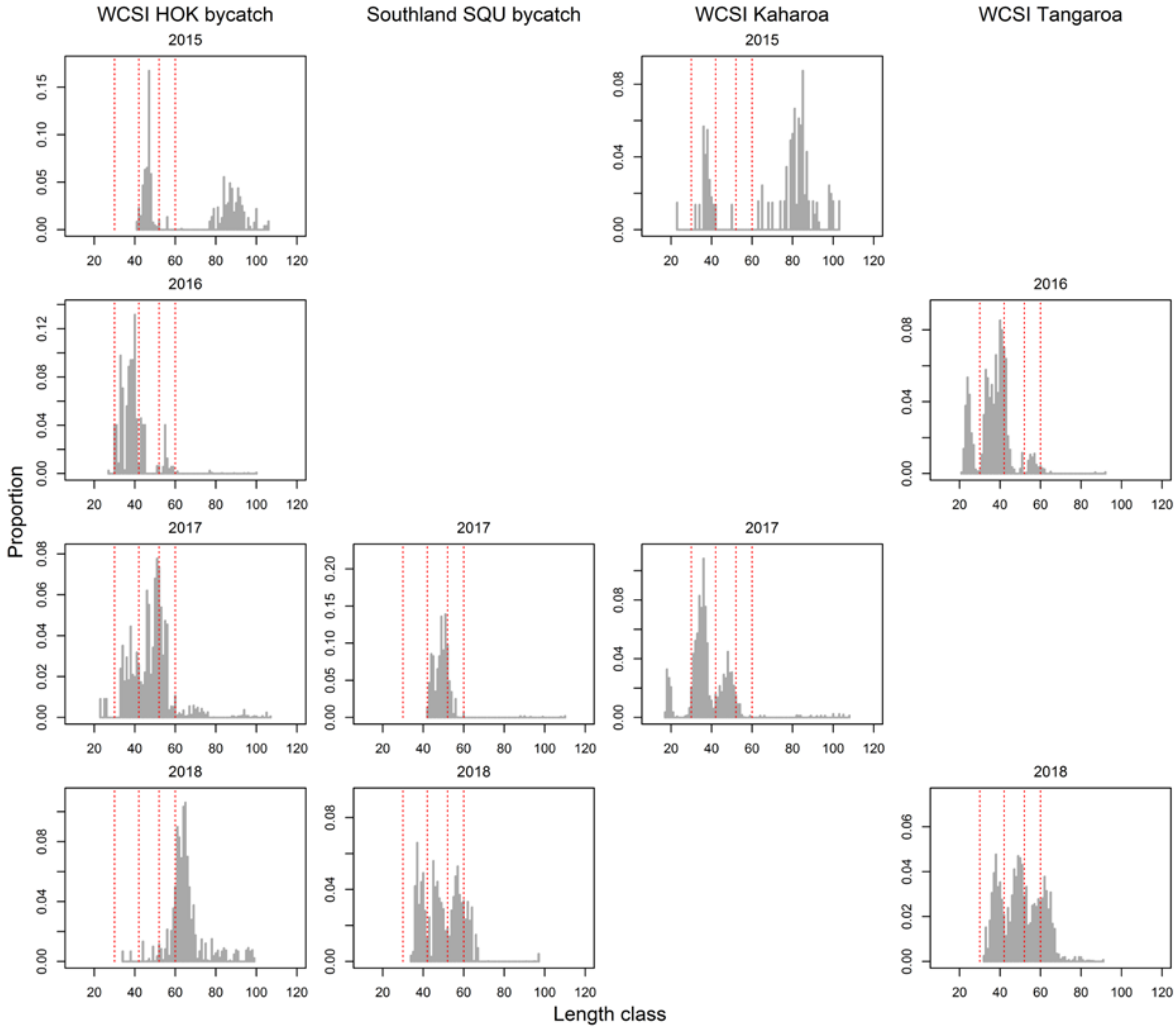

Figure 17: Length compositions of gemfish from the main commercial fisheries within SKI 3 and SKI 7 and the two WCSI trawl surveys from 2015 to 2018 (the year corresponds to the end of the fishing year, 2015 represents the 2014/15 fishing year). The vertical red lines represent the mean length-at-age of 1, 2, 3 and 4 year old fish from the established growth function (corresponding to 30, 42, 52 and 60 cm FL).

5 EXPLORATORY MODELLING

Gemfish in the SKI 3 and SKI 7 Fishstocks are assumed to represent a single biological stock (Fisheries New Zealand 2019 and Hurst & Bagley 1998). Previous assessment modelling of SKI 3/7 was conducted by Hurst & Bagley (1998), primarily based on the time-series of Southland trawl surveys. Since then, considerably more data have been collected from the gemfish fisheries by the Observer Programme and from the two sets of WCSI trawl surveys. In addition, this study has derived a time-series of CPUE indices from the main SKI 7 commercial fishery. An age structured population model provides a framework to evaluate the coherence among the trends in abundance and length/age composition from the range of data sets.

An exploratory model was configured integrating annual catches, trawl survey biomass indices and age/length compositions, the WCSI CPUE indices, and fishery length composition data. The model was implemented in Stock Synthesis (version V3.30.12), a flexible platform for implementing statistical, age structured population models (Methot & Wetzel 2013, Methot et al. 2019). The results of the modelling provide an opportunity to review the utility of the individual data sets and provide recommendations for developing a formal assessment for the SKI 3/7 stock. The results of the exploratory model are not intended to provide management advice regarding current stock status.

5.1 Commercial catch

Commercial catch data are available for the SKI 3 and SKI 7 fisheries from 1931 to the 2017/18 fishing year. The time-series of annual reported commercial catches were derived from Fisheries New Zealand (2019). Prior to 1975, annual catches from the fishery were negligible and were not included in the model.

The model data set was configured to include two fisheries based on the separate Fishstocks (SKI 3 and SKI 7). From the late 1980s, the catches from these fisheries were dominated by the bycatch of the Southland squid trawl fishery (SKI 3) and the bycatch of the WCSI hoki fishery (SKI 7).

The reported commercial catches from 1975–1986 were increased by 20% to account for an assumed level of under-reporting. Since the introduction of the Quota Management System (QMS), the accuracy of the reporting of commercial catches has improved considerably, although a degree of under-reporting may persist. For 1987–2018, reported catches were increased by 10% to account for a lower level of under-reporting in the more recent period. These assumptions are consistent with the formulation of the commercial catch histories incorporated in inshore finfish stock assessments (based on assumptions for SNA 1 made according to quota appeals when the QMS was first introduced) and may not be as relevant for the deepwater trawl fleet.

The SKI 3 and SKI 7 fisheries developed in the late 1970s and annual catches increased considerably to reach a peak in 1985/86, dominated by the catch from the SKI 3 Fishstock (Figure 18). The annual catches dropped markedly in 1986/87 and annual catches for both SKI 3 and SKI 7 continued to decline during the late 1980s and early 1990s. Annual catches remained at a low level over the subsequent years, with the exception of a small increase in catch from SKI 7 in 2003/04–2004/05 and a recent increase in catches from SKI 3 and SKI 7 (Figure 18).

There is no appreciable recreational or customary catch of gemfish in SKI 3 or SKI 7.

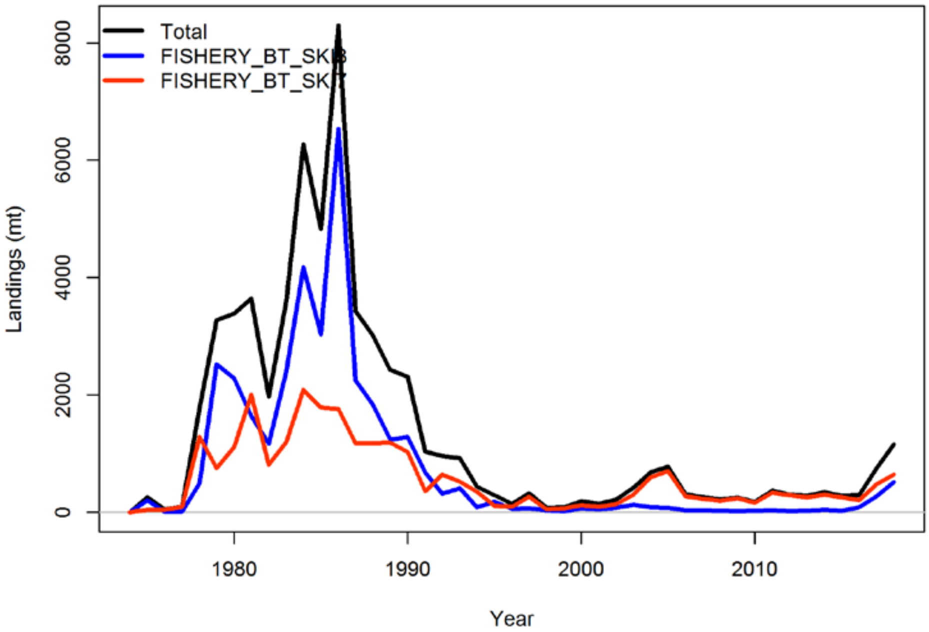

Figure 18: Annual catches from SKI 3 and SKI 7, including an allowance for unreported catches.

5.2 Trawl survey biomass indices and compositional data

The previous assessment modelling of SKI 3/7 assumed that the Southland trawl surveys conducted by *Shinkai Maru* (1981–1983) and *Tangaroa* (1993–1996) yielded biomass indices that were *"as comparable as possible in the absence of data on relative catching efficiency of the two vessels"* (Hurst & Bagley 1998). There was a decline of approximately 85% between the two sets of biomass estimates, while annual catches from SKI 3 declined by a similar amount (90%) during the same period. This suggests that most of the difference between the two sets of biomass indices could be attributable to a decline in stock abundance during the intervening years. Therefore, the exploratory model was configured to link the two sets of Southland trawl surveys (with an equivalent catchability coefficient), thereby increasing the influence of the time-series of trawl survey biomass estimates in the model. The influence of this assumption was evident when comparing the difference in the biomass trajectory from an alternative model option which included the two sets of trawl surveys as separate sets of abundance indices.

Age compositions were available from the four *Tangaroa* Southland trawl surveys conducted in 1993–1996 (Hurst & Bagley 1998). These data are considered to represent a key set of observations in the exploratory model; the age compositions were sampled randomly from the population and exhibit consistent patterns in the age structure from successive surveys. The observations were assigned a high relative weighting in the model (ESS 50) to ensure that the model adequately fitted these data. The formulation of the model selectivity function for the Southland trawl surveys assumed that the largest fish were fully available to the survey.

The model incorporated the abundance indices and length compositions from the two series of WCSI trawl surveys (*Kaharoa* and *Tangaroa*) described in Section 4. For each survey observation, the standard error of the index was equivalent to the native coefficient of variation (CV) of the survey biomass estimate. Scaled length compositions (both sexes combined) were available from the time-series of *Tangaroa* (R. O'Driscoll, NIWA) and *Kaharoa* (D. MacGibbon, NIWA) trawl surveys.

Table 5. Summary of input data sets for the southern gemfish population model. The relative weighting includes the Effective Sample Size (ESS) of age/length composition data and the coefficient of variation (CV) associated with the abundance data.

Data set	Model year(s)	N_{obs}	Relative weighting
WCSI CPUE indices	1997–2018	22	CV 50%
WCSI commercial LF	1987–89, 1991–96, 1999–2006, 2009, 2011–14, 2015–18	25	ESS 10
Southland commercial LF	1991–96, 2002–06, 2011, 2017, 2018	14	ESS 10
WCSI *Tangaroa* trawl survey indices and LF	2012, 2013, 2016, 2018	4	CV 23–43% ESS 1–20
WCSI *Kaharoa* trawl survey indices and LF	1992, 1994, 1995, 1997, 2000, 2003, 2005, 2007, 2009, 2011, 2013, 2016, 2018	13	CV 17–83% ESS 1–30
Southland *Tangaroa* trawl survey indices and age comp	1993–1996	4	CV 17–25% ESS 50
Southland *Shinkai* trawl survey indices	1981–1983	3	CV 17–33%

5.3 CPUE Indices

The CPUE indices derived in this study (Section 3) were incorporated in the exploratory model. The indices represented the relative abundance of the vulnerable biomass of the SKI 7 fishery (i.e., the bycatch of the hoki fishery). The model selectivity function assumed that all large gemfish were fully available to the fishery.

Initial model fits revealed a poor fit to the individual CPUE indices consistent with the relatively high standard error associated with the individual indices (CV 30–40%). An overall CV of 50% was assumed for the entire time-series. This level of variance enabled the model to fit the general trend in the CPUE indices in conjunction with the other data sets.

5.4 Commercial length composition data

The Observer Programme has sampled the gemfish catches from the squid trawl fishery (SKI 3) and hoki trawl fishery (SKI 7) over the last three decades (Appendix 2, Table A4). Overall, a relatively small number of trawls were sampled each year, representing a small proportion of the total gemfish catch from the fishery. For each fishery, annual length compositions (both sexes combined) were derived for years with at least 100 fish measured. Samples from individual trawls were combined in proportion to the gemfish catch in the sampled trawl.

In general, the annual length compositions reveal distinct cohorts that are present in both fisheries and persist over subsequent years. For example, the 2001 year class dominated the 2002 length compositions from the two fisheries and was apparent as a strong mode in the 2003–06 length compositions.

The individual fishery length compositions were assigned a moderate weighting (ESS 10) within the exploratory model.

5.5 Model Configuration

The model incorporated total annual SKI 3 and SKI 7 catches from 1975 to 2017/18 (Section 5.1) and the abundance indices from four sets of trawl surveys and the WCSI CPUE indices (Table 5). Age compositions were available from the *Tangaroa* Southland surveys (4 surveys 1993–1996) and length compositions were available from the WCSI *Tangaroa* and *Kaharoa* trawl surveys. Annual length compositions were also available from the bycatch of gemfish sampled by the Observer programme from the WCSI hoki fishery and the Southland squid fishery (SKI 3) (14 years) (Table 5).

The model commenced in 1975 and assumed that the initial population age structure was in an equilibrium, unexploited state. The population was partitioned by sex and included 15 age classes, the oldest age class representing an aggregated “plus” group (15 years and older). The model year represented the fishing year (October–September) as a single season. The 2017/18 fishing year (2018) was the terminal year of the model.

The key biological parameters for the southern gemfish stock were sourced from Fisheries New Zealand (2019) (Table 6). The variation in length-at-age was assumed to be a constant CV of 10% of the mean length-at-age. Maturity was assumed to be age-specific with all fish reaching sexual maturity at age 5 years.

Table 6. Model parameters and priors for the southern gemfish model.

Component	**Parameters**		**Value, Priors**
Biology	*M* (male and female)		0.25
	VB Growth	female	*k* = 0.178, *L1* = 29.5 cm, *Lmax* = 104.2 cm
		male	*k* = 0.242, *L1* = 29.5 cm, *Lmax* = 88.5 cm
	CV length-at-age (male and female)		0.10
	Length-wt	female	*a* = 9.5e-007, *b* = 3.47
		male	*a* = 1.2e-006, *b* = 3.41
	Maturity		0.0 1 yr, 0.1 2 yr, 0.4 3 yr, 0.8 4yr, 1.0 ≥5 yr
Recruitment	Ln*R0*		Uniform[0–10]
	B-H SRR steepness *h*		0.85
	SigmaR σR		1.0
	Recruitment deviates		Lognormal deviates (1975–2016)

The model included two fisheries that encompassed the catches from SKI 3 and SKI 7. The model was not partitioned by area, rather differences in the catch composition between the two fisheries were mediated by fishery-specific selectivity functions. Selectivities were parameterised as length-based functions; both fisheries were assumed to have full selectivity of the larger fish parameterised with a double normal function (constrained to approximate a logistic function). The WCSI CPUE indices were assigned an equivalent selectivity function to the SKI 7 commercial fishery.

The length compositions from the *Tangaroa* and *Shinkai Maru* Southland trawl surveys were very similar to the length composition of the catch from the SKI 3 fishery in corresponding years (Hurst & Bagley 1998). On that basis, the Southland trawl surveys were assumed to have an equivalent selectivity to the SKI 3 commercial fishery. The catchability coefficients (*q*) for the *Tangaroa* and *Shinkai Maru* Southland trawl surveys were assumed to be equivalent (following Hurst & Bagley 1998). This is an influential assumption in the model as it directly attributes the magnitude of the decline in the biomass indices between the two sets of surveys to a decline in stock abundance.

Different selectivity functions are assumed for the WCSI *Tangaroa* and *Kaharoa* trawl surveys reflecting the different timing of the surveys and the spatial domain of the surveys. The *Kaharoa* trawl survey occurs during summer when a significant proportion of the adult component of the stock is considered to reside in the Southland area (i.e. outside of the survey area). Further, the survey does not encompass the entire depth range of gemfish off the west coast South Island and is likely to disproportionately sample the juvenile component of the stock. On that basis, the selectivity function for the *Kaharoa* trawl survey was constrained to decline for larger fish.

In contrast, the depth range of the WCSI *Tangaroa* trawl survey encompasses the entire distribution of adult gemfish, while the survey occurs immediately prior to the main spawning period. The model was configured with a selectivity function that assumed that all fish (above a threshold length) were equally vulnerable to the survey (approximating a logistic function). The limited number of observations (four surveys) precludes the reliable estimation of more complex selectivity functions.

Annual recruitments were derived from a Beverton-Holt spawner-recruitment relationship with an assumed steepness (*h*) of 0.85. Recruitment deviates were estimated for virtually the entire model period (1975–2016, 42 deviates) with an assumed variation (σR) of 1.0. The relatively high level of variation is consistent with the high degree of variability observed in the year classes present in the length/age compositional data.

For each set of trawl surveys, the precision of the individual biomass indices was assumed to be equivalent to the native CV of the survey (i.e., no additional process error was applied). The CPUE indices were assigned a CV of 0.50 based on the standard error of the individual indices and the relatively high variation in the model residuals.

The four age compositions from the Southland *Tangaroa* trawl surveys were assigned a relative high weighting (Effective Sample Size ESS of 50) reflecting the consistency of the age compositions from the successive surveys. For many of the surveys, limited numbers of gemfish were caught and, hence, relatively small numbers of fish were measured (Appendix 2, Table A4). Thus, individual length compositions were assigned an Effective Sample Size (ESS) proportional to the number of fish measured, reducing the influence of length compositions derived from small samples. For each series, the larger samples were assigned a relatively high weighting on the basis that the length compositions represent a random, stratified sample of the vulnerable population (Table 4).

Length compositions from the commercial fisheries were each assigned a moderate weighting (ESS 10) based on the level of consistency between length compositions from successive years of sampling from the two fisheries.

The formulation of the individual likelihood components is documented in Methot & Wetzell (2013). The estimation procedure minimises the negative log-likelihood of the objective function. The resultant model is not intended to provide a comprehensive assessment of the southern gemfish stock, rather it provides the framework for evaluating the consistency in the trends in the population dynamics from multiple data sets. The parameterisation of the model was refined during the initial development of the model. However, the modelling has not included a thorough evaluation of sensitivities to key model assumptions (especially fishery and survey selectivity, trawl survey catchability and recruitment variability) or included a comprehensive evaluation of the influence of key data sets (such as via likelihood profiling).

5.6 Model results

The model provides a reasonable fit to the time-series of CPUE indices from the WCSI hoki fishery, including the initial increase in the indices during the mid 2000s (Figure 19). Over the following decade (2006–2015) abundance is predicted to decline, although the CPUE indices are relatively uninformative through this period. The model fits the large increase in the CPUE indices from 2016 to 2018.

The *Kaharoa* and *Tangaroa* WCSI trawl survey indices both increased in the recent years, although the magnitude of the respective increase deviates from the increase predicted by the model; the model over-estimated the extent of the increase in the *Kaharoa* index from 2017, while under-estimating the extent of the increase in the *Tangaroa* index from 2018 (Figure 19).

The model fits the overall magnitude of the decline in the Southland trawl survey biomass indices between the early 1980s (*Shinkai Maru*) and mid 1990s (*Tangaroa*) (Figure 19).

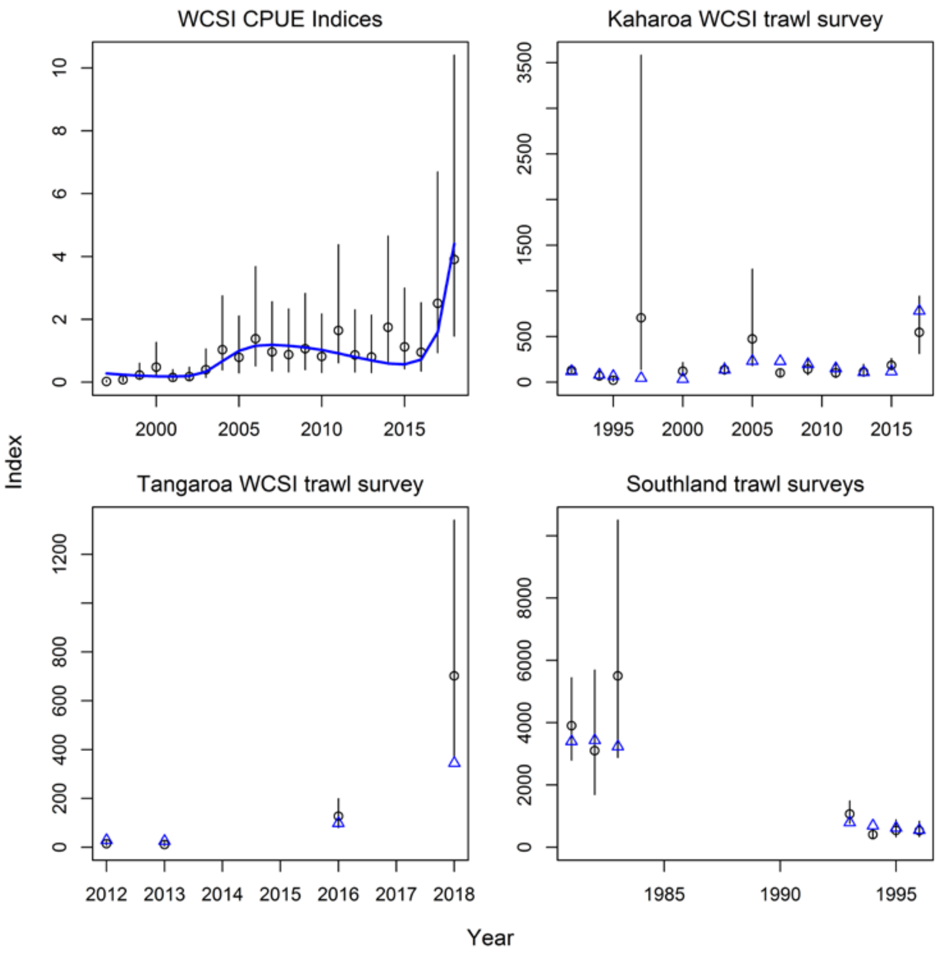

Figure 19: Observed (black circles) and predicted (blue triangles) CPUE indices and trawl survey biomass indices.

The selectivity of the *Kaharoa* trawl survey is estimated to increase sharply from 35 cm in length to full selectivity at about 40 cm and then attenuate from about 65 cm (Figure 20).

The selectivity of the WCSI *Tangaroa* trawl survey was assumed to approximate a logistic function, with full selectivity of all large fish. Selectivity increased from about 20 cm in length and full selectivity was attained at about 25 cm (Figure 20).

For the WCSI commercial fishery, full selectivity is estimated to be attained from about 70 cm (Figure 20), corresponding to an age of about 5 years, the age at which gemfish are assumed to reach full maturity.

An equivalent selectivity function was assumed for the Southland trawl surveys (*Shinkai Maru* and *Tangaroa*) and the Southland (SKI 3) fishery. Selectivity is estimated to increase over a broad length range from about 45 cm and attaining full selectivity at about 90 cm (Figure 20).

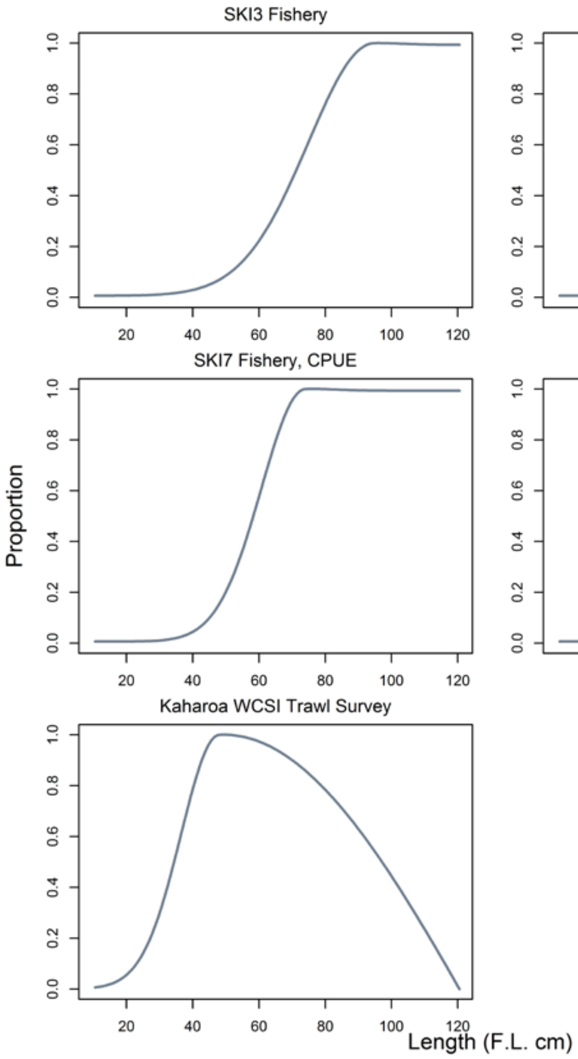

Figure 20: Length based selectivity functions estimated for the SKI 3 and SKI 7 commercial fisheries and trawl surveys.

The age compositions from the *Tangaroa* Southland trawl surveys are characterised by the persistent strong year classes that dominate the age structure of the four successive surveys (Figure 21). Overall, the model provides a good fit to the female age compositions. However the fit to the male age compositions is relatively poor; the proportions of fish in the older (10–12 year) age classes are under-estimated by the model, while the proportions of younger fish (4–6 years) are over-estimated (Figure 21). This suggests that there are differences in the selectivity of male and female fish which are not entirely consistent with the assumption of a sex invariant selectivity function.

Overall, the model fits the observed variation in the year class strength evident in the age compositions (strong year classes in 1982, 1984, 1985 and 1989; weak year classes in 1986–1988) (Figure 21).

The SKI 3 commercial fishery was assumed to have a selectivity that was equivalent to the Southland trawl surveys. During the early 1990s, the length compositions from the SKI 3 fishery were dominated by fish in the 75–90 cm length range (Figure 22). This mode is likely to correspond to the older cohorts (8–12 years) that dominated the age compositions from the Southland *Tangaroa* trawl surveys in 1993 and 1994 (Figure 21). The model approximates the observed length compositions from the early 1990s, although the fits are poor indicating a degree of conflict with the trawl survey age compositions, particularly the relative strength of the 1989 year class (age 4 year in the 1993 trawl survey).

A strong (2001) cohort recruited to the SKI 3 commercial fishery in 2002 and appeared to dominate the length compositions from the fishery over the subsequent years (2003–2006). The model fitted the general progression of the cohort in the length compositions (Figure 22). More recently, strong length modes of relatively small fish were present in the 2017 and 2018 length compositions. However, the model does not adequately fit these observations (Figure 22). This may be related to the low selectivity estimated for fish in the smaller length intervals (40–60 cm).

The length compositions from the WCSI commercial fishery reveal the presence of a strong cohort in successive annual samples from the early and mid 1990s (Figure 23). This cohort appears to be consistent with the strong year class that was sampled as 4–7 year old fish from the Southland trawl survey. The appearance of a further strong cohort in the fishery from 2002 is also consistent with the recruitment patterns observed in the SKI 3 commercial fishery during the early–mid 2000s (Figure 22). This cohort is likely to be the cause of the increase in the CPUE indices from the SKI 7 fishery during the mid 2000s (Figure 19). The model fits the general pattern in the time-series of length composition data from the SKI 7 fishery throughout this period (Figure 23).

In 2016, a further strong cohort recruited to the SKI 7 fishery and dominated the length compositions from 2016–2018 (Figure 23). However, the fit to the 2018 length composition was poor with the model predicting a considerably broader length distribution than the observed. This lack of fit may be partly attributable to a degree of conflict with the length composition data from the 2018 WCSI *Tangaroa* trawl survey (Figure 24). The survey sampled a broader length range (35–70 cm) of gemfish which is comprised of three cohorts, whereas only the largest of these cohorts was present in the commercial length composition (Figure 23). This cohort had been previously sampled by the 2016 *Tangaroa* trawl survey (at a mode of about 40 cm) (Figure 24). The *Kaharoa* trawl survey sampled the same cohort a year later (2017) at a mode of about 50 cm, while also sampling a younger cohort (mode at about 35 cm) (Figure 25). The *Kaharoa* trawl surveys also sampled the strong cohorts that were evident in the commercial fisheries in the early–mid 1990s and early–mid 2000s. Overall, the model estimates the general patterns in the time-series of length compositions from the *Kaharoa* surveys, although the individual fits were generally poor (Figure 25).

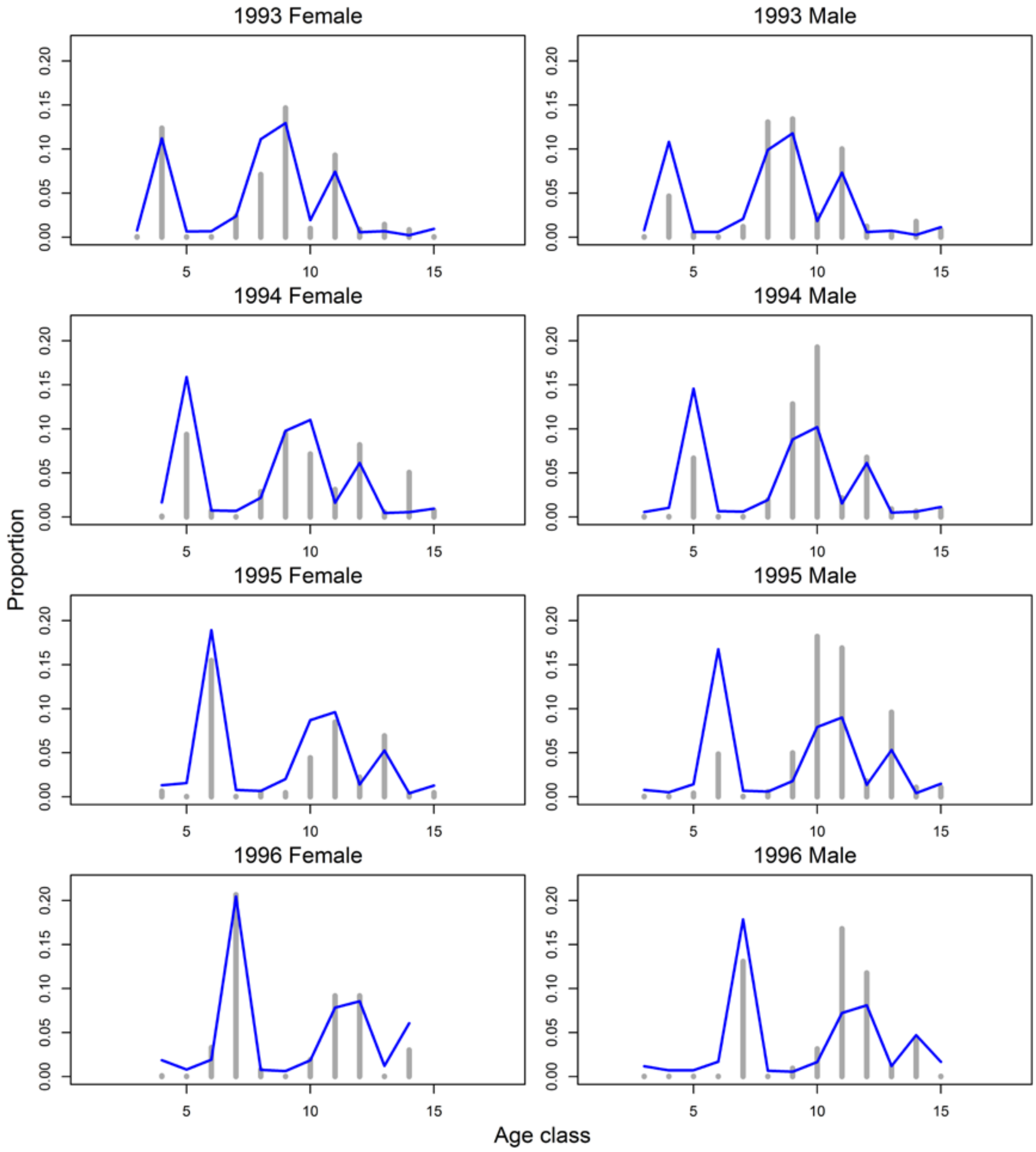

Figure 21: Observed (histograms) and predicted (line) proportions at age from the *Tangaroa* Southland trawl surveys.

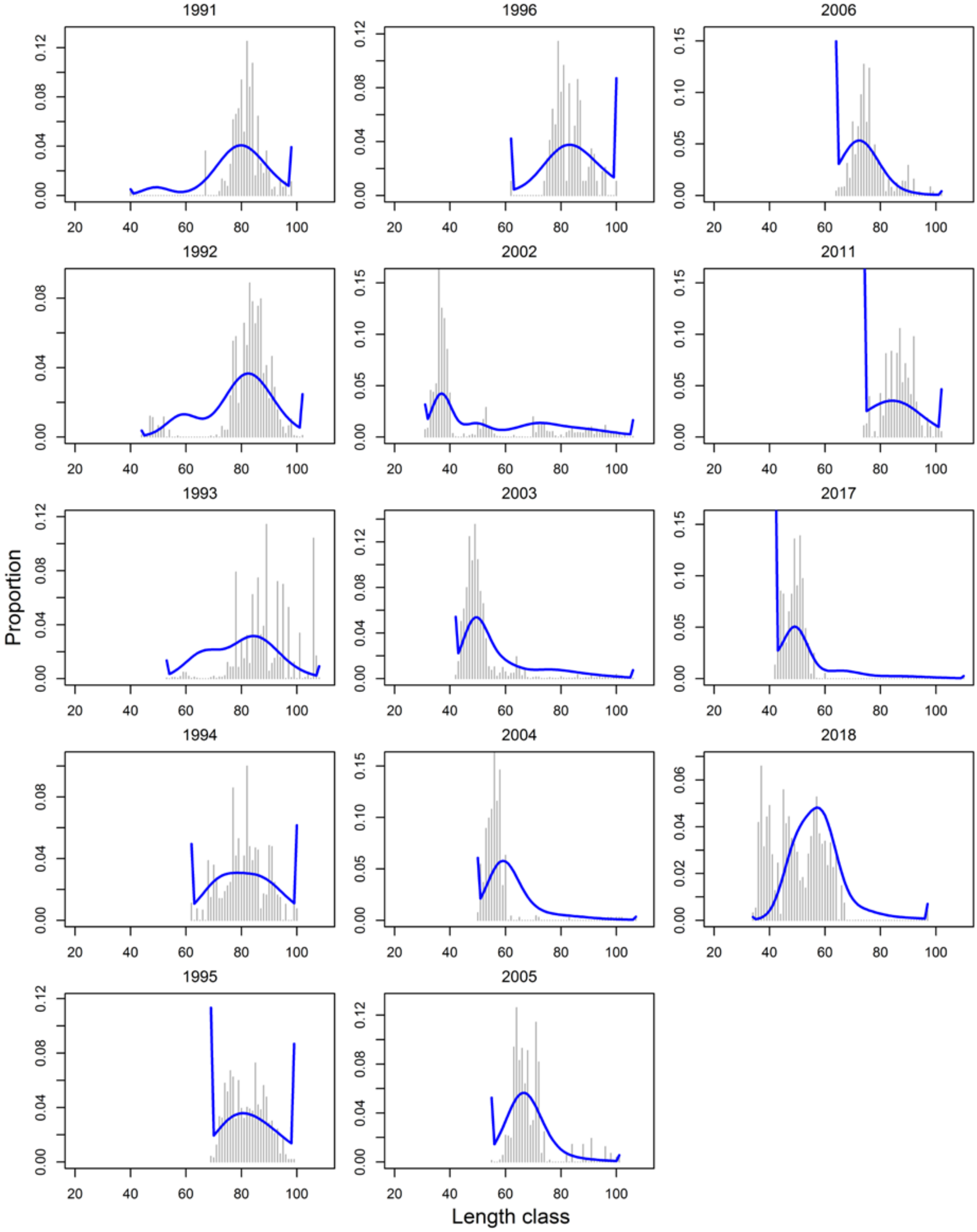

Figure 22: Observed (histograms) and predicted (line) proportions at length for gemfish sampled from the Southland (SKI 3) commercial (squid) fishery.

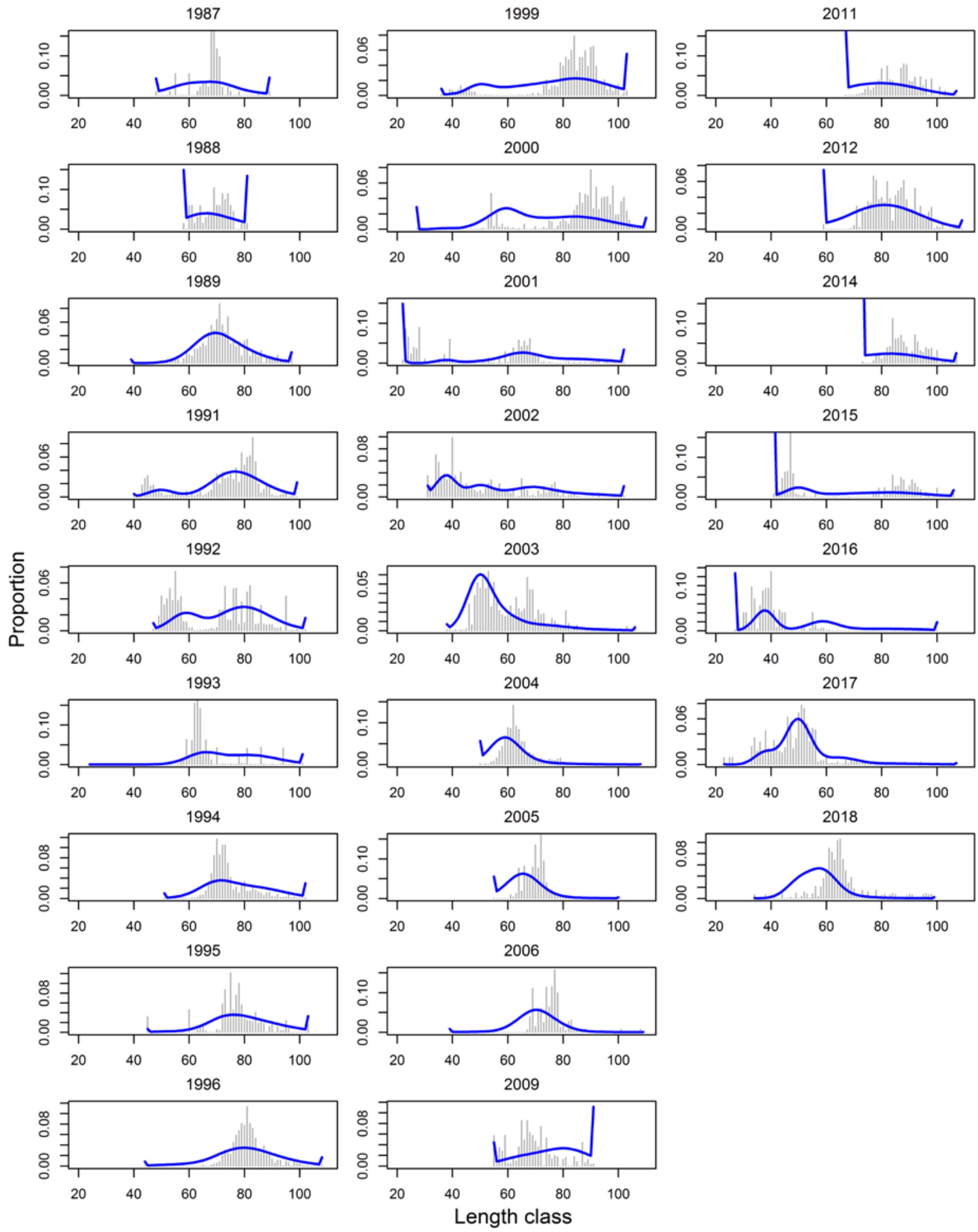

Figure 23: Observed (histograms) and predicted (line) proportions at length for gemfish sampled from the WCSI (SKI 7) commercial (hoki) fishery.

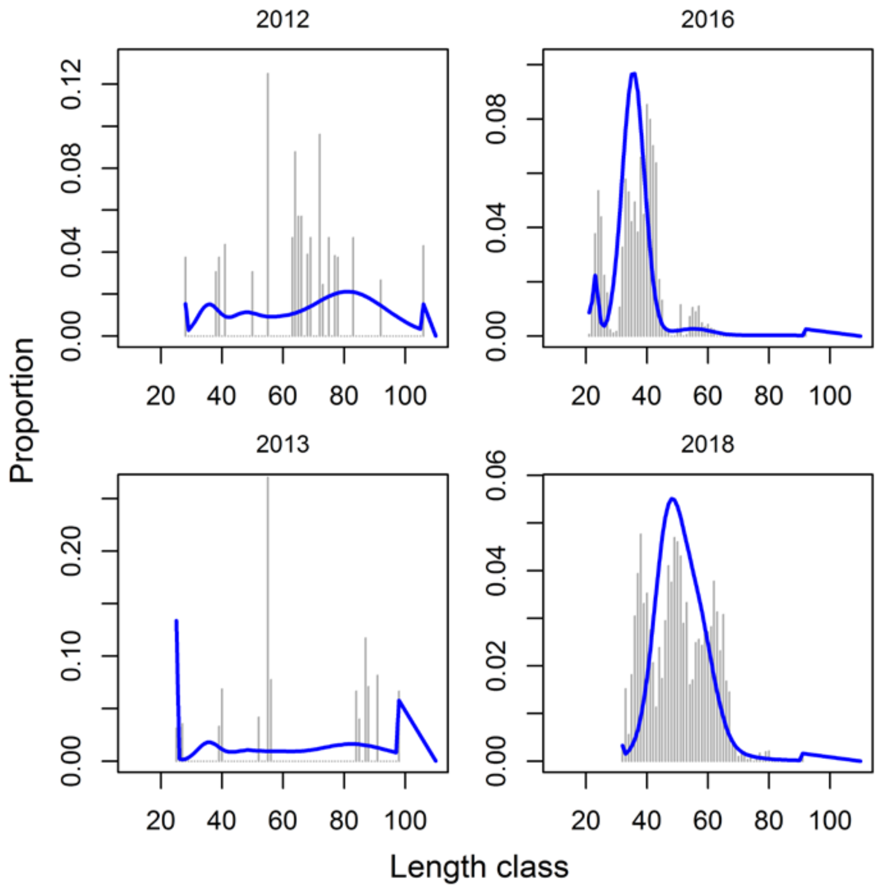

Figure 24: Observed (histograms) and predicted (line) proportions at length for gemfish sampled from the Tangaroa WCSI trawl survey.

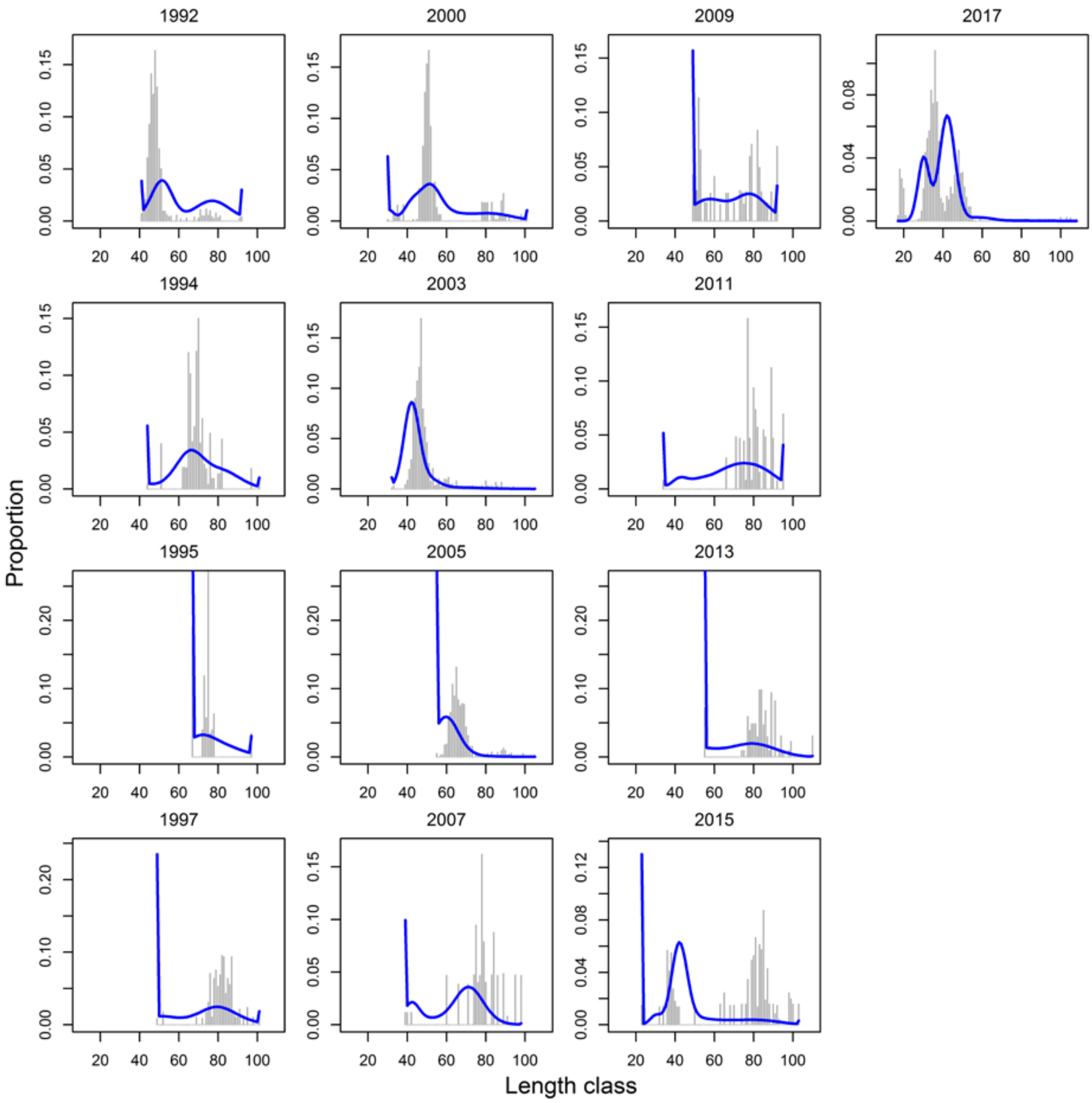

Figure 25: Observed (histograms) and predicted (line) proportions at length for gemfish sampled from the Kaharoa WCSI trawl survey.

The model dynamics are characterised by episodic patterns of recruitment and negligible recruitment during the intervening years. The model estimated relatively strong recruitment during the early-mid 1980s (1982, 1984, 1985) and in 1989 (Figure 26). Recruitment occurred in 2001 and this year class is estimated to have supported the catches over the following years. Recent recruitments (2013–16) are estimated to be exceptionally high, strongly influenced by the large increase in the CPUE indices from 2016 and, to a lesser extent the WCSI trawl survey biomass indices (Figure 26).

The model also estimated a large recruitment in 1975 (Figure 26). This represents the first year of recruitment deviates estimated in the model. The relative strength of this year class is not informed by the age composition data from the Southland *Tangaroa* trawl survey. Rather, it is likely that the model estimates the strong recruitment to shift the stock from initial equilibrium conditions to sustain the very high catches during the late 1980s.

Correspondingly, spawning biomass is estimated to have increased substantially in the early 1980s and then declined substantially during the mid–late 1980s and 1990s, reaching a very low level in the early 2000s (Figure 27). Spawning biomass is estimated to have increased in the mid 2000s following the recruitment of the 2001 year class. This cohort was depleted over the following years and spawning biomass declined to 2015 before increasing substantially in 2017 and 2018. However, the level of spawning biomass in the terminal year (2018) is poorly determined due to uncertainty in the magnitude of the estimates of recent recruitment (Figure 27).

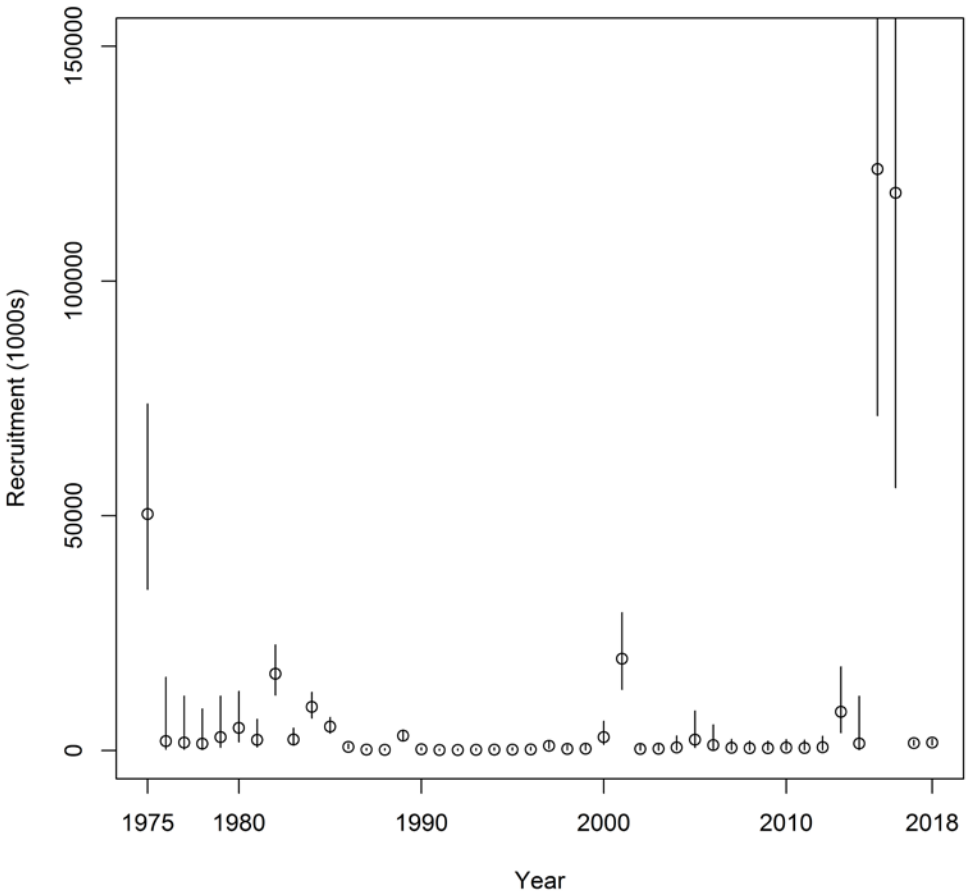

Figure 26: Estimates of annual recruitments (numbers of fish) and the 95% confidence intervals estimated from the exploratory modelling. The recruitment deviates are not estimated for the last two years in the model (2017, 2018).

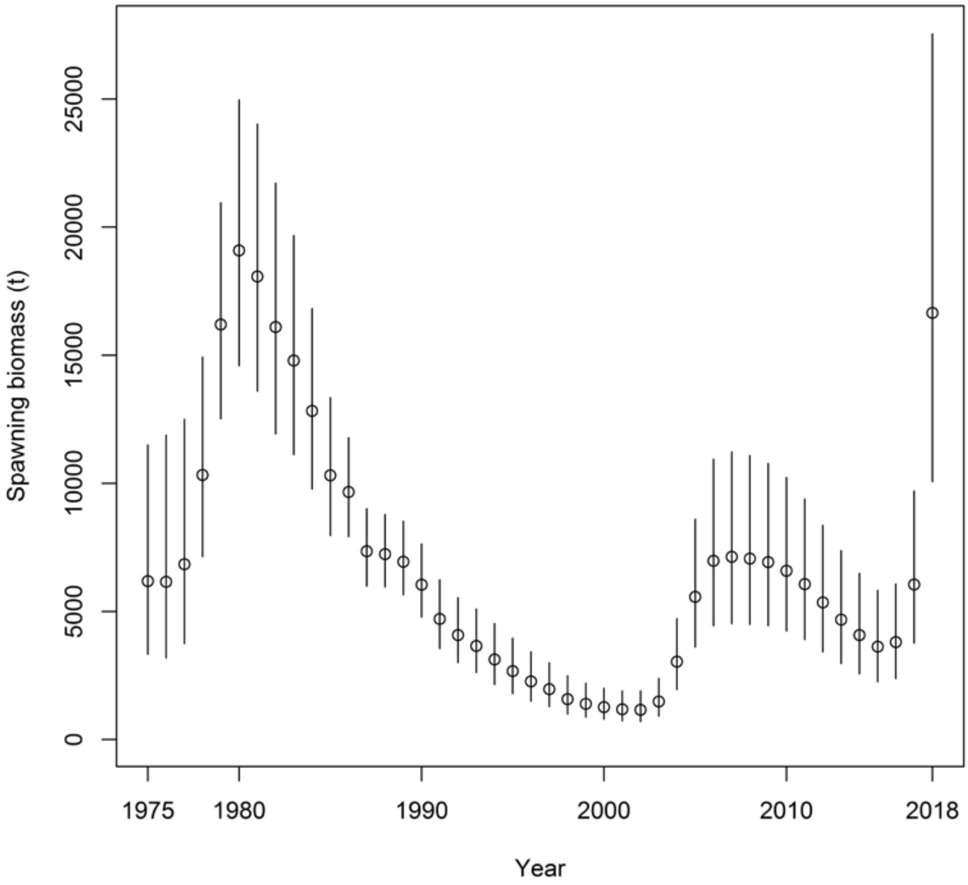

Figure 27: Spawning biomass (mature, female) and 95% confidence interval estimated from the exploratory modelling.

6 DISCUSSION

The SKI 7 CPUE indices are highly influential in the exploratory model as they provide the longest, continuous series of abundance indices monitoring the adult component of the stock. The recent large increase in the CPUE indices strongly influences the recent trends in biomass estimated by the model, specifically the large increase in biomass in the terminal year of the model (2018). There is uncertainty regarding the reliability of the CPUE indices as an index of stock abundance due to a number of factors: 1) the CPUE indices were derived from the bycatch of the WCSI hoki fishery and may be influenced by changes in the operation of the target fishery, 2) the CPUE indices appear to be sensitive to the selection criteria applied to define the subset of the catch and effort data incorporated in the analysis and 3) the two components of the combined CPUE model (binomial and lognormal indices) have different trends in the annual indices with the large recent increase in the CPUE indices dominated by the trend in the binomial indices.

The trends in the time-series of CPUE indices are generally coherent with the available length composition data from the fisheries and trawl surveys. The increase in the CPUE indices in the early 2000s is consistent with the presence of a strong cohort in the length compositions from the SKI 3 and SKI 7 fisheries (from 2002) which was also sampled by the WCSI *Kaharoa* trawl survey. Similarly, the recent large increase in the CPUE indices followed the presence of strong cohorts in the length compositions from the recent WCSI *Kaharoa* and *Tangaroa* trawl surveys and the SKI 3 and 7 commercial fisheries.

The large increases in the binomial CPUE indices corresponded with the recruitment of a strong cohort to the WCSI fishery (in 2002/03–2005/06 and 2016/17–2017/18), comprised of fish in the 50–70 cm length range. The fish comprising these length modes were more abundant (numerically) and, potentially, more widely distributed, which appears to have resulted in a relatively high encounter rate in the fishery (and a higher binomial index). However, the overall weight of the catches of recently recruited fish was relatively low. Consequently, the increase in the binomial CPUE indices tended to be followed by an increase in the lognormal CPUE indices as the mass of fish in the cohort increased (through growth) and the weight of individual catches increased. For example, the increase in the binomial indices in 2002/03–2005/06 was followed by an increase in the lognormal indices in 2007/08–2008/09. A similar pattern is also evident following the smaller increase in the binomial index in 2009/10–2010/11.

The modelling results indicate that the relatively modest catches from the SKI 3/7 fisheries during the mid–late 2000s and early 2010s were primarily sustained by a single year class (2001). This year class was estimated to have been of a similar magnitude to the stronger year classes that recruited during the early–mid 1980s (Hurst & Bagley 1998). Those year classes are likely to have contributed to the higher level of catch in the late 1980s, although the catches were not sustained through the early 1990s. The model estimates that the recruits from the early–mid 1980s were essentially depleted by about 1992. Recruitment is estimated to have been negligible throughout the 1990s.

A previous study linked variability in the recruitment of southern gemfish during 1982–1994 to prevailing environmental conditions (Renwick et al. 1998). Stronger year classes were associated with years of infrequent southwesterlies and positive SST anomalies off the west coast of the South Island (during March–October) (Renwick et al. 1998). For comparison with the previous study, a comparable time-series of SST anomalies was derived, extended to include the more recent period (to 2018) using weekly optimum interpolation (OI) sea surface temperature (SST) analysis data (Reynolds et al. 2002). The time series indicates that sea surface temperatures were consistently higher and less variable during 1999–2018 compared to the preceding period (Figure 28). The population modelling estimated that recruitment was very low throughout the 2000s, with the exception of 2001, indicating that the previous correlation between recruitment strength and SST was not maintained over the more recent period. The current study did not re-evaluate the relationship between recruitment and frequency of southwesterlies.

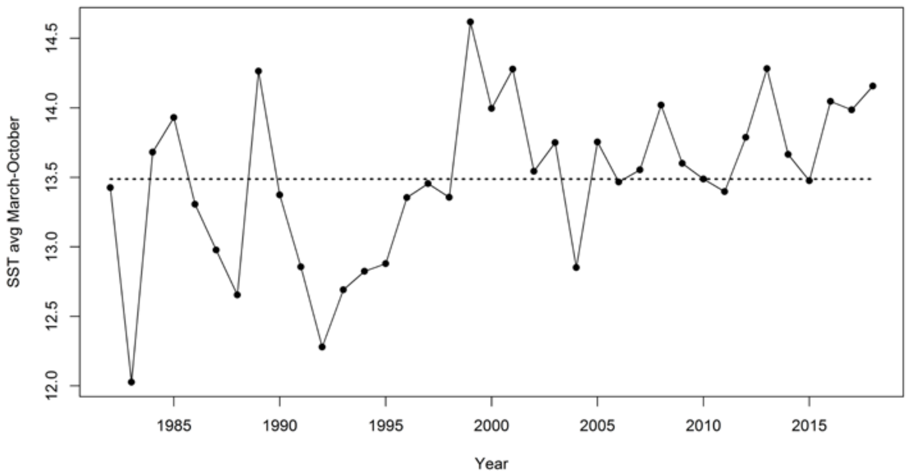

Figure 28. Sea surface temperature anomalies for west coast South Island (44°S, 168°E) derived from weekly optimum interpolation (OI) sea surface temperature (SST) analysis data (Reynolds et al. 2002).

The exploratory population model estimated exceptionally high recruitment for the recent year classes (2015 and 2016). These estimates of recruitment were driven by the recent large increase in the SKI 7

CPUE indices and the increase in the 2018 WCSI *Tangaroa* trawl survey biomass index, although the extent of the increase was substantially greater than the recent increase in abundance of juvenile gemfish monitored by the WCSI *Kaharoa* trawl survey. The recent length composition data indicate the presence of three relatively strong cohorts that were sampled by the WCSI trawl surveys and subsequently recruited to the SKI 3 and 7 commercial fisheries. However, the model does not appear to adequately resolve the relative strength the individual cohorts and, consequently, the fits to the recent (2016–2018) length compositions from the trawl surveys and commercial fisheries are poor. This may indicate that the assumption of constant selectivity is not appropriate for the commercial fisheries and/or that the length composition data are not entirely representative of the gemfish catch. It was only possible to appreciably improve the fit to the recent length compositions by excluding the last few years of CPUE indices and trawl survey biomass estimates and by reducing the catches in the terminal year. This result highlights a degree of conflict between the length composition data and the recent abundance indices, especially the CPUE indices.

The estimates of recent recruitment are very poorly determined by the model. More critically, the magnitude of these recruitment estimates are considered to be strongly biased by the influence of the recent CPUE indices; the magnitude of the estimates of recruitment is implausibly large in comparison to the time-series of recruitments estimated for the earlier period of the model. Over time, the estimation of the relative strength of these recent cohorts is likely to improve through continued monitoring of stock abundance (via CPUE indices and trawl surveys) in conjunction with the monitoring of catches from the fisheries.

Apart from the most recent years, the length composition data were relatively informative regarding the age structure of the population in the model. The variation in recruitment and rapid growth of individual cohorts for the first 6 years (to about 70 cm) enables individual cohorts to be monitored through successive years in the fishery. However, the length composition of larger (greater than 70 cm) fish may be comprised of multiple year classes that are not discernible from the length frequency data. It is recommended that the recent age structure of the catch and/or trawl survey biomass is determined. This would improve the understanding of the age structure of the population and, thereby, improve the estimation of recent stock dynamics (recruitment and biomass).

The current model is considered to provide a reasonable approximation of the SKI 3/7 stock dynamics from the late 1980s to the early 2010s. The stock is likely to have been at a relatively low level throughout this period, at least relative to the level of stock abundance in the early 1980s. The available data sets all indicate that there has been an increase in the abundance of gemfish from about 2015 following an increase in recruitment in recent years. However, the available data are insufficient to reliably estimate the magnitude of the recent increase in the abundance of the stock. Consequently, the results of the model are not sufficiently robust for the provision of management advice, particularly for the estimation of current stock status.

Nonetheless, the exploratory modelling indicates that a more comprehensive stock assessment model could be developed for SKI 3/7. This was beyond the scope of the current study and would require additional model development, including further evaluation of the precision of the CPUE indices, thorough testing of the assumptions related to fishery and survey selectivities, consideration of the catchability assumptions regarding the two sets of Southland trawl surveys (*Shinkai Maru* and *Tangaroa*), assumptions regarding initial population structure (in 1975), the relative weighting of the various input data sets, and the sensitivity of model results to key biological parameters (e.g. natural mortality, SRR parameters).

7 MANAGEMENT CONSIDERATIONS

The preliminary results of this study were presented to the Deepwater Stock Assessment Working Group (DWWG) in March 2019. A summary of the preliminary results of the modelling was included in the 2019 Plenary report (Fisheries New Zealand 2019), although the DWWG considered that the results were not sufficiently robust for the determination of current stock status. Nonetheless, the DWWG made a qualitative assessment of stock status based on recent trends in the CPUE and trawl survey biomass indices. The DWWG concluded that it was unlikely that current fishing mortality levels exceeded the overfishing threshold and that the stock was unlikely to be below the "hard limit" although more definitive statements regarding stock status were not possible.

A more thorough evaluation of the modelling results should be conducted by DWWG to consider the prospects for the development of a comprehensive stock assessment and/or recommendations for future monitoring of the SKI 3/7 stock. In the interim, catches from SKI 3 continued to exceed the TACC in 2018/19. Additional information regarding recent recruitment patterns is also available from the most recent (2019) *Kaharoa* trawl survey.

8 ACKNOWLEDGMENTS

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APPENDIX 1. CPUE DATA ANALYSIS

Table A1: Summary of the catch and effort data from the CPUE data set (core vessels only).

Fishing year	Number records	Number vessels	Number trips	Catch (t)	Number trawls	Duration (hrs)	Percent zero catch
1996/97	365	14	26	5.6	365	1 754	97.8
1997/98	426	17	20	2.3	426	2 103	97.2
1998/99	366	15	18	5.2	366	1 504	95.9
1999/2000	486	12	15	31.5	486	2 241	81.3
2000/01	237	12	13	3.8	237	1 259	87.8
2001/02	269	10	11	12.9	269	1 228	82.2
2002/03	255	13	15	16.3	255	1 705	67.1
2003/04	422	13	16	72.9	422	2 789	37.7
2004/05	117	6	8	31.9	117	914	27.4
2005/06	195	11	15	37.2	195	1 031	54.4
2006/07	110	5	5	22.4	110	252	64.5
2007/08	118	4	4	3.2	118	444	95.8
2008/09	55	7	8	2.0	55	147	94.5
2009/10	90	5	6	7.4	90	321	73.3
2010/11	169	11	13	32.7	169	548	72.8
2011/12	157	7	8	11.7	157	437	82.8
2012/13	368	10	12	17.5	368	1 381	83.7
2013/14	222	8	10	88.7	222	1 077	77.9
2014/15	271	11	12	35.0	271	1 319	88.9
2015/16	327	12	15	27.2	327	1 483	81.3
2016/17	292	12	14	76.9	292	1 826	54.8
2017/18	117	11	10	45.7	117	739	25.6

Table A2: Annual CPUE indices and the lower (LCI) and upper (UCI) bounds of the 95% confidence intervals.

Fishing	Combined			Binomial			Lognormal		
year	Index	LCI	UCI	Index	LCI	UCI	Index	LCI	UCI
96/97	0.021	0.004	0.067	0.056	0.020	0.147	0.306	0.115	0.772
97/98	0.064	0.014	0.175	0.252	0.092	0.541	0.253	0.089	0.576
98/99	0.184	0.042	0.498	0.315	0.106	0.682	0.593	0.216	1.256
99/00	0.464	0.152	1.070	0.743	0.353	1.293	0.632	0.282	1.323
00/01	0.203	0.051	0.581	0.541	0.217	1.008	0.380	0.153	0.828
01/02	0.187	0.058	0.437	0.784	0.377	1.318	0.242	0.109	0.469
02/03	0.420	0.167	0.918	1.290	0.781	1.817	0.329	0.145	0.624
03/04	1.056	0.434	2.147	2.017	1.574	2.302	0.530	0.231	1.046
04/05	0.872	0.374	1.709	2.130	1.720	2.387	0.414	0.177	0.787
05/06	1.329	0.504	2.865	1.454	0.893	1.944	0.923	0.405	1.842
06/07	0.969	0.338	2.124	1.107	0.566	1.692	0.892	0.393	1.786
07/08	0.898	0.147	3.000	0.445	0.131	1.047	2.027	0.562	4.882
08/09	0.683	0.069	2.620	0.342	0.079	0.912	1.996	0.387	5.682
09/10	0.767	0.246	1.831	1.121	0.562	1.738	0.695	0.260	1.426
10/11	1.666	0.537	3.712	1.126	0.611	1.682	1.489	0.617	2.820
11/12	0.896	0.265	2.125	0.916	0.448	1.500	0.986	0.373	2.036
12/13	0.730	0.227	1.808	0.788	0.375	1.299	0.932	0.398	1.873
13/14	1.648	0.511	3.820	0.782	0.381	1.308	2.129	0.918	4.410
14/15	1.071	0.289	2.803	0.575	0.234	1.043	1.874	0.713	3.914
15/16	1.136	0.385	2.624	0.939	0.481	1.485	1.223	0.525	2.426
16/17	2.690	1.070	5.367	1.859	1.366	2.213	1.463	0.650	2.881
17/18	4.045	1.671	7.792	2.418	2.257	2.499	1.692	0.714	3.271

APPENDIX 2. MODEL DATA SETS

Table A3: Annual catches (t) included in the preliminary model. The catches include an allowance for unreported catch (and differ from reported catches).

Year	SKI 3	SKI 7	Year	SKI 3	SKI 7
1975	206	44	2010	22	158
1976	10	43	2011	36	331
1977	5	89	2012	12	286
1978	492	1 284	2013	25	257
1979	2 524	754	2014	43	295
1980	2 279	1 109	2015	23	254
1981	1 643	2 003	2016	88	205
1982	1 166	810	2017	273	474
1983	2 400	1 200	2018	512	641
1984	4 177	2 089			
1985	3 040	1 789			
1986	6 535	1 762			
1987	2 250	1 176			
1988	1 830	1 180			
1989	1 239	1 191			
1990	1 280	1 025			
1991	678	358			
1992	316	642			
1993	408	516			
1994	83	353			
1995	176	113			
1996	54	89			
1997	64	262			
1998	30	48			
1999	19	65			
2000	68	118			
2001	52	96			
2002	79	135			
2003	127	295			
2004	86	596			
2005	79	699			
2006	30	273			
2007	29	230			
2008	20	197			
2009	12	234			

Table A4: Number of gemfish measured by the Observer programme from the WCSI hoki fishery and Southland squid fishery by year and the number of fish measured from the WCSI *Kaharoa* and *Tangaroa* trawl surveys. Numbers in bold indicate data used to derive length compositions for the preliminary model.

Fishing year	Year	Observer samples		WCSI trawl survey	
		HOK	SQU	*Kaharoa*	*Tangaroa*
1986/87	1987	**507**	22		
1987/88	1988	**205**	326		
1988/89	1989	**716**	0		
1989/90	1990	68	9		
1990/91	1991	**931**	**111**		
1991/92	1992	**864**	**324**	**473**	
1992/93	1993	**231**	**335**		
1993/94	1994	**2 362**	**110**	**97**	
1994/95	1995	**176**	**417**	**13**	
1995/96	1996	**413**	**94**		
1996/97	1997	95	76	**105**	
1997/98	1998	12	29		
1998/99	1999	**570**	42		
1999/00	2000	**520**	92	**149**	
2000/01	2001	**233**	16		
2001/02	2002	**382**	**531**		
2002/03	2003	**934**	**1270**	**346**	
2003/04	2004	**1 168**	**126**		
2004/05	2005	**806**	**175**	**247**	
2005/06	2006	**208**	**209**		
2006/07	2007	74	10	**29**	
2007/08	2008	1	3		
2008/09	2009	**139**	0	**47**	
2009/10	2010	5	2		
2010/11	2011	**160**	**101**	**45**	
2011/12	2012	**154**	0		**24**
2012/13	2013	0	10	**43**	**15**
2013/14	2014	**179**	11		
2014/15	2015	**157**	60	**77**	
2015/16	2016	**93**	0		**1 132**
2016/17	2017	**505**	**288**	**751**	
2017/18	2018	**446**	**1 081**		**1 242**