Length-based population model for scampi (*Metanephrops challengeri*) in the Bay of Plenty (SCI 1), Wairarapa / Hawke Bay (SCI 2) and Auckland Islands (SCI 6A)

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Tuck, I.D.;Dunn, A. (2012).
Length-based population model for scampi (*Metanephrops challengeri*) in the Bay of Plenty (SCI 1),
Wairarapa / Hawke Bay (SCI 2) and Auckland Islands (SCI 6A)
New Zealand Fisheries Assessment Report 2012/01. 125p.

CONTENTS

EXECUTIVE SUMMARY

The ongoing development of a Bayesian, length based population model for scampi has been continued through MFish project SCI200902. This work has revised existing models for scampi in the Bay of Plenty (SCI 1) and Wairarapa / Hawke Bay (SCI 2), and applied the approach developed for these stocks to scampi off the Auckland Islands (SCI 6A).

A range of complexity in data inputs and model spatial structure were examined for each area. Data inputs included CPUE, trawl and photographic survey indices, and associated length frequency distributions. The stocks were considered over a single area, and also stratified on the basis of depth and latitude.

In general, fits to abundance indices and length frequency data were not improved by increased spatial structure in the model, but some output parameters differed slightly between model runs. Fits to CPUE abundance indices were far better than attained in previous model implementations, and fits to other indices were reasonable.

Depending on the stock, either one or two models could be considered as base model options. Model outputs suggest that SSB in both SCI 1 and SCI 2 decreased up to the early 1990s, increased to a peak in about 1995, declined to the early 2000s, and has remained relatively stable since this time. The SSB in 2010 is estimated to be 40%–60% of B_0 in SCI 1, and 38%–50% of B_0 in SCI 2. These models were accepted by the Working Group. Projections for SCI 1 and SCI 2 were conducted up to 2015 on the basis of a range of catch scenarios (slightly above and below catch in most recent year or recent average catch, and also TACC if this differs from the previous catch levels). In both stocks, recent recruitment is estimated to have been lower than the long term average, and projections have been conducted on the basis of both long term and recent (last decade) recruitment scenarios.

For SCI 6A, model outputs suggest that SSB declined in the early 1990s, and has fluctuated around a relatively stable level since this time, and is currently 33%–53% of B_0. The default management target for scampi of 40% B_0 is within the range of % B_0 estimated for these stocks. These models were not accepted by the Working Group.

1.   INTRODUCTION

This report updates and develops the previously described Bayesian, length-based, two-sex population model for Bay of Plenty (SCI 1) and Wairarapa / Hawke Bay (SCI 2) scampi (Cryer et al. 2005, Tuck & Dunn 2006, Tuck & Dunn 2009). The first attempt at developing a length-based population model for any scampi stock was conducted for SCI 1 (Cryer et al. 2005), implemented using the general-purpose stock assessment program CASAL v2.06 (September 2004). This model for SCI 1 was developed further and the same model structure was also applied to SCI 2 in a later project (Tuck & Dunn 2006). The current study used CASAL v 2.22 (Bull et al. 2008) with a slightly modified selectivity option. Developments in the model implementation and structure have been largely based on suggestions raised at Shellfish Fisheries Assessment Working Group (SFAWG) meetings in 2007 and 2008 and the progress presented after the MFish funded Scampi Assessment Workshop (Tuck & Dunn 2009).

We describe the available data and how they were used, the parameterisation of the model, and model fits and sensitivity. This report fulfils Ministry of Fisheries project SCI2009/02 "*Stock assessment of scampi*", revising the stock assessment model for SCI 1and SCI 2, and undertaking a first assessment of SCI 6A.

2.   MODEL STRUCTURE

2.1.   Seasonal structure

Previous scampi assessment models for SCI 1 and SCI 2 (Cryer et al. 2005, Tuck & Dunn 2006) have not represented commercial or research trawl catch per effort data well, or the observed changes in sex ratio. Sensitivity and likelihood profile investigations indicate that various data available (length distributions from commercial and research trawling, abundance indices) were inconsistent between time steps in the model configuration, suggesting that allowing availability to the gear (represented by selectivity within the model) to vary between time steps may be appropriate, although further examination of the time steps used in the model would be required. There have also been concerns that the observed changes in the commercial CPUE and research trawl catch rates were not biologically feasible given current understanding of scampi growth rates if catchability is assumed to have remained constant over time, raising questions over their use as abundance indices.

Within the Ministry of Fisheries projects SCI200601 and SCI200803 (Tuck & Dunn 2009), the previous model structure was discussed in relation to current understanding of scampi biology, and available data was examined to determine if a more appropriate model structure could be identified. For SCI 1, surveys since the mid 1990s have not covered the most northerly area of the fishery, and subsequently the length based model has not included this area. The contribution of landings from this area has consistently been about 40% of the total SCI 1 landings since the mid 1990s, and this additional area was therefore also included in the data examined.

SCI 1 and SCI 2
Current knowledge of the timing of scampi biological processes in SCI 1 and SCI 2 are summarised in Table 1 (Tuck 2010). From patterns in ovary and egg stage observed from commercial and research trawl sampling, along with the proportion of soft animals and ovigerous females, mature female moulting appears to occur around October and November, just after the hatching period (August and September), with mating occurring at this time and new eggs being spawned onto the pleopods in November – January. The main male moulting is completed well before the female moult (since mating occurs post

moult for females, but the males must have completed the moult to mate), and appears to be concentrated in April and May, but may start as early as February. There is also some evidence of male moulting in September – November, generally for smaller (less than 40mm CL) animals.

The combination of biological processes for males and females lead to different relative availabilities of the two sexes through the year, resulting in the pattern of sex ratio (displayed as proportion males) shown in Figure 1. Males are markedly less abundant than females in catches between February and April (male catches being reduced during their moulting period), but females also dominate catches to a lesser extent between May and September.

Table 1: Summary of scampi biological processes for SCI 1 and 2. Source; (Tuck 2010).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Male moult		?	?	X	X							
Female moult										X	X	
Mating										X	X	
Eggs spawn	X										X	X
Eggs hatch								X	X			
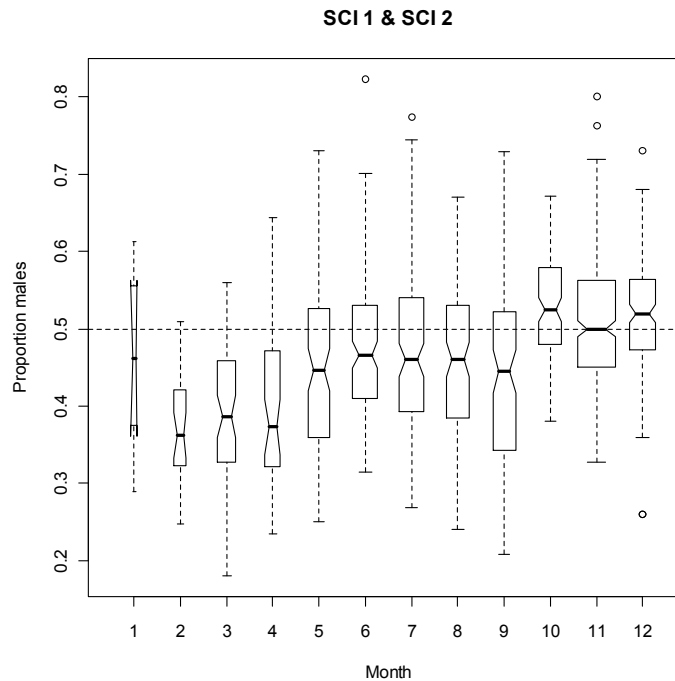
Figure 1: Boxplots of proportion of males in catches by month from observer sampling in the SCI 1 and SCI 2 fisheries. Box widths proportional to square root of number of observations for that month.

The same model structure and time steps have been applied to both SCI 1 and SCI 2 (Table 2).

Table 2: Annual cycle of the population model for SCI 1 and SCI 2, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur together within a time step occur after all other processes, with 50% of the natural mortality for that time step occurring before and 50% after the fishing mortality.

Step	Period	Process	Proportion in time step
1	Oct–Jan	Growth (both sexes)	
		Natural mortality	0.33
		Fishing mortality	From TCEPR
2	Feb–April	Recruitment	1.0
		Maturation	1.0
		*Growth (males)**	
		Natural mortality	0.25
		Fishing mortality	From TCEPR
3	May–Sept	Natural mortality	0.42
		Fishing mortality	From TCEPR

* - the main period of male moulting appears to be from February to April. In the model both sexes are assumed to grow at the start of step 1, and this male growth period (February to April) is ignored. Sensitivities to an additional growth for males at this time are explored.

SCI 6A

Current knowledge of the timing of scampi biological processes in SCI 6A are summarised in Table 3 (Tuck 2010). From patterns in ovary and egg stage observed from commercial and research trawl sampling, along with the proportion of soft animals and ovigerous females, mature female moulting appears to occur around November and December, just after the hatching period (October and November), with mating occurring at this time and new eggs being spawned onto the pleopods in January – February. The main male moulting is completed between December and March.

The combination of biological processes for males and females lead to different relative availabilities of the two sexes through the year, resulting in the pattern of sex ratio (displayed as proportion males) shown in Figure 2. This figure has been plotted on a half monthly basis. Males are markedly less abundant than females in catches between December and March (male catches being reduced during their moulting period), the ratio of the sexes in the catches is roughly equal between April and June, and also in November, with males dominating from July to October.

On the basis our understanding of the timing of biological processes for scampi in this area, and the seasonal pattern in sex ratio, we have defined the modelled year as running from mid-November, with three time steps, mid-November to mid-April, mid-April to June, and July to mid-November (Table 4).

Table 3: Summary of scampi biological processes for SCI 6A. Source; (Tuck 2010).

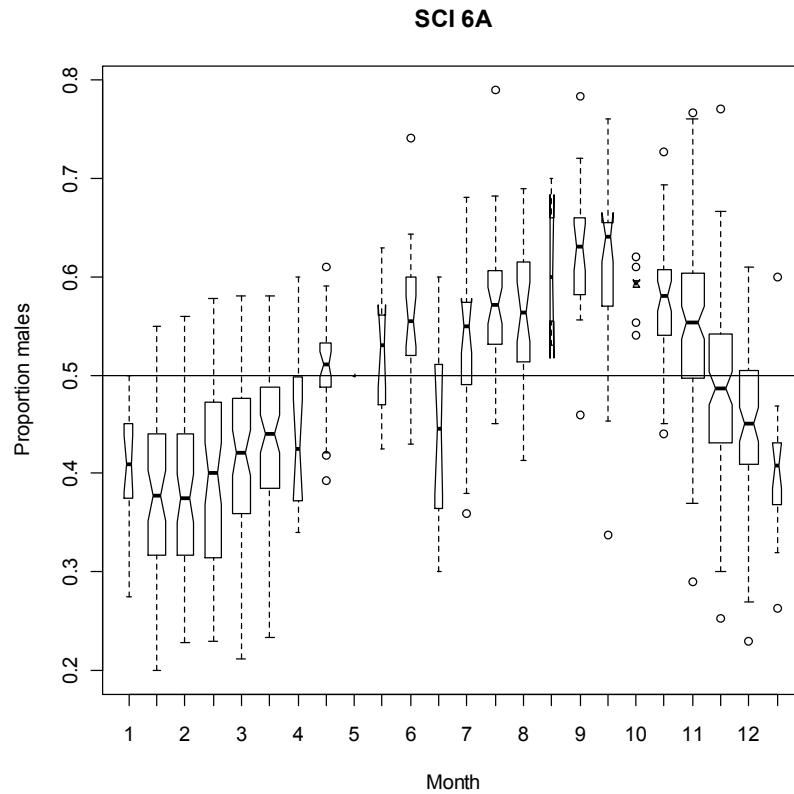|	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Male moult	X	X	X									X
Female moult											X	X
Mating											X	X
Eggs spawn	X	X										
Eggs hatch										X	X	

SCI 6A

Figure 2: Boxplots of proportion of males in catches by half month from observer sampling in the SCI 6A fishery. Box widths proportional to square root of number of observations for that half month.

Table 4: Annual cycle of the population model for SCI 6A, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur together within a time step occur after all other processes, with 50% of the natural mortality for that time step occurring before and 50% after the fishing mortality.

Step	Period	Process	Proportion in time step
1	Mid Nov–	Maturation	1.0
	Mid Apr	Growth (both sexes)	
		Natural mortality	0.415
		Fishing mortality	From TCEPR
2	Mid Apr –	Recruitment	1.0
	Jun	Natural mortality	0.21
		Fishing mortality	From TCEPR
3	Jul–Mid	Natural mortality	0.375
	Nov	Fishing mortality	From TCEPR

2.2.   Spatial structure and the model partition

In the models, the partition accounts numbers of males and females by length class within an annual cycle, where movements between length classes are determined by sex-specific, length-based growth parameters. Individuals enter the partition by recruitment and are removed by natural mortality and

fishing mortality. The model's annual cycle is based on the fishing year and is divided into the three time-steps described above for the respective stocks (Table 2 and Table 4). The choice of three time steps was based on current understanding of scampi biology and sex ratio in catches. Note that model references to "year" within this report refer to the modelled or fishing year, and are labelled as the most recent calendar year, i.e., the fishing year 1998–99 is referred to as "1999" throughout.

Investigations into factors affecting scampi catch rates and size distributions (Cryer & Hartill 2000, Tuck 2009) have identified significant depth and spatial effects and therefore spatial and depth stratification was also considered for the model. For convenience, the spatial strata adopted within the model are those used for survey stratification that cover the core areas of the respective fisheries. Models were run for a range of combinations of structure complexity (spatial and depth structure) and data (CPUE, trawl surveys, length distributions).

Catches generally occur throughout the year, and we divided the catch among the time-steps according to the proportion of estimated catches recorded on Trawl Catch, Effort, and Processing Returns (TCEPR). Recreational catch, customary catch, and illegal catch are ignored. The maximum exploitation rate (i.e., the ratio of the maximum catch to biomass in any year) is not known, but we constrained it to no more than 0.9 in a time-step (i.e., we assume that no more than 90% of the stock can be taken in a time step). Individuals are assumed to recruit to the model at age 1, with the mean expectation of recruitment success predicted by a Beverton Holt stock-recruitment relationship. Length at recruitment is defined by a normal distribution with mean of 10 mm OCL with a c.v. of 0.4. Relative year class strengths are encouraged to average 1.0. Natural mortality is assumed known at 0.2 (Cryer & Stotter 1999). Previous implementations of the scampi assessment model have assumed that growth is known (from tag and aquarium data), but in the current model it is estimated, fitting to the tag (Cryer & Stotter 1997, Cryer & Stotter 1999) and aquarium data (Cryer & Oliver 2001) for SCI 1 and SCI 2, and tag data for SCI 6A.

The model uses capped logistic length based selectivity curves for commercial fishing, research trawl surveys, and photographic surveys, assumed constant over years, but allowed to vary with sex, time step and spatial strata (where included). While the sex ratio data suggest that the relative catchability of the sexes vary through the year (hence the model time structure adopted), there is no reason to suggest that assuming equal availability, selectivity at size would be different between the sexes. Therefore a new selectivity implementation was developed within CASAL, which allowed the L_{50} (size at which 50% of individuals are retained) and a_{95} (size at which 95% of individuals are retained) selectivity parameters to be estimated as single values shared by both sexes in a particular time step and spatial strata, but allowed for different availability between the sexes through estimation of different a_{max} (maximum level of selectivity) values for each sex. In SCI 1 and SCI 2, selectivity is assumed to be the same in time steps 1 and 3, owing to the relative similarity in sex ratio (Figure 1). In SCI 6A, selectivity is assumed to be the same in time steps 2 and 3.

## 2.3. Biological inputs

2.3.1. Recruitment

Few data are available on recruitment. Relative year class strengths were assumed to average 1.0 up to the last three years, and are fixed at 1 for these. In the initial model development (Cryer et al. 2005) lognormal priors on relative year class strengths were assumed, with mean 1.0 and c.v. 0.2, and the sensitivity of year class strength (YCS) variation was examined in further developments (Tuck & Dunn 2006). More recent model investigations, particularly those fitting the CPUE indices, suggest that the constraint on variability in YCS may be too severe, and the SFAWG suggested increasing the c.v. In the current implementation, lognormal priors on relative year class strengths were assumed, with mean 1.0 and c.v. 1.0. The relationship between stock size and recruitment for scampi is unknown. However, New Zealand scampi have very low fecundity (Wear 1976, Fenaughty 1989) (in the order of tens to hundreds

of eggs carried by each female), so very successful recruitment is probably not plausible at low abundance. Scampi enter the model partition as 1 year olds. The distribution of their sizes was assumed to be normal with mean 10 mm OCL and c.v. 0.4.

2.3.2. Growth

SCI 1 and SCI 2
Scampi growth has been estimated from wild-tagged scampi in SCI 1 (Cryer & Stotter 1997, Cryer & Stotter 1999) and aquarium-reared scampi from SCI 2 (Cryer & Oliver 2001) (Figure 3).
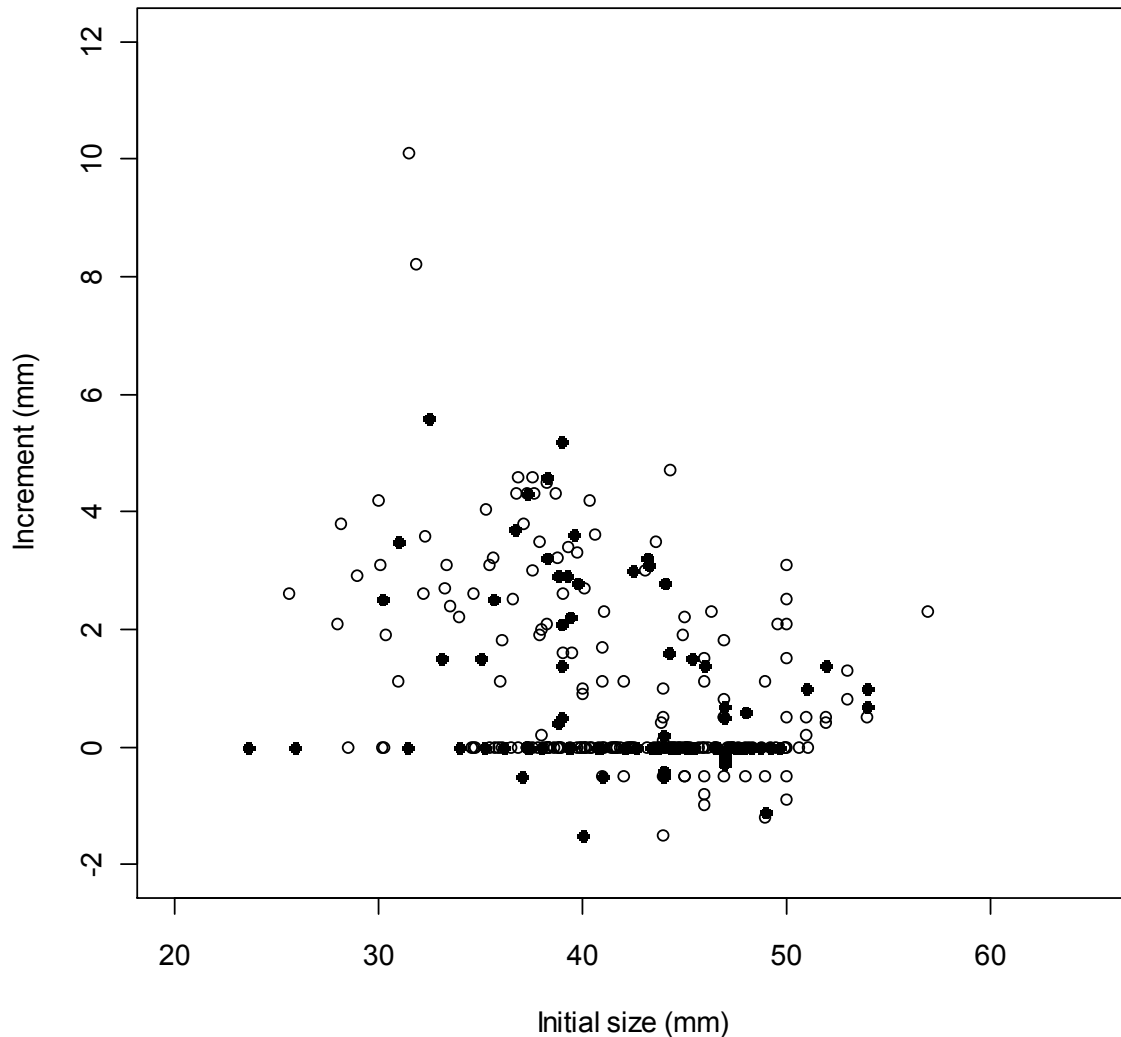
Figure 3: Growth increment data from scampi tagging in SCI 1 and SCI 2, and aquarium studies. Solid and hollow symbols represent males and females.

Previously, the combined data set has been analysed externally and the estimated growth parameters for each sex fixed in the model. However, given the strong influence growth has on length based models, and the scatter around the externally fitted relationships in Figure 3, the fitting of the growth data has been included within this model.

On the basis of the time steps within the model structure, the tag data can be split into three release events. Recaptures of tagged scampi from these releases are tabulated by recapture time step in Table 5. Within the analysis, animals from both wild release and aquarium studies have been combined, although the numbers of animals are provided separately in Table 5.

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Table 5: Numbers of scampi recaptured by release and recapture time step (SCI 1 and 2).

Release/Recapture	1996-3	1997-1	1997-2	1997-3
1996-2		20	7	13
1996-3*	12	15 (28)	2 (21)	42 (30)
1997-1			15	80

* - recaptures from1996-3 release include 79 animals in aquaria and 71 from wild releases. For recaptures, numbers in parenthesis represent aquarium animals.
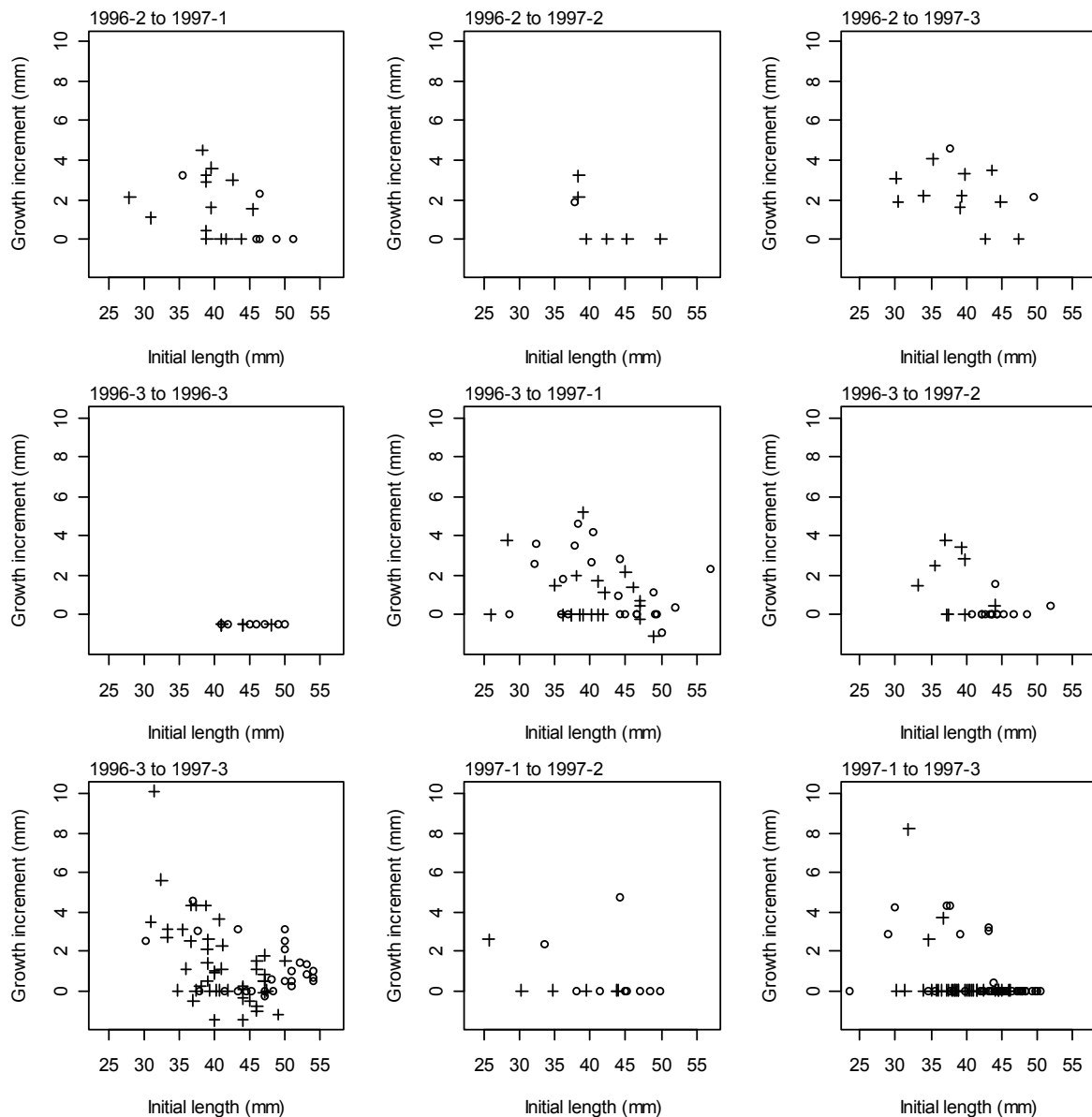

Figure 4: Plot of initial length against growth increment by combination of release and recapture time steps. Males represented by hollow symbols, females represented by crosses.

For the nine combinations of release and recapture the length increment is plotted by sex against initial length in Figure 4. The model structure has a growth period assigned to the start of time step 1 for both sexes, and the sensitivity to a further growth period assigned to the start of time step 2 for males is also examined. For neither model approach would growth be expected for those animals released in 1996-3 and recaptured in 1996-3, or females released 1997-1 and recaptured in 1997-2 or 1997-3 (although 4 of

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40 females showed some growth). The animals released and recaptured in 1996-3 have been excluded from the model for simplicity.

SCI 6A

Scampi growth has been investigated through field tagging exercises in SCI 6A in 2007, 2008 and 2009 (Tuck et al. 2007, Tuck et al. 2009a, Tuck et al. 2009b). As with the model for SCI 1 and SCI 2, growth data is fitted within the model. Growth increment for all tagged scampi from SCI 6A is shown in relation to initial length in Figure 5. Growth increment at size appears greater than the SCI 1 data for females, but similar (or smaller) for males. The tag recapture data for each release event have been split into year-time step combinations, and the numbers of recaptures per event are tabulated in Table 6.
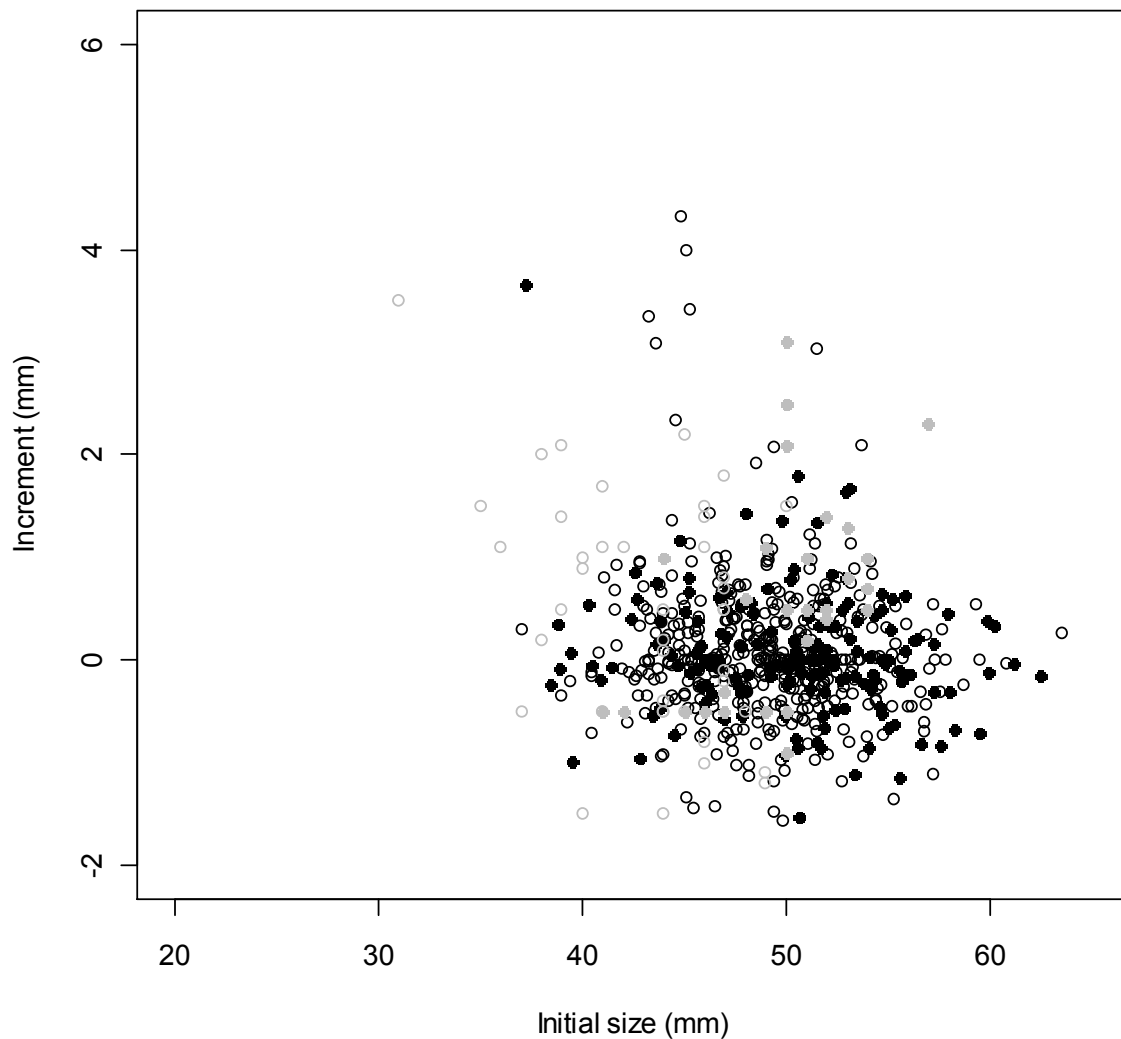
Figure 5: Growth increment data from scampi tagging in SCI 6A. Solid and hollow symbols represent males and females respectively. Wild tagged scampi from SCI 1 overlayed in grey for comparison.

Table 6: Numbers of scampi recaptured by release and recapture time step (SCI 6A).

Release/ Recapture	2007-1	2007-2	2007-3	2008-1	2008-2	2008-3	2009-1	2009-2	2009-3	2010-2
2007-1	26	42	81	4	6	6	0	1	1	0
2008-1				47	30	76	18	23	14	0
2009-1							51	136	78	1
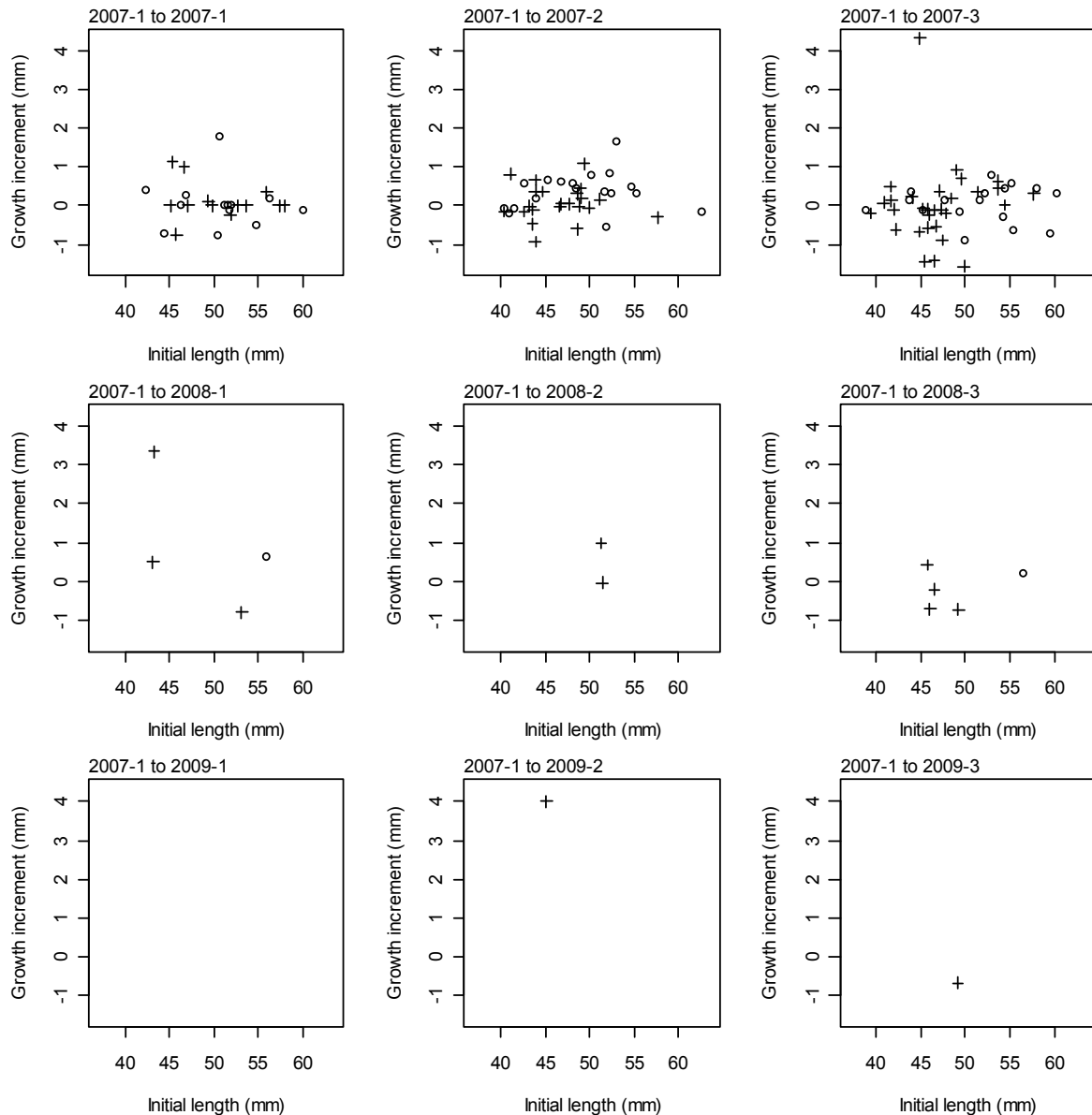
Figure 6: Plot of initial length against growth increment by combination of release and recapture time steps for 2007 releases. Males represented by hollow symbols, females represented by crosses.

For the various combinations of release and recapture, the length increment is plotted by sex against initial length for the 2007 release in Figure 6, and for the 2008 and 2009 release in Figure 7. Growth for both sexes is thought to occur in time step 1.
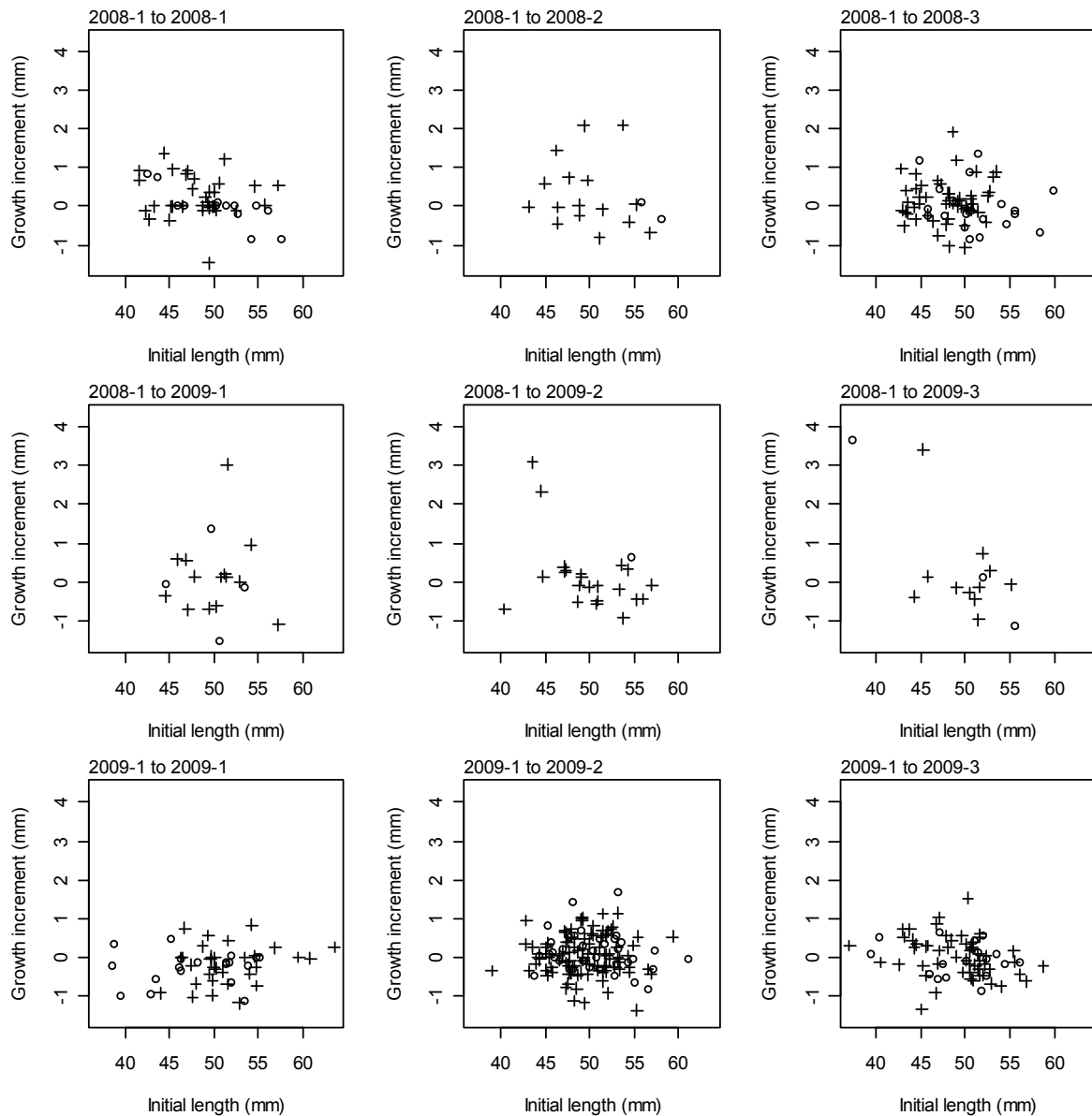
Figure 7: Plot of initial length against growth increment by combination of release and recapture time steps for 2008 and 2009 releases. Males represented by hollow symbols, females represented by crosses. One animal released in 2009-1 and recaptured in 2010-2 not represented.

Given the overall size distribution of scampi from SCI 6A (compared to the other areas examined), it would be anticipated that the growth increment at size would be greater than in SCI 1 and SCI 2. This would appear to be the case for females, but was not observed for males (Figure 5). This may be related to the timing of the tagging exercise in relation to the moult cycle.

2.3.3. Maturity

The proportion of females mature at each 1 mm size class have been recorded during all research surveys since 1993. These data have been combined for females from SCI 1 and 2, assuming internal gonad stages 2–5 to be mature, and stage 1 to be immature. Data from SCI 6A are analysed separately. No data are available for the maturity of male scampi, so their maturity ogive was assumed identical to that of females, although studies on *N. norvegicus* have suggested that male maturity may occur at a larger size

(although possibly the same age) than females (Tuck et al. 2000). Maturity is not considered to be a part of the model partition, but proportions mature were fitted within the model based on a logistic ogive with a binomial likelihood (Bull et al. 2008). Analysis of the proportion mature data, modelled as a function of length within a GLM framework, with a quasi distribution of errors and a logit link (McCullagh & Nelder 1989),

$$P.mature = a + b * Length$$

which equates to the logistic model. The model was weighted by the number measured at each length. After obtaining estimates for the parameters a and b, the length at which 50% are mature (L_{50}) was calculated from:
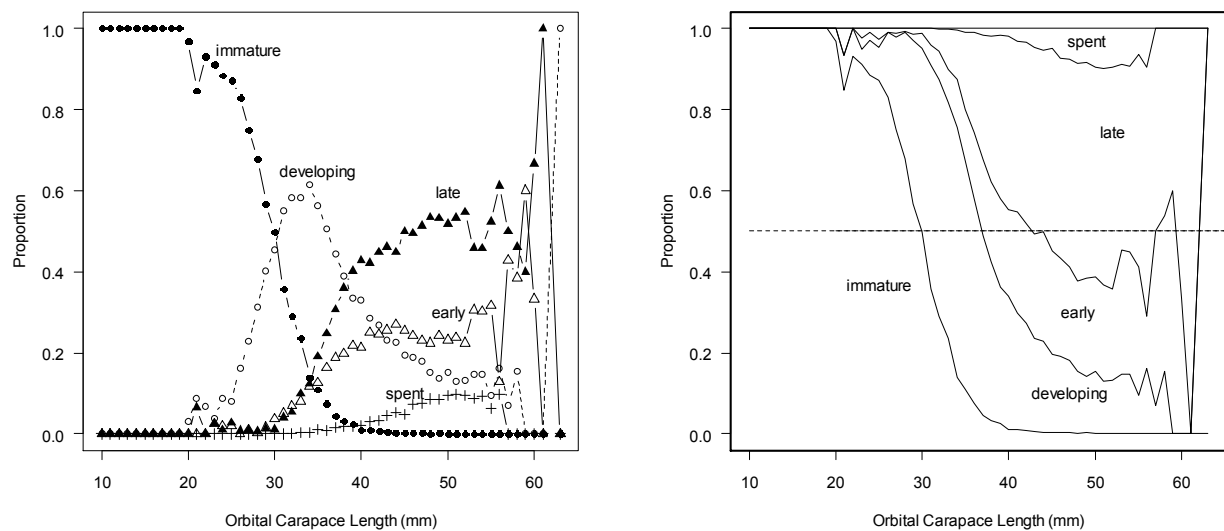
$$L_{50} = -\frac{a}{b}$$

with selection range (SR) calculated from:

$$SR = \frac{(2.\ln(3))}{b}$$

SCI 1 and SCI 2

Female maturity data for SCI 1 and 2 are summarised in Figure 8 (Tuck & Dunn 2006). The L_{50} estimate for the pooled SCI 1 and SCI 2 data was 29.7 mm, with a selection range a_{25} to a_{75} of 5.3mm.
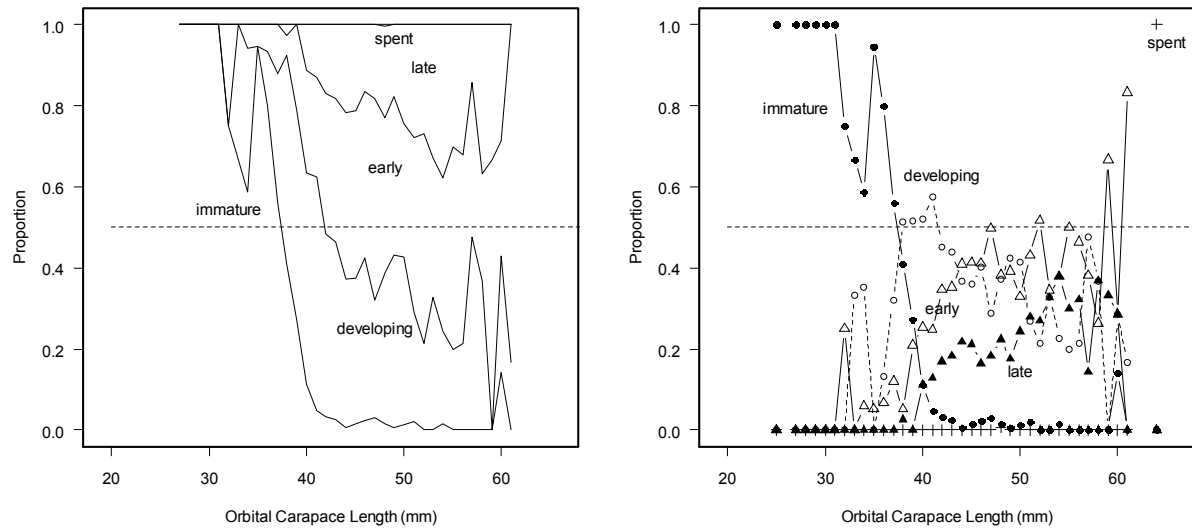

Figure 8: Proportions of female scampi having various developmental stages of internal ovaries. Left panel shows proportions of each stage separately, right panel shows combined proportions. Aggregated data from research voyages in SCI 1 and 2.

SCI 6A

Female maturity data for SCI 6A are summarised in Figure 9. The L_{50} estimate for the SCI 6A data was 37.0 mm, with a selection range a_{25} to a_{75} of 5.8mm. The larger L_{50} for SCI 6A (compared to SCI 1 and SCI 2), would support the suggestion of faster growth (larger increments at size) in this stock.

Studies on *Nephrops* have identified spatial variability in size at maturity related to variability in growth, with age at onset of maturity remaining relatively constant (Tuck et al. 2000).

Figure 9: Proportions of female scampi having various developmental stages of internal ovaries. Left panel shows proportions of each stage separately, right panel shows combined proportions. Aggregated data from research voyages in SCI 6A.

2.3.4. Natural mortality

The instantaneous rate of natural mortality, M, has not been estimated directly for any scampi species, but estimates have been made based on the estimate of the K parameter from a von Bertalanffy growth curve (Cryer & Stotter 1999) using a correlative method (Pauly 1980, Charnov et al. 1983). For the current model, M is fixed at 0.2.

2.4. Catch data

Data for the models were collated over the spatial and temporal strata as defined in the model structure. Spatial strata (Figure 10) used in each model were restricted to the core depth range of the fisheries (300–500m for SCI 1 and SCI 2, 350–550m for SCI 6A), and were strata 202, 203, 302 (combined with 402) and 303 (combined with 403) for SCI 1, 702, 703, 802 and 803 for SCI 2, and 350, 400, 450 and 500 for SCI 6A. The combination of SCI 1 strata 302 and 402, and 303 and 403 was implemented to simplify the structure (reduce the number of strata), given the relatively low level of sampling in 402 and 403. Estimated landed catch by fishing year and strata-time step are provided in Table 7 for SCI 1, Table 8 for SCI 2, and Table 9 for SCI 6A. Expansion of the SCI 1 modelled area to include survey strata 202 and 203 has increased the proportion of the fishery included in the model from about 60% to over 98% for SCI 1. The modelled area for SCI 2 has consistently included 97 to 98% of the fishery (except 2005: 80%). The modelled area for SCI 6A has included about 90% of the fishery over its history.
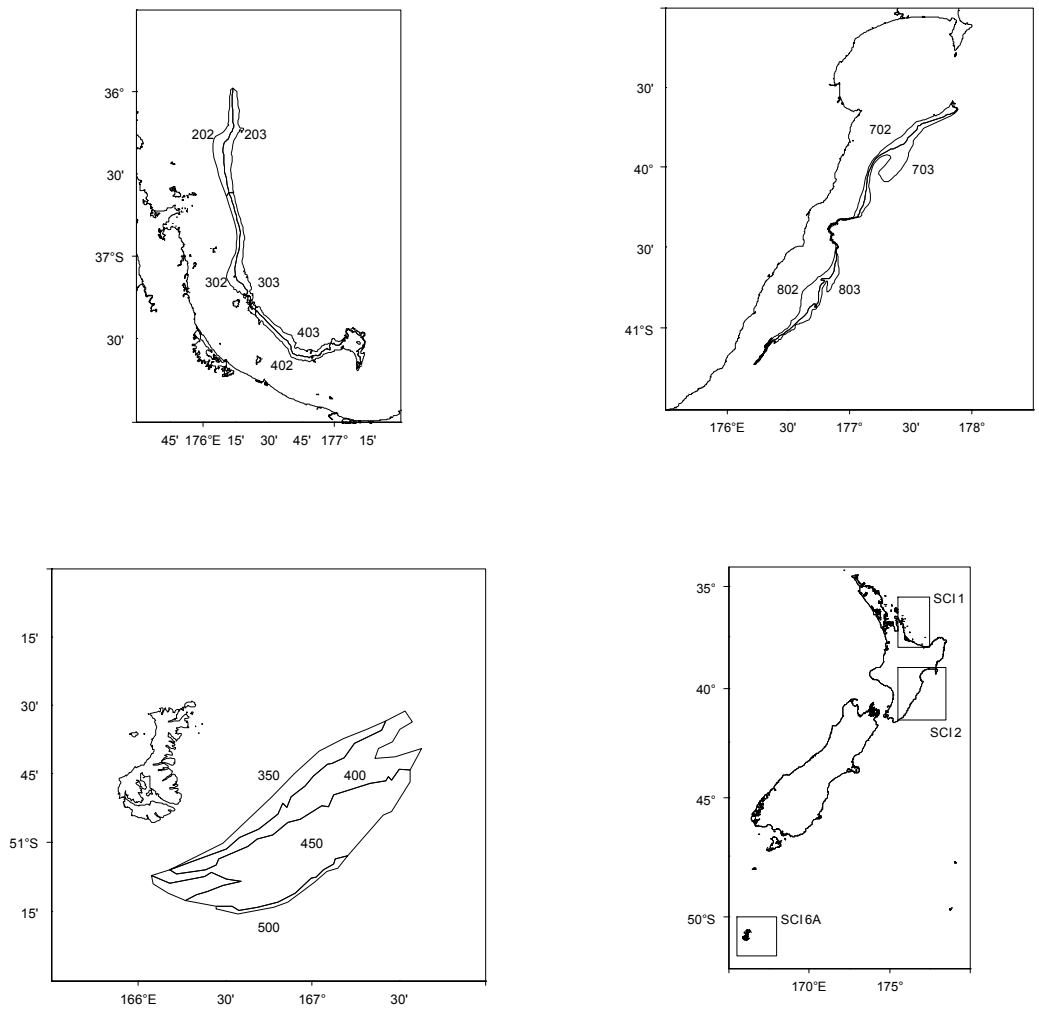
Figure 10: Survey strata for SCI 1 (top left), SCI 2 (top right), SCI 6A (bottom left). Bottom right plot shows general area locations.

The breakdown of catches on an annual basis by stratum is also in Figure 11 for SCI 1, Figure 12 for SCI 2, and Figure 13 for SCI 6A. It can be seen that in each stock, the both the pattern and magnitude of catches vary between strata over time.

Table 7: Estimated landed catch (t) from SCI 1 by fishing year and spatial strata-time step.

| Fishing year	202_1	202_2	202_3	203_1	203_2	203_3	3/402_1	3/402_2	3/402_3	3/403_1	3/403_2	3/403_3	Total
1987	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.95	0.58	0.00	0.95	2.59	5.10
1988	0.00	0.00	0.00	0.00	0.01	0.06	0.00	2.80	1.72	0.00	2.82	7.68	15.10
1989	0.00	0.00	0.00	0.00	0.05	0.25	0.00	11.13	6.84	0.00	11.22	30.50	60.00
1990	0.29	0.00	0.24	0.22	0.08	0.00	32.00	10.43	34.36	15.66	4.45	6.26	104.00
1991	0.11	0.02	30.20	0.00	0.49	35.22	29.91	21.83	17.70	13.77	11.14	18.62	179.00
1992	8.17	0.28	15.05	3.51	0.26	6.98	43.84	9.99	21.95	12.38	1.43	8.16	132.00
1993	17.85	0.71	4.32	1.93	0.17	13.25	19.96	17.21	15.45	3.92	3.54	15.69	114.00
1994	22.51	0.76	5.12	4.92	0.00	13.84	35.06	0.44	8.32	12.82	0.04	11.18	115.00
1995	30.05	11.73	15.37	1.86	5.05	6.77	14.51	6.30	4.53	7.03	3.65	7.15	114.00
1996	22.49	0.28	0.41	17.50	13.26	2.84	9.61	1.65	7.86	20.02	8.26	12.82	117.00
1997	0.58	8.08	1.90	19.45	17.55	5.87	3.07	1.02	1.89	33.32	13.51	10.75	117.00
1998	15.11	0.00	0.17	25.45	0.54	0.17	25.63	3.12	4.50	22.17	5.43	4.71	107.00
1999	6.57	2.59	0.00	11.28	6.13	0.00	27.83	17.93	3.44	16.36	12.87	5.00	110.00
2000	3.86	1.38	20.66	7.95	6.72	17.88	2.75	2.46	30.65	7.79	13.53	8.37	124.00
2001	22.38	9.04	1.87	15.18	2.45	1.10	35.60	16.72	1.29	9.09	4.33	0.95	120.00
2002	33.12	0.00	0.00	27.87	0.00	0.00	44.73	0.00	0.00	18.28	0.00	0.00	124.00
2003	30.85	0.00	0.00	19.18	0.00	0.00	54.77	0.00	0.00	16.20	0.00	0.00	121.00
2004	33.04	0.00	0.00	21.20	0.00	0.00	53.12	0.00	0.00	12.64	0.00	0.00	120.00
2005	15.70	9.08	9.85	13.12	5.46	10.24	10.12	8.28	11.56	6.93	11.03	2.61	114.00
2006	8.37	8.69	11.80	4.68	2.59	21.72	18.47	13.96	4.67	9.58	0.69	3.79	109.00
2007	13.44	4.65	12.60	4.93	3.77	9.76	18.42	18.95	7.63	6.61	6.84	2.39	110.00
2008	13.80	4.83	4.42	1.95	2.77	9.33	22.13	18.34	3.61	10.55	7.54	2.73	102.00
2009	9.48	4.02	1.07	6.59	3.14	3.54	19.61	8.88	8.26	14.75	2.40	4.26	86.00
2010	15.17	0.35	0.82	15.31	0.74	0.49	29.07	9.06	22.52	5.93	5.02	6.91	111.40

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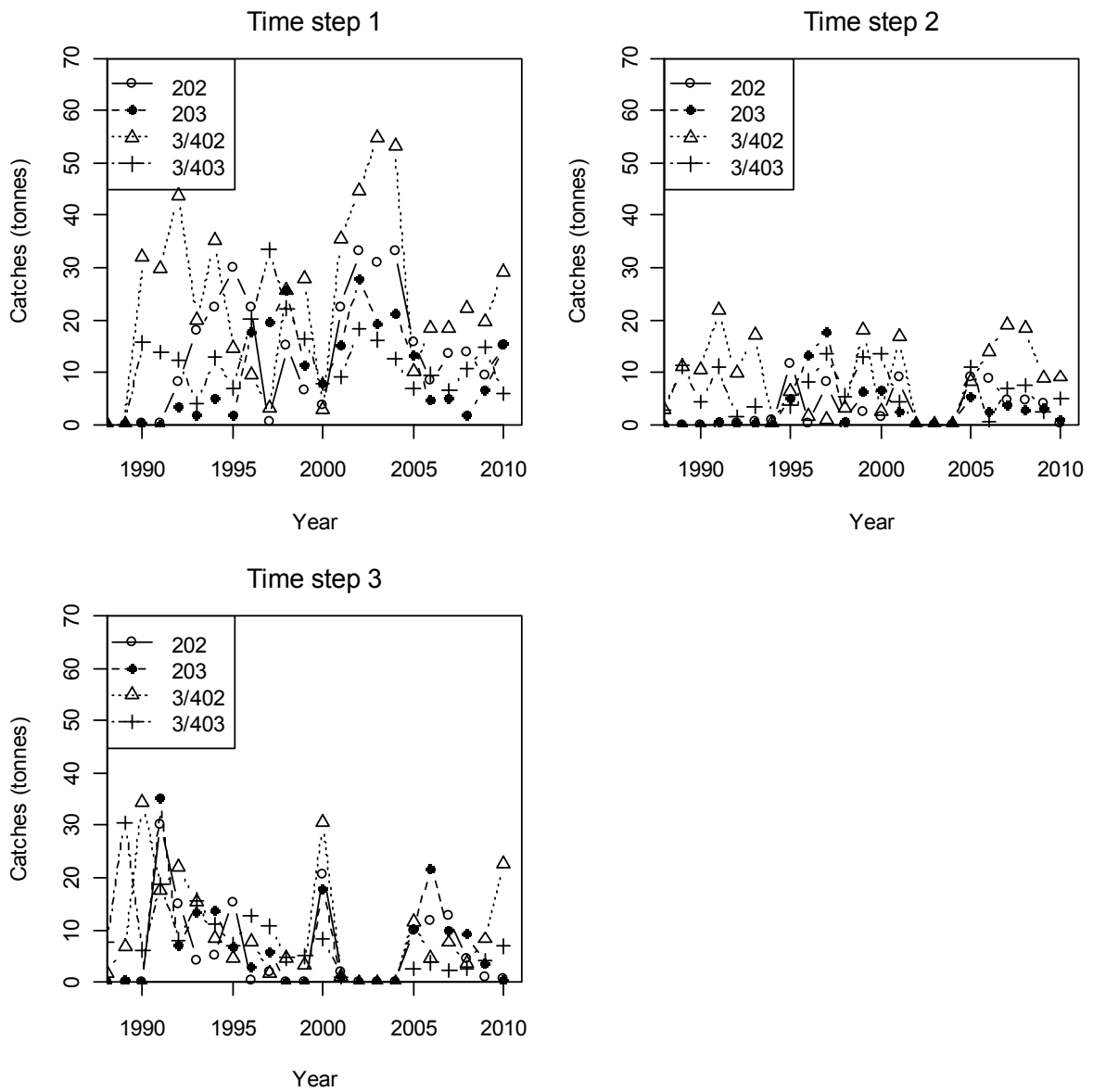
Figure 11: Annual breakdown of scampi catches by stratum and timestep in SCI 1.

Table 8: Estimated landed catch (t) from SCI 2 by fishing year and spatial strata-time step.

| Fishing year	702_1	702_2	702_3	703_1	703_2	703_3	802_1	802_2	802_3	803_1	803_2	803_3	Total
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	3.15	0.00	0.00	0.00	0.00	0.35	1.49	0.00	0.00	0.01	5.00
1989	0.00	0.00	10.52	0.00	0.00	0.00	0.00	1.18	4.98	0.00	0.00	0.03	16.72
1990	16.49	14.03	55.10	0.11	0.00	3.10	0.21	23.65	24.36	0.00	0.04	0.00	137.09
1991	45.32	15.03	36.33	0.19	0.57	11.13	89.73	40.10	43.34	0.00	0.00	1.68	283.42
1992	39.04	4.09	45.75	0.40	0.00	8.82	27.48	15.12	59.78	0.12	0.00	2.20	202.78
1993	49.61	23.90	25.48	2.91	0.87	5.81	20.58	34.95	36.19	0.00	0.00	1.01	201.30
1994	18.93	51.30	84.45	1.95	1.17	5.78	9.01	0.88	58.91	0.06	0.00	3.74	236.18
1995	20.57	14.31	23.16	8.07	0.75	3.20	40.30	26.22	70.88	0.05	1.01	6.93	215.46
1996	70.86	20.59	45.73	15.28	0.47	8.15	20.06	5.37	35.27	1.88	0.01	4.64	228.29
1997	41.22	35.43	48.72	7.79	12.97	19.56	13.91	21.29	5.78	0.86	0.53	0.78	208.84
1998	77.76	13.40	2.13	8.30	2.04	0.82	64.69	28.02	17.04	1.29	0.00	0.69	216.17
1999	67.36	26.20	16.13	10.07	6.21	8.68	48.00	35.80	6.55	1.45	0.00	0.22	226.66
2000	42.84	7.56	50.60	9.01	0.05	8.17	48.96	7.09	15.01	0.76	0.00	0.25	190.31
2001	16.67	20.13	49.47	0.81	0.14	5.37	10.82	11.97	27.46	0.00	0.05	0.06	142.96
2002	41.58	47.01	37.92	1.98	2.50	15.60	20.43	48.07	18.15	1.45	0.00	0.87	235.57
2003	33.89	10.72	10.15	3.00	3.99	3.94	40.37	22.56	0.12	0.00	0.25	0.00	128.97
2004	27.06	15.86	0.39	4.45	1.67	0.00	7.53	6.15	0.00	0.19	0.00	0.00	63.29
2005	20.63	5.32	5.77	4.00	0.37	3.01	8.15	3.51	5.17	0.12	0.00	0.50	56.55
2006	16.21	5.72	21.21	1.14	0.16	6.25	18.15	0.16	5.71	0.24	0.00	0.20	75.13
2007	12.42	15.61	11.37	2.24	0.30	2.07	21.09	9.79	3.85	0.11	0.10	0.00	78.93
2008	32.79	4.55	0.27	1.37	0.07	0.00	19.80	0.97	0.10	0.67	0.00	0.00	60.58
2009	18.25	4.16	5.65	0.68	0.05	0.00	15.04	7.37	0.80	0.00	0.00	0.00	52.00
2010	34.18	5.06	20.16	0.17	0.17	1.46	47.80	5.22	9.67	0.96	0.00	0.31	125.15
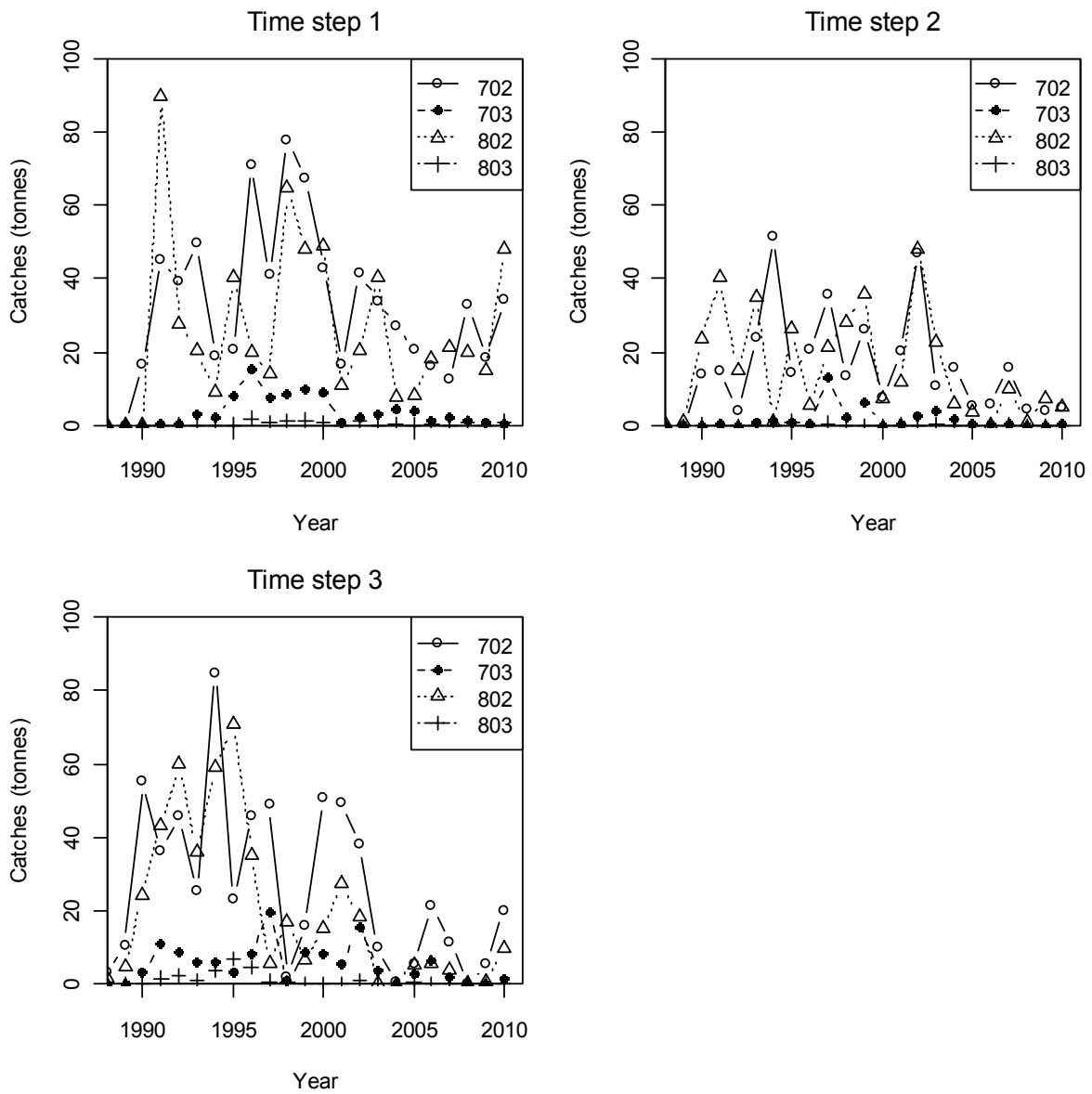
Figure 12: Annual breakdown of scampi catches by stratum and timestep in SCI 2.

Table 9: Estimated landed catch (t) from SCI 6A by fishing year and spatial strata-time step.

Modelled year	350_1	350_2	350_3	400_1	400_2	400_3	450_1	450_2	450_3	500_1	500_2	500_3	Total
1991	0.93	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	1.43
1992	66.44	5.92	1.91	122.30	46.84	7.21	20.45	14.09	1.46	0.23	28.81	0.00	315.66
1993	46.61	2.42	3.56	50.97	4.93	5.67	40.95	1.29	15.56	19.53	0.00	1.19	192.66
1994	46.89	0.00	2.58	94.48	0.00	11.53	74.55	0.00	15.34	30.46	0.00	8.28	284.10
1995	30.12	3.60	0.06	43.45	17.89	11.82	41.94	20.91	27.63	12.58	1.79	24.82	236.62
1996	7.41	0.92	0.69	61.08	8.22	11.59	64.40	10.39	39.23	40.12	1.55	15.85	261.44
1997	0.00	0.34	0.00	31.41	10.53	0.77	95.46	17.46	11.02	22.44	9.52	22.66	221.59
1998	9.53	2.62	0.00	62.92	19.25	5.60	38.20	50.22	29.57	4.03	11.57	0.35	233.85
1999	6.26	0.00	0.00	51.51	15.96	2.20	84.96	15.46	20.30	17.70	16.25	20.17	250.77
2000	0.87	1.47	0.00	18.53	10.47	5.31	110.28	46.77	29.54	19.86	14.39	10.03	267.53
2001	1.05	0.00	0.44	9.80	11.99	3.35	45.44	57.10	67.00	7.87	21.39	9.61	235.05
2002	0.73	0.00	1.27	20.59	0.00	9.38	140.14	0.00	44.32	28.86	0.00	8.08	253.37
2003	3.31	0.00	5.08	17.06	0.00	35.20	106.27	0.00	50.70	13.85	0.00	4.78	236.25
2004	2.55	0.00	0.38	46.80	0.00	34.39	94.61	0.00	32.78	23.50	0.00	16.17	251.17
2005	7.91	22.49	3.62	33.23	37.05	37.78	28.08	24.07	39.84	10.05	6.39	42.50	293.01
2006	2.63	2.23	2.03	33.00	63.99	5.17	43.07	17.77	94.19	4.02	0.50	13.17	281.77
2007	0.42	0.55	0.27	27.73	26.77	48.98	36.02	10.69	104.01	2.56	1.26	14.72	273.98
2008	0.17	0.56	1.29	15.72	36.63	27.18	58.71	3.36	101.78	9.85	0.17	24.03	279.46
2009	2.21	7.99	1.01	21.19	56.11	24.76	23.43	9.09	38.54	9.69	0.79	21.26	216.08
2010	0.20	0.23	0.00	7.44	4.31	1.44	24.76	40.92	22.00	3.53	5.15	3.70	113.69
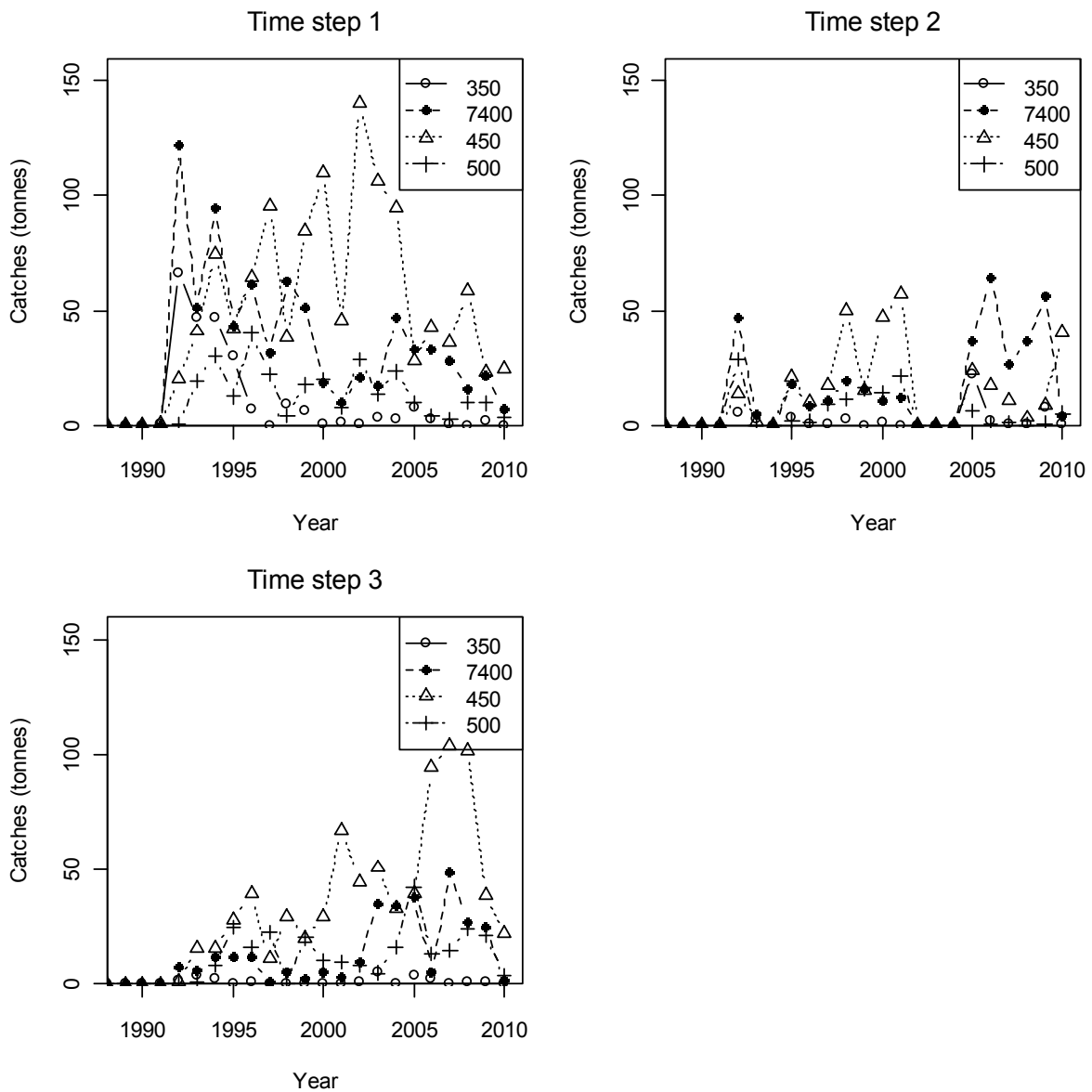
Figure 13: Annual breakdown of scampi catches by stratum in SCI 6A.

There are no known recreational or customary catches of scampi, or information on illegal catches, and all are ignored in the model.

2.4.1. Length frequency of the commercial catch

Length frequency samples from the commercial catch have been taken by scientific observers since 1992 (Hartill & Cryer 2000). Estimates of the length-frequency (with associated c.v.s) of the commercial catch by time step and strata were derived using the NIWA catch-at-age software (Bull & Dunn 2002), using 1 mm (OCL) length classes by sex. For models where the spatial structure was simplified, samples from strata were combined, weighting the proportions at length in each stratum by the amount of catch estimated to have been taken from these areas using the estimated catches reported on TCEPR. Numbers of hauls sampled by fishing year and strata-time step are presented for SCI 1 in Table **10**, SCI 2 in Table 11, and SCI 6A in Table 12, as are the total number of observer trips by fishing year. Individual observer trips may overlap time steps and record observations from more than one spatial stratum. Although data

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are often available for multiple hauls within fishing year and strata-time step combinations, these data are very rarely from more than one trip in a time step.

The observer sampling can be quite patchy in some areas (Hartill & Cryer 2000), and the previous model development (Cryer et al. 2005, Tuck & Dunn 2006) showed that the fitted data did not match the observed length frequency distributions well in some years and time steps, resulting in the recommendation that the representativeness of the available observer data be examined. The depth distribution of the fishery is poorly represented by observer sampling in some years (Tuck & Dunn 2006), and the inclusion of depth in the model stratification is hoped to alleviate this to some extent. Overall the level of sampling for the fisheries is low, and this remains a problem in implementing a length based model.

Table 10: Numbers of commercial hauls in SCI 1 targeting scampi for which length frequency data are available, by fishing year and spatial strata-time step. The number of separate fishing trips contributing to the data each year are indicated in the far right column.

Fishing year	202_1	202_2	202_3	203_1	203_2	203_3	3/402_1	3/402_2	3/402_3	3/403_1	3/403_2	3/403_3	Trips
1990–91	0	0	8	0	0	59	0	0	24	0	0	9	3
1991–92	0	0	16	1	0	0	14	0	0	1	0	0	2
1992–93	2	0	0	0	0	0	1	0	0	0	0	0	1
1993–94	0	0	0	0	0	0	0	0	1	0	0	0	2
1994–95	0	0	3	0	0	0	0	0	0	0	0	0	1
1995–96	0	0	0	1	0	1	4	0	0	0	0	0	2
1996–97	0	0	0	0	7	0	0	1	0	0	8	0	1
1997–98	0	0	0	0	0	0	0	0	0	0	0	0	1
1998–99	0	0	0	0	4	0	0	6	0	0	4	0	2
1999–00	0	0	4	0	0	16	0	0	8	0	0	3	1
2000–01	0	0	0	0	0	0	0	0	0	0	0	0	0
2001–02	0	0	0	2	0	0	1	0	0	0	0	0	1
2002–03	0	0	0	0	0	0	0	0	0	0	0	0	0
2003–04	1	0	0	1	0	0	0	0	0	0	0	0	1
2004–05	0	0	6	0	0	7	0	0	2	0	0	1	1
2005–06	2	0	9	2	0	15	2	0	0	7	0	1	2
2006–07	3	0	9	3	0	1	13	0	4	1	0	2	3
2007–08	0	0	0	5	0	0	7	22	0	12	10	0	2
2008–09	2	0	0	4	0	0	14	0	0	6	0	0	1
2009-10	9	2	2	0	0	4	2	8	13	2	5	11	3

Table 11: Numbers of commercial hauls in SCI 2 targeting scampi for which length frequency data are available, by fishing year and spatial strata-time step. The number of separate fishing trips contributing to the data each year are indicated in the far right column.

Fishing year	702_1	702_2	702_3	703_1	703_2	703_3	802_1	802_2	802_3	803_2	803_3	Trips
1990–91	0	0	31	0	0	18	0	0	12	0	0	4
1991–92	9	0	0	0	0	0	5	0	0	0	0	1
1992–93	1	0	8	0	0	1	2	0	18	0	0	3
1993–94	0	0	32	0	1	2	0	0	25	0	0	3
1994–95	0	4	7	0	2	0	0	17	24	1	6	3
1995–96	13	0	4	0	0	0	0	0	10	0	1	1
1996–97	27	1	5	1	0	0	6	0	0	0	0	2
1997–98	3	1	0	1	1	0	0	0	0	0	0	1
1998–99	49	19	0	12	6	0	23	0	0	0	0	4
1999–00	27	0	1	23	0	0	29	0	0	0	0	4
2000–01	43	0	7	2	0	1	16	0	0	0	0	3
2001–02	29	0	59	0	0	0	13	0	0	0	0	3
2002–03	11	0	5	2	0	0	0	0	0	0	0	2
2003–04	0	0	0	0	0	0	0	0	0	0	0	0
2004–05	0	0	0	0	0	0	6	0	0	0	0	1
2005–06	0	0	0	0	0	0	0	0	0	0	0	0
2006–07	0	3	4	0	0	0	0	1	0	0	0	1
2007–08	14	8	2	2	0	0	8	3	1	0	0	3
2008–09	0	12	0	0	0	0	0	0	0	0	0	1
2009-10	0	0	7	0	0	2	0	0	0	0	0	1

Table 12: Numbers of commercial hauls in SCI 6A targeting scampi for which length frequency data are available, by fishing year and spatial strata-time step. The number of separate fishing trips contributing to the data each year are indicated in the far right column.

Modelled year	350_1	400_1	450_1	450_2	450_3	500_1	500_2	500_2	Trips
1990–91	0	0	0	0	0	0	0	0	0
1991–92	38	57	13	0	0	8	0	0	6
1992–93	20	15	1	0	0	1	0	0	2
1993–94	10	31	57	0	0	26	0	1	5
1994–95	1	4	15	0	0	0	0	0	1
1995–96	1	11	44	0	0	5	0	0	2
1996–97	0	0	25	0	0	45	1	1	2
1997–98	8	39	17	1	0	1	0	0	4
1998–99	0	2	13	0	0	6	0	0	1
1999–00	0	1	22	0	0	1	0	0	1
2000–01	0	0	31	0	0	4	1	0	3
2001–02	0	1	53	0	0	2	0	0	4
2002–03	3	35	47	0	0	2	0	0	3
2003–04	0	0	0	0	0	0	0	0	0
2004–05	0	2	25	0	2	6	0	2	2
2005–06	0	0	0	0	0	0	0	0	0
2006–07	0	25	6	0	0	0	0	0	2
2007–08	0	1	20	0	0	5	0	0	1
2008–09	1	12	17	0	0	0	0	0	2
2009-10	0	0	0	22	0	0	2	0	1

2.5.   Resource surveys and other abundance information

2.5.1.   Photographic estimates of abundance

Photographic surveys of SCI 1 and SCI 2 (Cryer et al. 2003, Tuck et al. 2006, Tuck et al. 2009b) have been used to estimate the abundance of burrows thought to belong to scampi in 1998, 2000–2003, and 2008 (for SCI 1) and 2003–2006 (for SCI 2). Photographic surveys have been conducted in SCI 6A in 2007–2009 (Tuck et al. 2007, Tuck et al. 2009a, Tuck et al. 2009b). The major burrow opening indices for the three modelled stocks are shown in Figure 14, along with the indices based on observed scampi. Within the assessment models for each stock, the raised estimates of major burrow openings are used as a relative abundance index, with q interpreted as the proportion of model stock abundance explained by the burrows included in the analysis of photographic surveys (assuming 100% occupancy). The expansion of the SCI 1 modelled area to include strata 202 and 203 means that 44% of the total area covered by the model is outside the area covered by the photo survey. The catchability term for the photo survey (q-$Photo$) has previously been examined in relation to its components, based on spatial coverage of the survey area compared to the modelled area, major burrow occupancy rate and major burrow opening detection rate (Tuck & Dunn 2006) (although it is recognised these may be further sub-divided). This investigation concluded that the previous assumptions (log-normally distributed prior of 1.0, c.v. of 0.5) for a prior on q-$Photo$ were not inappropriate (Cryer et al. 2005). This approach is re-examined in this report, taking into account the fact that the survey only covers 56% of the modelled area, and scampi density may be different in the unsurveyed area.

It is unclear whether photographic surveys from SCI 6A can be used in the same way as SCI 1 and SCI 2 in the assessment model. Photographic surveys within SCI 6A have consistently noted relatively high proportions of larger scampi on the seabed, and apparently not associated with a burrow (Tuck et al. 2007, Tuck et al. 2009a, Tuck et al. 2009b). These animals have often been observed within a trench like feature, and it has been hypothesised that some larger scampi in SCI 6A may not maintain burrows (similar behaviour has been observed in *Nephrops* on the sandier margins of scampi grounds in Scotland, although not to the same extent as in SCI 6A; observation by author). Therefore, in the current implementation of the assessment model for SCI 6A, a "scampi out of burrows" index has been developed, rather than a burrow index. The catchability term for this "scampi out of burrows" index (q-$Scampi$) is described below (2.6.1). It may also be possible to include a burrow index for this stock in future models, although additional information on the estimated proportion of the population maintaining a burrow will be required in determining a prior for q-$Photo$.

Length frequency distributions were estimated for the relative photographic abundance series, by measuring the widths of a large sample of major burrow openings in the images, and converting these to orbital carapace lengths using a regression of OCL on major opening width (Cryer et al. 2005). To estimate the c.v.s at length for each year, we used a bootstrap procedure, resampling with replacement from the original observations of burrow width, converting each observation to an estimated scampi size (in OCL), using an error term sampled from a normal distribution fitted to the regression residuals. Compared with the length frequency distributions from trawl catches, this procedure gave very large c.v.s, but we think this is realistic given the uncertainties involved in generating a length frequency distribution from burrow sizes. The length frequency distributions for the "scampi out of burrows" index for SCI 6A were estimated by measuring the OCL of all scampi out of burrows observed within each SCI 6A survey. To estimate the c.v.s at length for each year, we used a bootstrap procedure, resampling with replacement from the original observations.
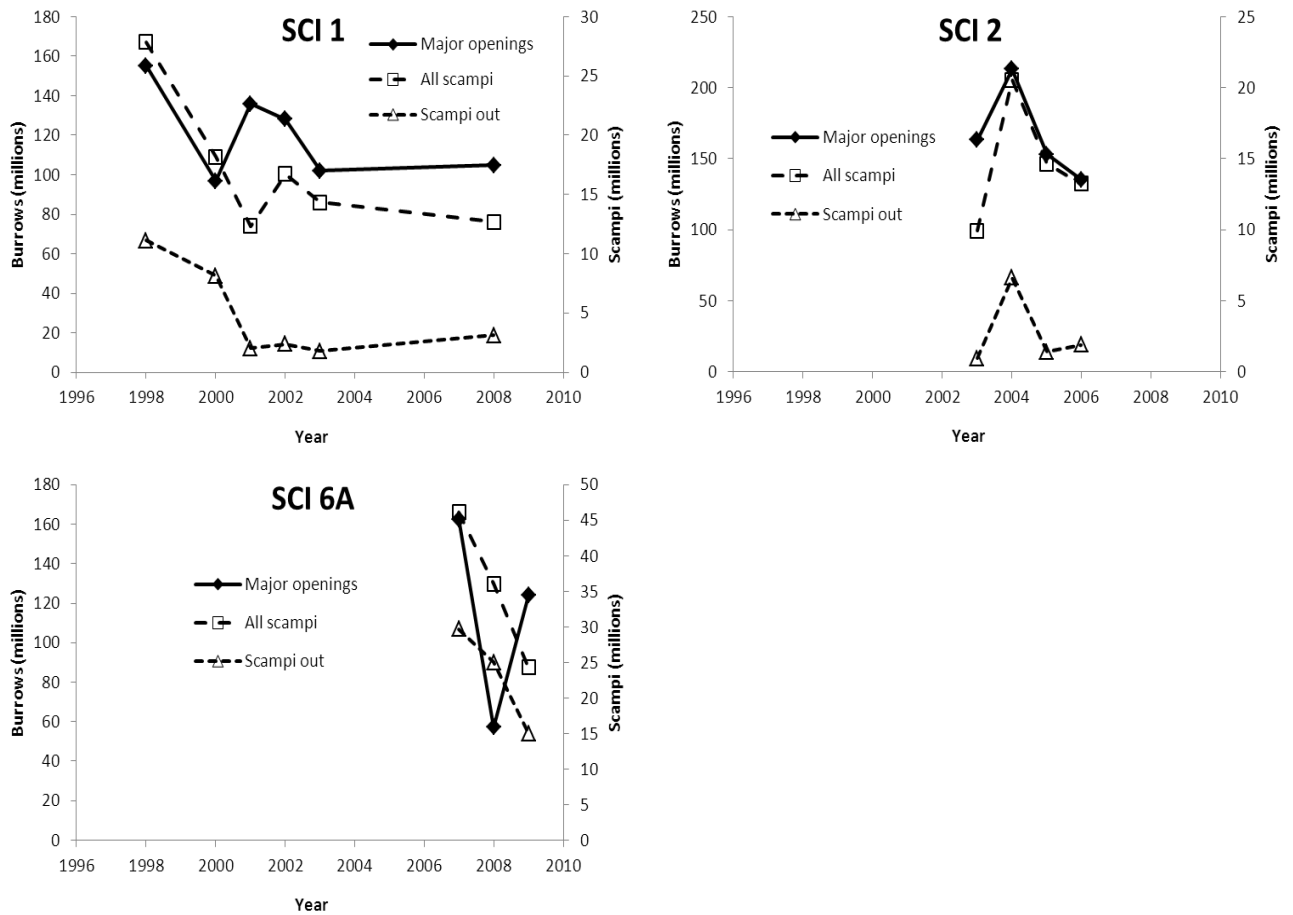
Figure 14: Comparison of abundance indices from photographic surveys of SCI 1 (top left), SCI 2 (top right), and SCI 6A (bottom left). Solid symbol - major burrow openings, Hollow square – all visible scampi, hollow triangle – scampi out of burrows.

2.5.2.   Research trawl indices of relative abundance

Stratified random trawl surveys of scampi in SCI 1 and SCI 2, 200–600 m depth, were conducted in 1993, 1994, and 1995. Formal trawl surveys to estimate relative abundance were discontinued following this, because it was inferred from the results that catchability had varied between surveys. Nevertheless, research trawling has continued in both areas for a variety of other purposes (in support of a tagging programme to estimate growth in 1995 and 1996, to assess selectivity of research and commercial mesh sizes in 1996, and in support of photographic surveys since 1998). Identical gear has been used throughout (30 mm cod-end and 80 mm wings and belly), or we have selected only those tows where the standard gear was used (on gear selectivity trials). The number of research tows available by fishing year and strata time step combinations are shown for SCI 1 in Table 13 and for SCI 2 in Table 14. Trawl surveys have only been conducted in 2007–2009 in SCI 6A , associated with photographic surveys (Table 15). We assume these time series (Figure 15) to be an estimate of abundance and fitted to these estimates within the model using observed c.v.s (assumed to be log-normally distributed).

Table 13: Numbers of research survey hauls in SCI 1 by fishing year and spatial strata-time step.

Fishing year	202_1	202_2	203_1	203_2	3/402_1	3/402_2	3/403_1	3/403_2
1992–93	3	0	3	0	12	0	12	0
1993–94	5	0	4	0	13	0	9	0
1994–95	5	0	4	0	13	0	9	0
1995–96	0	0	0	0	0	39	0	8
1997–98	0	0	0	0	10	10	0	0
1999–00	0	2	0	2	0	5	0	3
2000–01	0	0	0	0	0	7	0	5
2001–02	0	0	0	0	0	6	0	8
2007–08	0	0	0	0	0	4	0	6

Table 14: Numbers of research survey hauls in SCI 2 by fishing year and spatial strata-time step.

Fishing year	702_1	702_2	703_1	703_2	802_1	802_2	802_1	803_2
1992–93	11	0	5	0	6	0	4	0
1993–94	9	0	6	0	9	0	3	0
1994–95	8	0	8	0	9	0	4	0
1999–00	0	0	0	0	4	4	4	3
2002–03	0	1	0	2	0	2	0	2
2003–04	1	1	1	0	0	2	0	2
2004–05	0	2	0	2	0	2	0	2
2005–06	0	2	0	2	0	2	0	2

Table 15: Numbers of research survey hauls in SCI 6A by modelled year and spatial strata-time step.

Modelled year	350_1	400_1	450_1	500_1
2006–07	2	2	7	1
2007–08	2	3	5	2
2008–09	3	5	8	3
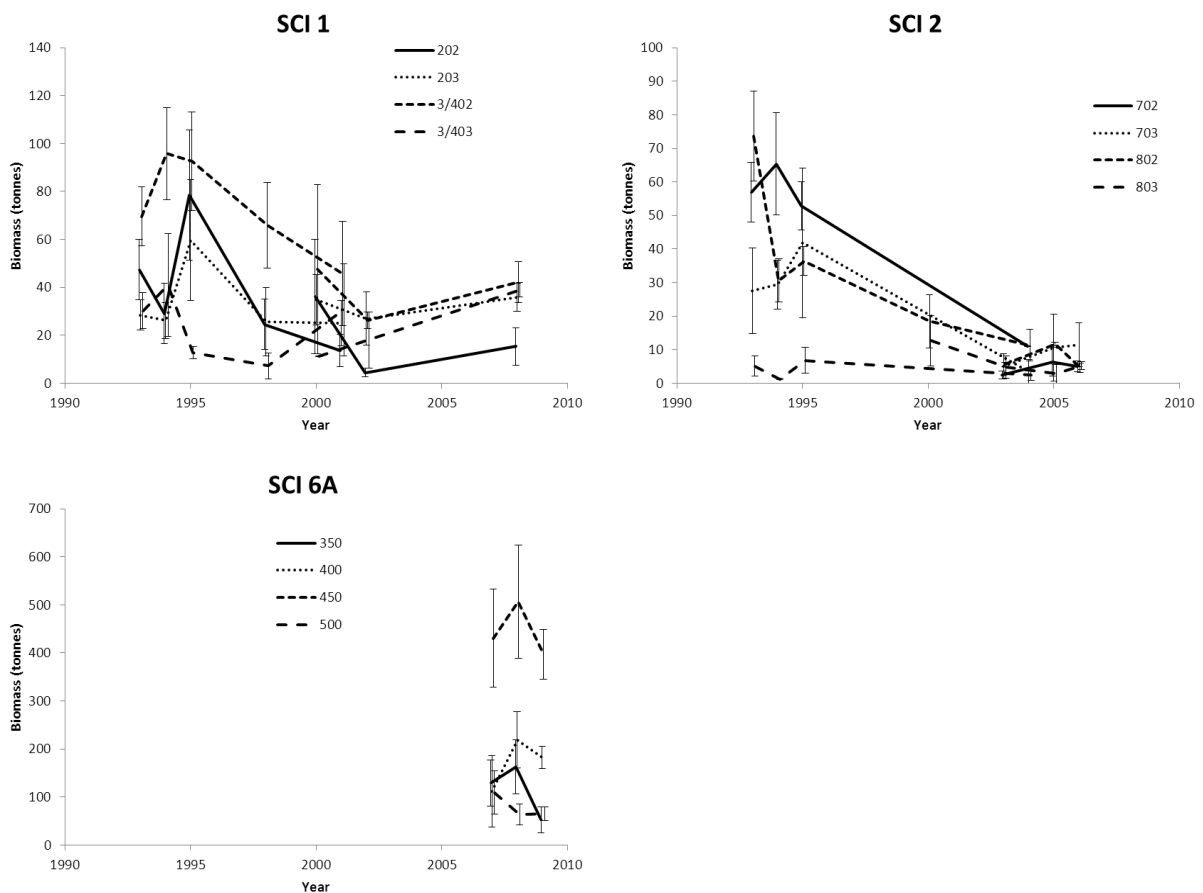
Figure 15: Estimated scampi abundance from research trawling in SCI 1 (top left), SCI 2 (top right), and SCI 6A (bottom left) by strata. For SCI 1 and SCI 2, early series conducted in time step 1, while later series conducted in time step 2. For SCI 6A, all three surveys conducted in time step 1.

2.5.3. Length frequency distributions from research trawling

Length frequency samples from research trawling have been taken by scientific staff since 1993 in SCI 1 (Table 13) and SCI 2 (Table 14), and since 2007 in SCI 6A (Table 15). Estimates of the length-frequency distribution (with associated c.v.s) were derived using the NIWA catch-at-age software (Bull & Dunn 2002), using 1 mm (OCL) length classes by sex. These were calculated separately for the sexes and for each strata-time step in the model.

2.5.4. Commercial catch-effort indices of relative abundance

Fully standardised indices for the SCI 1 and SCI 2 scampi fisheries were calculated up to the 1997–98 fishing year (Cryer & Coburn 2000), although these authors found that the standardised index was highly correlated with much simpler unstandardised indices (total catch divided by total fishing effort), and these simpler indices have been used since (Hartill & Cryer 2004). A recent characterisation of scampi fisheries (Tuck 2009) revisited the standardised indices, analysing catch estimated from the TCEPR in relation to fishing year, month, tow duration, time of day, depth and spatial location. Standardised indices were estimated for each strata-time step combination implemented in the various levels of model complexity, and these have been used as an index of relative abundance within the model, using the annual c.v.s estimated within the standardisation. The standardised indices are plotted for each stratum by time step for SCI 1 in Figure 16, for SCI 2 in Figure 17, and for SCI 6A in Figure 18. Recent changes in gear

configuration (moving to triple rig trawls) in some parts of the scampi fleet have not been allowed for in these indices. These changes are not thought to influence the SCI 1 and SCI 2 fisheries, but are of relevance for SCI 6A.

Although the patterns of catches vary quite considerably between strata in each of the stocks (see Figure 11 and Figure 12), the CPUE indices are quite consistent within time step for each stock.
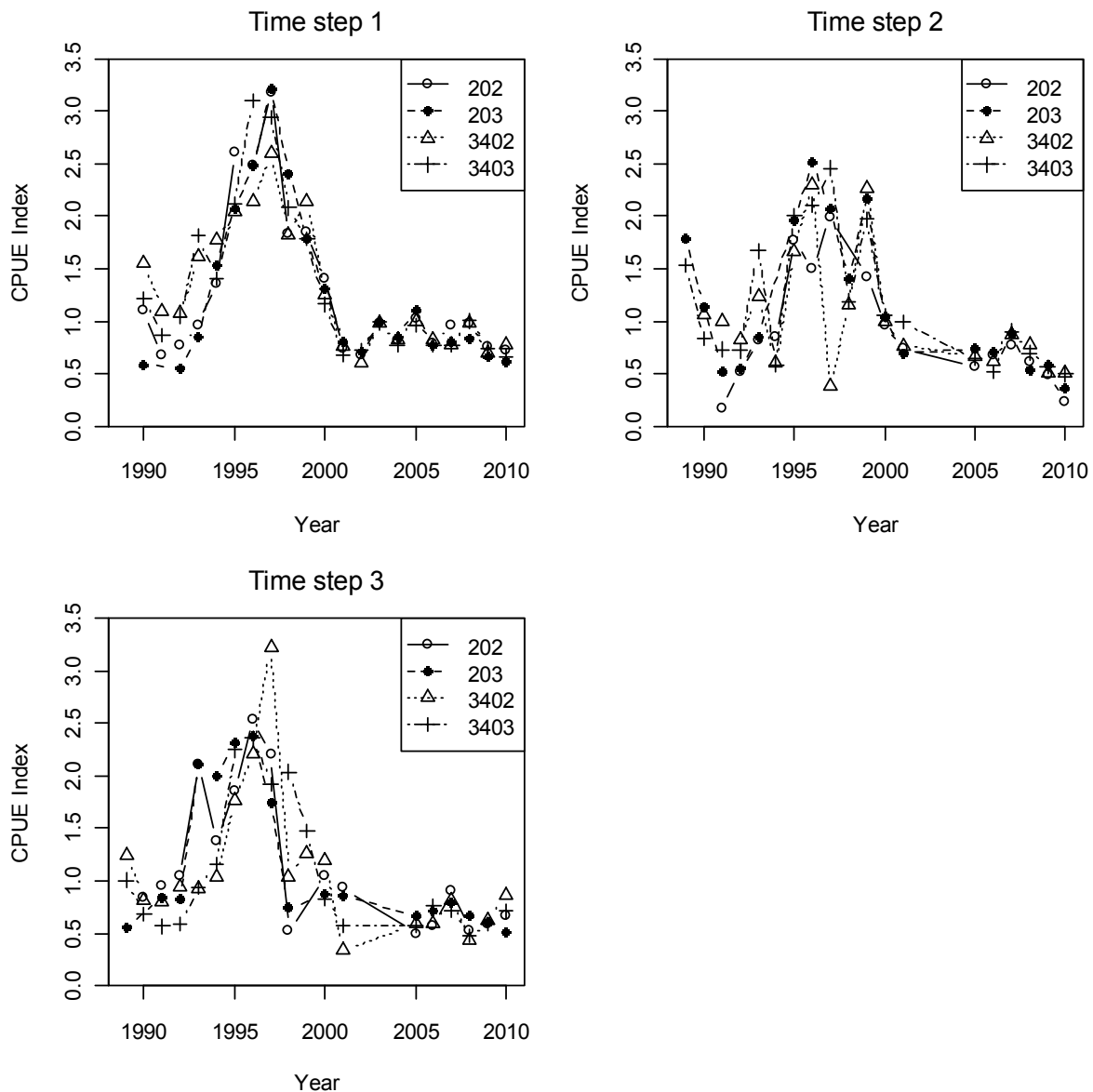
Figure 16: Standardised abundance indices estimated from TCEPR data for each strata-time step in SCI 1.

The appropriateness of incorporating the CPUE series into the assessment model has previously been raised at the SFAWG. The use of the CPUE as an index of abundance has been questioned owing to concerns that changes in these indices may be strongly influenced by changes in catchability caused by the behaviour of scampi rather than by changes in abundance. The sensitivity of the model to inclusion of these data is examined.
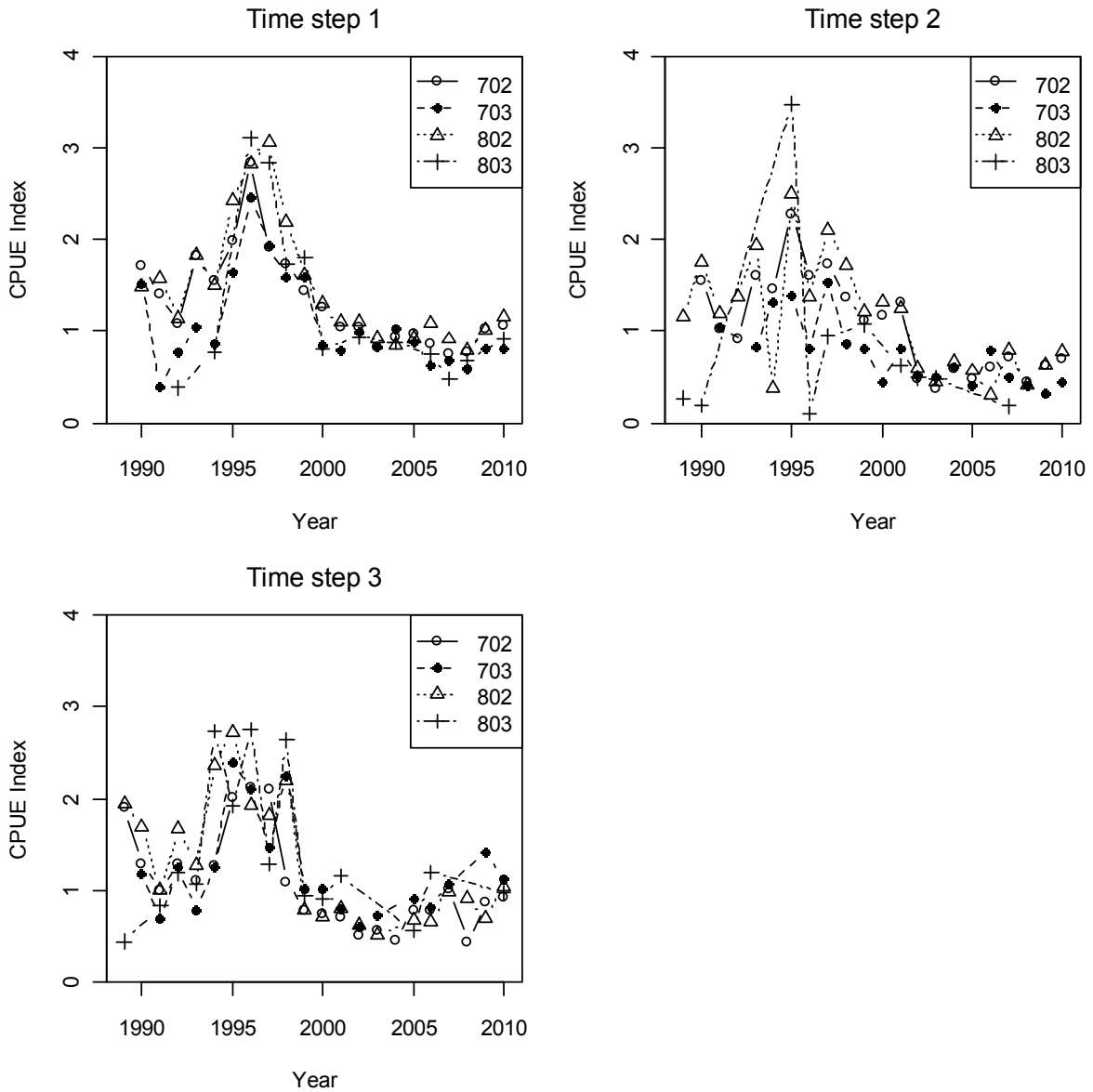
Figure 17: Standardised abundance indices estimated from TCEPR data for each strata-time step in SCI 2.
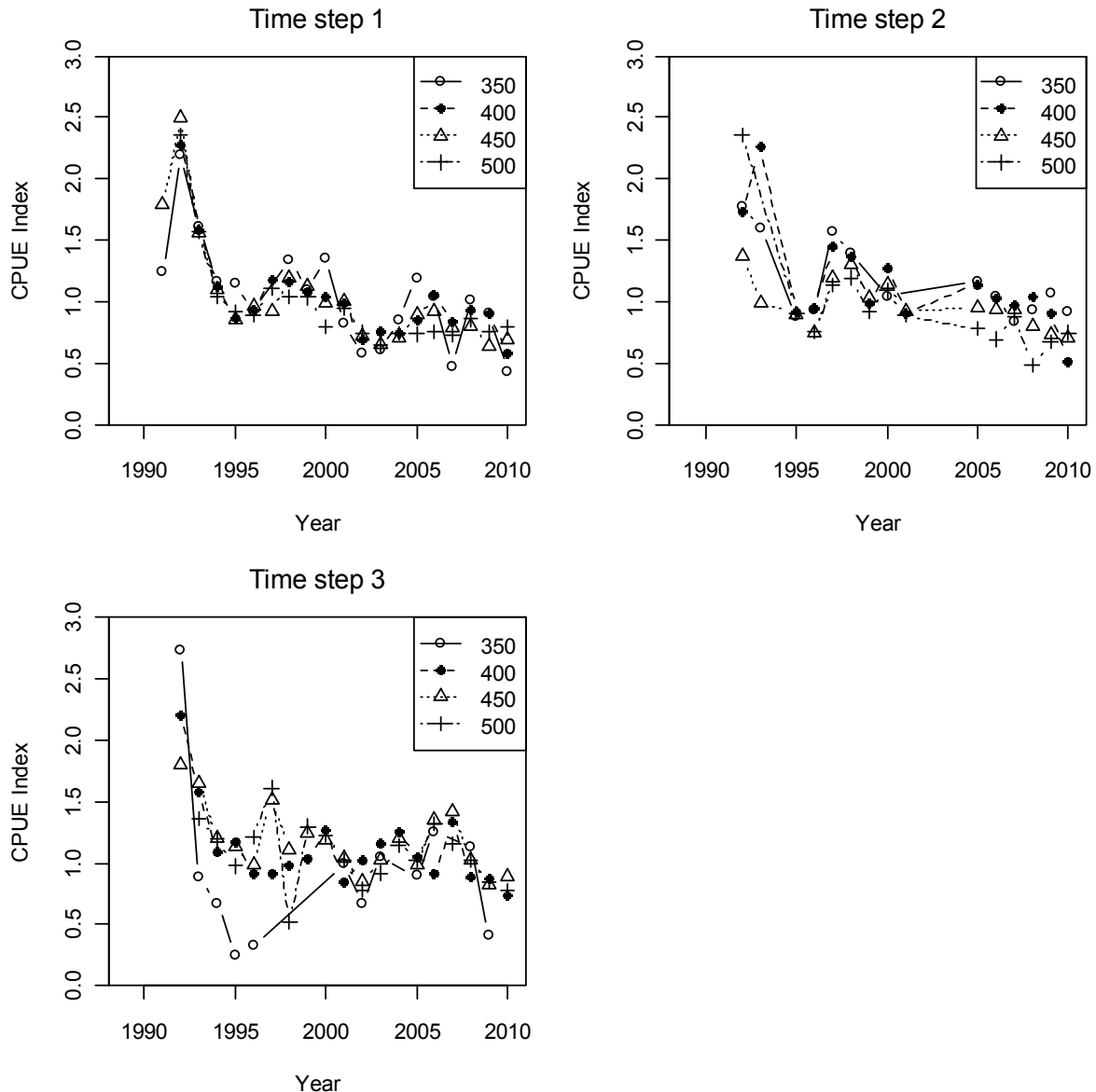
Figure 18: Standardised abundance indices estimated from TCEPR data for each strata-time step in SCI 6A.

2.5.5. Mark recapture data from SCI 6A

As described above (2.3.2) scampi tagging has been undertaken in SCI 1 and SCI 6A to estimate growth, and these data offer the potential of also being used to estimate stock size. The study in SCI 1 was conducted in a very localised area (Cryer & Stotter 1997, Cryer & Stotter 1999), and concerns have been expressed over the return rates (less than 1%). The series of investigations in SCI 6A (Tuck et al. 2007, Tuck et al. 2009a, Tuck et al. 2009b) have been conducted over a larger proportion of the area of the fishery, and return rates have been better (about 5%), but release locations were not random (Figure 19), and over the whole survey area there is clearly not an equal probability of recapturing a tagged animal. If the data are limited to the main areas of release and recapture, the assumption of equal probability of recapture is more likely to be valid, but trying to incorporate a mark recapture stock size estimate for only a portion of the stock into the assessment model is not practical within the current model structure.

Rather than fitting the mark recapture data within the model to estimate stock size, we have used the Petersen method to estimate the fishable stock size outside the model for the main release areas in each year, and used these estimates in conjunction with trawl survey data to inform q priors.
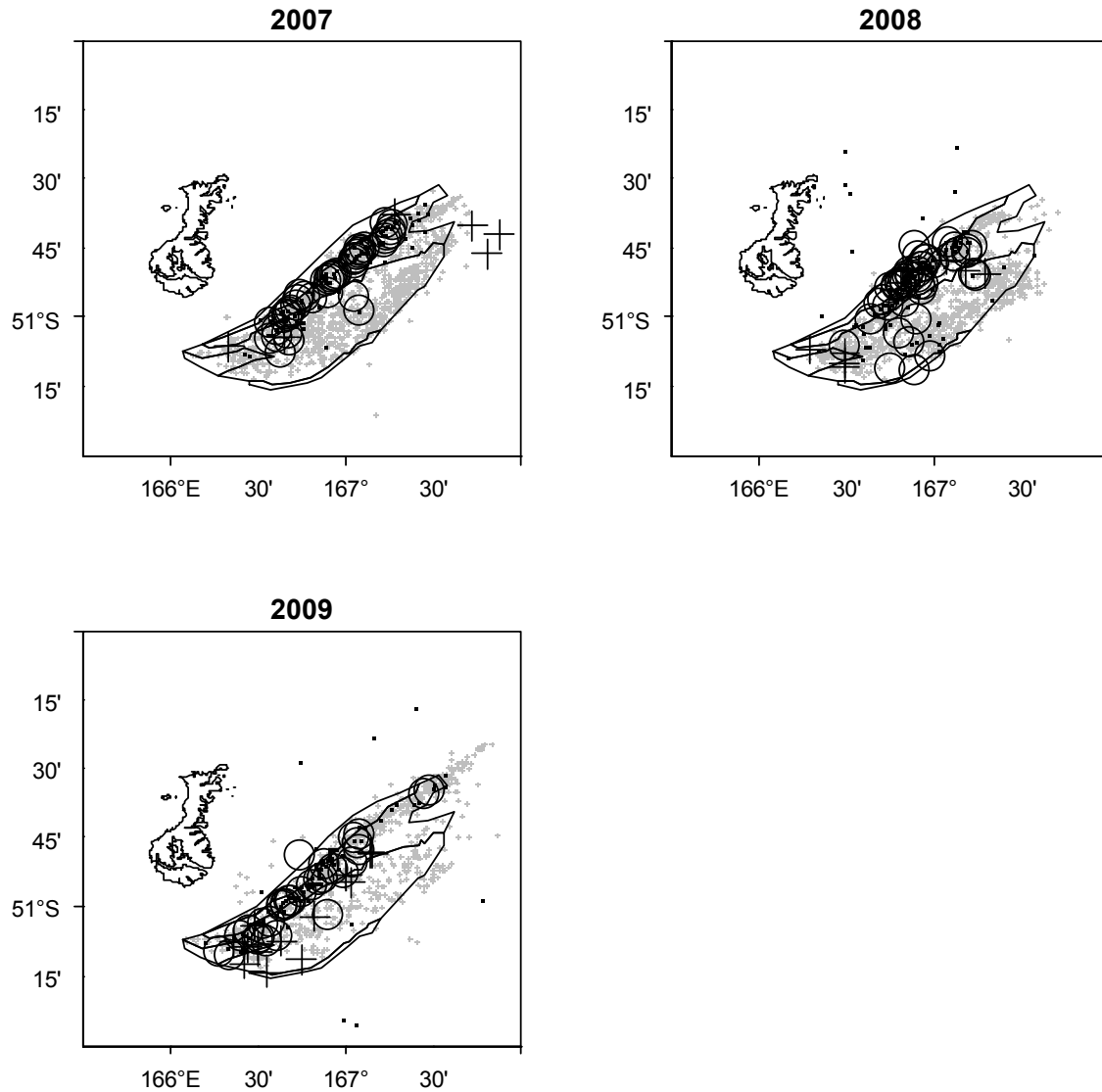
Figure 19: Scampi release (from which animals have been recaptured: black circle, and from which no recaptures have been reported: black cross) and recapture (black dot) locations by year in SCI 6A. Grey dots represent mid points of commercial tows from TCEPR by vessels that returned tagged scampi.

For each of the tagging exercises, the main area of tag releases and recaptures were delimited, and fishing activity targeting scampi conducted within the area identified. The decline in recapture rates beyond the first year (Table 6) suggests that there may be some tag loss at moulting, and to minimise the effect of this, only fishing activity and recaptures up to early November in the year of release are considered. Fishing activity and tag recaptures are summarised for each year in Table 16.

Seven vessels (labelled A–G) recorded scampi targeted fishing in the relevant areas. Of these, only vessel E recorded no tag recaptures. Other vessels recorded tags from some trips, or in some years, but not in others. The tagging programme was well publicised to the scampi fishing industry, and given that the tag

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colours were chosen to contrast with the scampi, and that animals are individually handled during grading and packing, tag detection rates were expected to be very high (although they have not been quantified). In analysing the tag recapture data, detection (and reporting rates) have been assumed to be 100% for all vessels, or 100% for trips reporting at least one tag, and 0% for trips not reporting any tags.

No tagging studies for scampi have been specifically designed to estimate stock size, and tag mortality (including any mortality associated with returning to the seabed) has not been examined. Discard mortality in European scampi fisheries is estimated to be 60–70% (Wileman et al. 1999), based on animals returned to the seabed and held in cages, and therefore not including any predation on the surface or in the water column. In these European fisheries, discarded animals are generally discarded because they are undersize, and therefore may not represent the undamaged and lively animals selected for tagging. The release methodology employed (weighted paper bag with dissolving fastening) is intended to return the scampi to the seabed rapidly and minimise surface or water column predation, but recent acoustic tagging work in SCI 3 (personal observation by primary author) suggests that groups of scampi emerging from seabed release may also be subject to predation.

The length frequency distributions of released and recaptured scampi (Figure 20) suggest that smaller females may be slightly underrepresented in recaptures, although this may be related to mortality or behaviour. The overall sex ratio of the tagged scampi reflects catches at the time of the survey, and 61.2% of tagged animals were female. Given that over much of the recapture period considered (March–October) catches are more even in their sex ratio, or dominated by males (Figure 2), one would expect the sex ratio of recaptured animals to include relatively more males than the releases. Females made up 67.7% of recaptures, implying that males were less available than expected (either owing to greater mortality or behavioural factors). In each year tagging has occurred around March when males are moulting, and the apparent difference between the sexes may be related to this. Cryer & Stotter (1999) tagged scampi in SCI 1 in September and also noted that females had a higher recapture rate than males. Most male moulting is thought to occur in SCI 1 and SCI 2 in February–April, but there is evidence of moulting by smaller males (greater than 40mm CL) in September (Tuck 2010).

Table 16: Summary of fishing activity and tag recaptures in main tag release areas for each year of SCI 6A tagging study.

		2007					2008					2009		
Vessel	Catch (kg)	Start	End	Tags	Vessel	Catch (kg)	Start	End	Tags	Vessel	Catch (kg)	Start	End	Tags
F	3 522	20/02	10/03	4	C	50	13/03	6/04	2	C	8 340	8/02	26/03	24
C	6 860	28/02	31/03	2	A	2 760	26/03	17/04	7	F	3 140	23/02	21/03	0
G	3 890	25/03	2/05	4	G	17 470	6/04	17/05	20	C	2 970	5/04	17/05	43
F	4 790	26/03	8/04	7	A	6 460	5/05	1/06	6	B	4 937	7/04	6/06	20
C	4 505	18/04	2/05	0	A	7 740	12/06	22/07	22	G	9 675	7/04	25/05	32
C	5 430	10/05	15/06	16	C	3 590	13/06	25/07	15	A	246	18/04	9/05	0
G	4 078	18/05	16/06	23	G	4 870	11/07	30/08	12	F	985	21/04	9/05	0
F	7 451	25/05	30/06	2	A	3 635	5/08	27/08	0	F	4 446	13/05	14/07	0
G	4 260	27/06	6/08	9	C	940	5/08	5/09	3	C	5 140	26/05	30/06	9
C	5 150	28/06	6/08	5	B	1 670	22/08	30/09	6	G	9 850	1/06	10/07	67
E	4 040	27/07	16/08	0	G	420	6/09	30/09	0	A	6 865	9/06	5/07	2
A	5 346	29/07	20/08	3	A	1 400	8/09	6/10	0	A	9 330	12/07	14/08	55
G	5 986	13/08	18/09	10	C	460	13/09	30/09	5	G	6 400	28/07	4/09	0
A	1 882	28/08	25/09	10	B	150	3/10	25/10	0	F	3 200	1/08	27/09	0
D	11 614	28/08	23/10	25	G	590	3/10	19/10	0	A	5 580	28/08	25/09	0
G	600	25/09	30/09	1	A	1 670	19/10	15/11	0	G	2 080	12/09	30/09	0
G	500	1/10	3/11	4	G	1 780	28/10	26/11	0	C	6 570	28/09	27/10	12
A	348	8/10	5/11	1	C	970	3/11	13/12	2	G	4 300	4/10	24/10	0
F	7 267	28/10	23/11	12	A	1 980	22/11	12/12	0	C	2 630	31/10	20/11	1
E	10 215	2/11	4/12	0						G	1 200	5/11	9/12	0
C	5 890	3/11	15/12	0										
G	5 892	11/11	15/12	0										
A	4 188	16/11	6/12	7										

Figure 20: Proportional length frequency of scampi released and recaptured in SCI 6A, all years combined.

For each year of the tagging study, the fishable stock abundance has been estimated from tag recaptures using the Petersen method. Tag detection and reporting rates have been assumed to be 100% for all trips, or 100% for trips reporting tags and 0% for others. Tag mortality is assumed to be 0% or 75%. Stock abundance has been estimated for both sexes together, and for the sexes separately. Commercial catches have been converted to numbers by sex, using MFish observer data. Fishable stock estimates have been converted to density estimates over the relevant tag release areas, and are compared with trawl survey density estimates for the same areas in Table 17. Assuming that the fishable population is sampled equally by the commercial and the trawl survey gear (commercial gear with cod end mesh smaller than generally used commercially), then the trawl survey density estimate / fishable population estimate provides an estimate of *q-Trawl* as used in the model, the *q* for the trawl survey. Tuck et al. (2007) did not identify differences in scampi length distributions when comparing research and commercial cod ends. The *q-Trawl* estimates are consistently higher for females than males, as might be expected as males are underrepresented in catches at the time of year the survey has been conducted. For the most pessimistic assumptions considered (providing the lowest population estimates), *q-Trawl* is about 0.5–0.6, and is lower for other combinations.

Table 17: Fishable population density estimates (for different assumptions for tag detection and reporting, and tag mortality) compared with trawl survey estimates.

Tag mortality	Detection & reporting	Year	Trawl survey (.m^{-2})	Tag population estimate Combined sexes (.m^{-2})	Males (.m^{-2})	Females (.m^{-2})	Males + Females (.m^{-2})	Trawl survey q Combined sexes (.m^{-2})	Males (.m^{-2})	Females (.m^{-2})	Males + Females (.m^{-2})
0%		2007	0.0026	0.0183	0.0085	0.0097	0.0182	0.1414	0.1324	0.1500	0.1418
		2008	0.0029	0.0273	0.0139	0.0138	0.0277	0.1063	0.0815	0.1280	0.1047
	100%	2009	0.0017	0.0174	0.0099	0.0086	0.0184	0.0991	0.0722	0.1185	0.0937
75%		2007	0.0026	0.0046	0.0021	0.0024	0.0046	0.5648	0.5280	0.5986	0.5657
		2008	0.0029	0.0068	0.0035	0.0035	0.0069	0.4248	0.3248	0.5112	0.4177
	100%	2009	0.0017	0.0044	0.0025	0.0021	0.0046	0.3961	0.2881	0.4732	0.3739
0%	100% for trips reporting tags, 0% for others	2007	0.0026	0.0164	0.0076	0.0087	0.0163	0.1580	0.1475	0.1680	0.1585
		2008	0.0029	0.0240	0.0121	0.0123	0.0244	0.1208	0.0934	0.1443	0.1190
		2009	0.0017	0.0118	0.0066	0.0058	0.0125	0.1464	0.1075	0.1740	0.1385
75%	100% for trips reporting tags, 0% for others	2007	0.0026	0.0041	0.0019	0.0022	0.0041	0.6314	0.5884	0.6707	0.6323
		2008	0.0029	0.0060	0.0030	0.0031	0.0061	0.4825	0.3722	0.5762	0.4747
		2009	0.0017	0.0030	0.0017	0.0015	0.0031	0.5852	0.4288	0.6948	0.5530

2.5.6. Observations on level of exploitation

Previous model runs have suggested that catches have been relatively low compared to the estimated stock biomass. The SFAWG suggested that the total area fished relative to the stock area should be examined, to give an indication of exploitation over time. The area fished by demersal trawling has recently been examined within MFish project BEN200601 (Baird et al. 2011). The assumptions on swept width (ranging from 90 – 150m, depending on vessel) from this study were applied to tows targeting scampi recorded in the TCEPR database, to estimate the area fished by each tow, which were then summed within each modelled area and fishing year. Total annual fished area was divided by the modelled area, to estimate the proportion of the modelled area fished each year (Figure 21).

In recent years, the total area of seabed fished (including overlapping tows) has been 1 to 1.5 times the main fishery area of each of the stocks considered. Exploitation rate in any year is a function of the proportion of the total area fished and the scampi emergence and vulnerability rates.
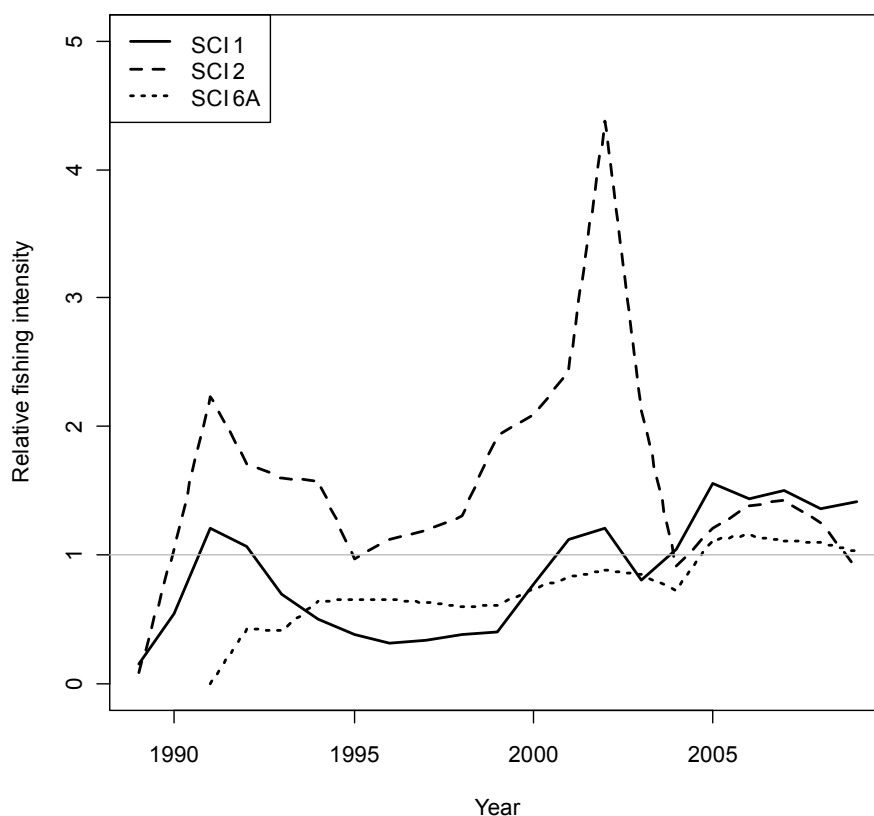
Figure 21: Estimated relative fishing intensity of modelled area (summed swept width of scampi targeted fishing within modelled area divided by modelled area) by fishing year.

2.6. Model assumptions and priors

Maximum Probability Density (MPD) fits were found within CASAL using a quasi-Newton optimiser and the BETADIFF automatic differentiation package (Bull et al. 2008). Fitting was done inside the

model except for N-based process errors, which were estimated using the *Neff* function (Appendix 1) (Francis 2011). CASAL was also used to run Monte-Carlo Markov Chains (MCMC) on the base models. MPD output was analysed using the extract and plot utilities in the CASAL and CASALUTILS libraries running under the general analytical package R.

The initial model was based on that described by Tuck & Dunn (2009). To reduce the number of fitted parameters, the catchability coefficients (*q*'s) for commercial fishing, research trawling, and photographic surveys were assumed to be "nuisance" rather than free parameters. The only informative priors used in the initial model were for *q-Photo, q-Trawl*, and the YCS vector (which constrains the variability of recruitment).

2.6.1. *q-Photo* and *q-Scampi*

The factors considered to affect *q-Photo* (interpreted as the proportion of model stock abundance represented by the counted burrows included in the analysis of photographic surveys) are:

- Spatial coverage of the survey compared to modelled area;
- Relative density of scampi in the surveyed area compared to the unsurveyed area if spatial coverage not 100% (only relevant for SCI 1 photo survey);
- Major burrow openings maintained by each scampi (inverse of occupancy); and
- Major burrow opening detection rate,

with the four factors being multiplicative. It is assumed that the occupancy and detection factors contributing to *q-Photo* are constant over time and between strata and management area, although differences in underwater visibility and the occurrence of other burrowing species may have an influence.

For each of the component factors, best estimates and upper and lower bounds were identified. Each of the best estimates and bounds were then combined multiplicatively to estimate an overall best estimate and upper and lower bound for *q-Photo*. These bounds and best estimate were assumed to represent the 2.5th 50th and 97.5th percentiles of the *q-Photo* distribution. These values were fitted within a binomial GLM (probit link) to estimate the slope and intercept of the cfd, which in turn were used to estimate the mean and standard deviation of the lognormal distribution of the prior (pers. comm. Murray Smith, NIWA.)

Spatial coverage determines a raising factor for converting the survey estimate to the modelled area estimate. For SCI 2 the full modelled area is surveyed, and spatial coverage is 100%. For SCI 1 the surveyed area covers only 66% of the full modelled area.

Spatial variability in density of scampi has been inferred from variability in catch rates (Tuck 2009) and burrow densities (Tuck et al. 2007). There is evidence that emergence (as estimated by the relationship between emerged scampi and burrow counts) may vary with latitude, even within management areas (Tuck 2010), but given that we have no relative emergence data outside the photo survey area, we assume emergence rate is constant within time steps and fisheries. For SCI 1, trawl surveys covered the whole modelled area between 1992–93 and 1994–95, and again in 1999–00 (Table 13). Observer sampling of the commercial fishery has been patchy (Table 10), but there are a number of occasions when comparable depth strata have been sampled by the same vessel in the same model time step. The trawl survey and observer data were combined, and relative catch rates (numbers.h^{-1}) were estimated for the surveyed and unsurveyed areas within the 300–400 m and 400–500 m depth bands, and for the whole area. The best estimate of relative density within the respective areas is taken as the mean of the relative density distribution, while the bounds are taken as the 2.5th and 97.5th percentiles.

Burrow occupancy rate can be considered to be the proportion of scampi burrows occupied by a scampi. Photo surveys for scampi in New Zealand are based on counts of major burrow openings. Although more

than one scampi may inhabit a burrow system (as observed for *Nephrops*; Bell et al. 2006), we assume here that each individual would have its own major opening, and that minimum entrances per scampi (maximum occupancy) is 1. Individual scampi may maintain more than one major opening, or even burrow system, and no studies to date have estimated scampi burrow occupancy in New Zealand. The upper limit on burrows per scampi has been taken as 5 (occupancy of 0.2), although other values were considered within sensitivity analysis. Marrs et al. (1996) analysed data sets from seven field programmes (from SCUBA diveable depth on the west coast of Scotland) and estimated burrow system occupancy to be 68% (about 1.5 burrows per scampi). This provides the best occupancy rate estimate available, although it is recognised that burrow system occupancy may overestimate major burrow opening occupancy, if systems have more than one major opening.

The burrow detection rate relates the numbers of burrows counted to the numbers of burrows present on the seabed. No studies to date have estimated scampi burrow detection rate in New Zealand. However, comparison of the canonical indices from individual readers in the analysis of reader bias for each photographic survey series (Tuck et al. 2006, 2009a, 2009b) may provide an initial indication of the range of detection rates (comparing the least and most conservative readers to the average). For SCI 1, if it is assumed the most optimistic reader had a detection rate of 1 (100%), then the standardised count across all readers would have a rate of 0.80 (only detecting 80% of burrows). If the least optimistic reader had a rate of 1 then the standardised count across all readers would have a rate of 1.16 (estimating 1.16 times more burrows than actually present). For SCI 2 and SCI 6A, equivalent detection rate ranges are 0.67–2.40 and 0.61–1.93, respectively. At an individual image level detection rate may be zero, but these ranges may provide appropriate bounds on detection rate over a whole survey. Marrs et al. (1996) compared *Nephrops* burrow system counts from video survey tows and diver, and found that estimates were not significantly different for experienced readers in relatively "simple" burrow communities, but that detection rates from video (video count / diver count) were 1.5 (counts overestimated by 50%) where other burrowing species made detection more complex. In the absence of other information from New Zealand, this detection rate of 1.5 is taken as the best estimate, with the detection rate ranges multiplied by this to estimate the bounds.

For each stock, the best estimates and bounds for each component and the resulting estimates for *q-Photo* are provided in Table 18. The resulting *q-Photo* distributions are shown in Figure 22.

Table 18: Component factors for estimation of prior for *q-Photo*.

Factor		Lower bound	Best estimate	Upper bound	Source
SCI 1					
Relative area	A	0.66	0.66	0.66	Surveyed area/modelled area
Relative density	R				2.5, 50 & 97.5 percentiles of
		0.99	1.22	1.42	relative catch rate
Occupancy		1.00	0.68	0.20	(Marrs et al. 1996)
Burrows/scampi	B	1.00	1.47	5.00	1/occupancy
Ratio of reader indices		0.80	1.00	1.16	Range of detection rates
Detection	D	1.20	1.50	1.74	1.5 * ratio
q-Photo		0.78	1.78	8.13	A*R*B*D
SCI 2					
Occupancy		1.00	0.68	0.20	(Marrs et al. 1996)
Burrows/scampi	B	1.00	1.47	5.00	1/occupancy
Ratio of reader indices		0.67	1.00	2.40	Range of detection rates
Detection	D	1.01	1.50	3.60	1.5 * ratio
q-Photo		1.01	2.21	18.00	B*D

For the SCI 6A model, *q-Scampi* represents the proportion of model stock abundance represented by the scampi out of burrows from the photographic survey. As discussed above, there is an indication from the

surveys in this area that larger scampi may not maintain burrows to the same extent as they do in other areas, and therefore could potentially be available to a photographic survey all of the time, indicating a best estimate of 1 for *q-Scampi*. Model runs have been examined with *q-Scampi* fixed at 1, and also with a prior of 1, and c.v. of 0.2.
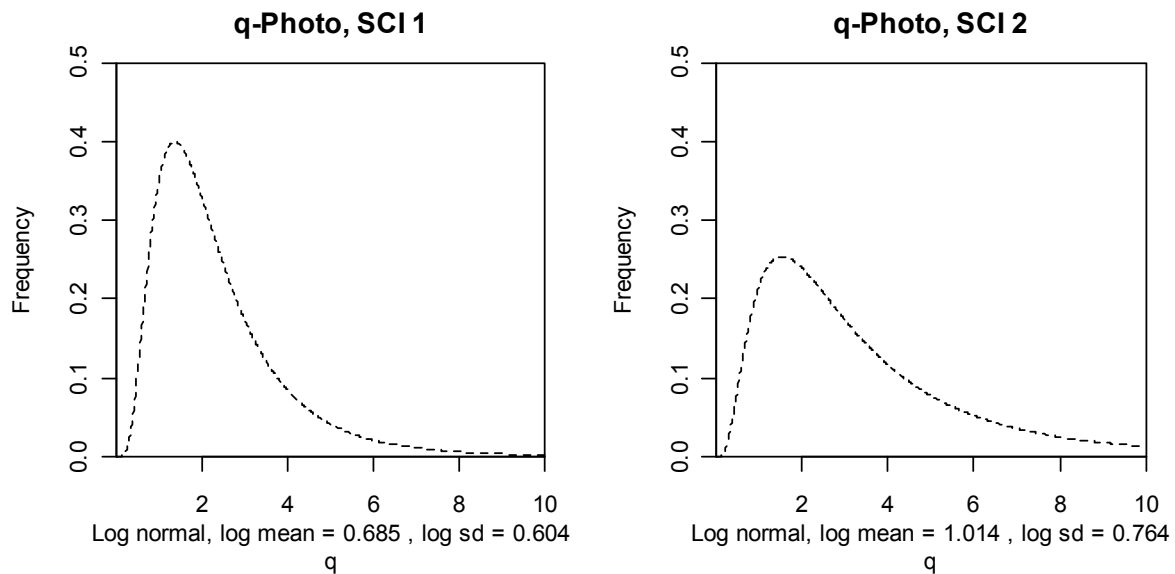
Figure 22: Estimated distribution of *q-Photo* for SCI 1 and SCI 2.

2.6.2. *q-Trawl* survey

The factors considered to affect *q-Trawl* (when interpreted as the proportion of model stock abundance accounted for by the trawl survey abundance) are:

- Spatial coverage of the survey compared to modelled area;
- Relative density of scampi in the surveyed area compared to the unsurveyed area (if spatial coverage not 100%);
- Availability of scampi to trawl gear (emergence);
- Relative availability of scampi in the surveyed area compared to the unsurveyed area (if spatial coverage not 100%); and
- Relative availability of scampi at time of survey compared to annual average,

with the factors being multiplicative. Trawl survey data is fitted within different versions of the model at the stratum level, and also for the whole survey (strata combined). Therefore, priors for *q-Trawl* were estimated for each of these levels.

Spatial coverage determines a raising factor for converting the survey estimate to the modelled area estimate. For SCI 1, the four strata, 202, 203, 3/402, and 3/403 make up 16.9%, 17.2%, 35.3%, and 30.6% of the modelled area, respectively. For SCI 2 the four strata, 702, 703, 802, and 803 make up 21.7%, 36.7%, 26.0%, and 15.6% of the modelled area, respectively.

Two approaches are available to provide estimates of scampi emergence (Table 19). The first is based on direct observation data, where *Nephrops* were fitted with acoustic tags (Chapman et al. 1974, 1975), and animal emergence was tracked through presence/absence of tag acoustic signal. For each day of the experiment, the proportion of the 24 hour period that the animal was emerged was calculated, and the best estimate and bounds of emergence represent the median, 2.5[th] and 97.5[th] percentiles of this distribution. The alternative approach considered data from scampi surveys. For SCI 1 and SCI 2 separately, the 2.5[th]

50th and 97.5th percentiles of scampi out / burrow counts, at the station level, were taken as estimates of emergence relative to burrow count. It must be remembered that this burrow count needs to be scaled by burrows per scampi and detection rates (from the estimation of *q-Photo*), and also while burrows of relatively small scampi are counted, emerged animals (seen in photographs and also caught in trawls) are generally larger (greater than 34 mm CL). Therefore a scaling factor to account for the fact that not all the scampi that generate countable burrows belong to the trawlable population is required. The values provided in Table 19 have been estimated from the proportion of the size distribution of scampi estimated to be greater than 34 mm CL, from the size distribution of measured burrows using the approach described by Cryer et al. (2005). The values presented here do not include the uncertainty around the length distributions estimated from the burrow sizes, and therefore the lower and upper bounds presented almost certainly underestimate the 95% confidence limits. Estimates of emergence from the visible scampi data were obtained by dividing emergence relative to burrow count (E) by proportion of burrows from the trawlable population (P), and then multiplying this by burrows per scampi and detection rate (B) (Table 19). The resulting distributions of these and the *Nephrops* emergence estimate are shown in Figure 23.

Table 19: Component factors for estimation of prior for *q-Trawl* for SCI 1 and SCI 2.

Factor		Lower bound	Best estimate	Upper bound	Source
Nephrops emergence		0.06	0.20	0.475	(Chapman et al. 1974, 1975)
SCI 1					
Emergence relative to burrow count	E	0.015	0.027	0.075	Animal and burrow counts from photo surveys
Proportion of burrows from trawlable population	P	0.46	0.41	0.38	Estimated size distribution of scampi from scampi burrows
Counted burrows/animal in population	B	1.20	2.21	8.70	From estimation of *q-Photo* (burrows/scampi * detection)
q-Trawl		0.04	0.145	1.72	(E/P)*B
SCI 2					
Emergence relative to burrow count	E	0.001	0.015	0.033	Animal and burrow counts from photo surveys
Proportion of burrows from trawlable population	P	0.50	0.41	0.26	Estimated size distribution of scampi from scampi burrows
Counted burrows/animal in population	B	1.01	2.21	18.00	From estimation of *q-Photo*
q-Trawl		0.002	0.081	2.285	(E/P)*B

The apparent difference in scampi burrow occupancy and emergence behaviour in SCI 6A also has implications for the estimation of the prior for *q-Trawl* for this stock. If scampi spend more time out of burrows in SCI 6A than in other areas, then *q-Trawl* is likely to be higher, although the potentially heavily mounded nature of the seabed (recently observed in SCI 3, not examined appropriately to date in SCI 6A) might mean that even scampi out of burrows would be missed by trawl gear. Therefore, while *q-Trawl* is unlikely to be as high as *q-Scampi* for this stock, population estimates from mark recapture data suggest it could be as high as 0.6, on the basis of assumptions made above (2.5.5)

q-Trawl (Nephrops emergence)

Log normal, log mean = -1.669 , log sd = 0.529

q-Trawl, SCI 1 (visible scampi)

Log normal, log mean = -1.746 , log sd = 0.976

q-Trawl, SCI 2 (visible scampi)

Log normal, log mean = -2.569 , log sd = 1.797
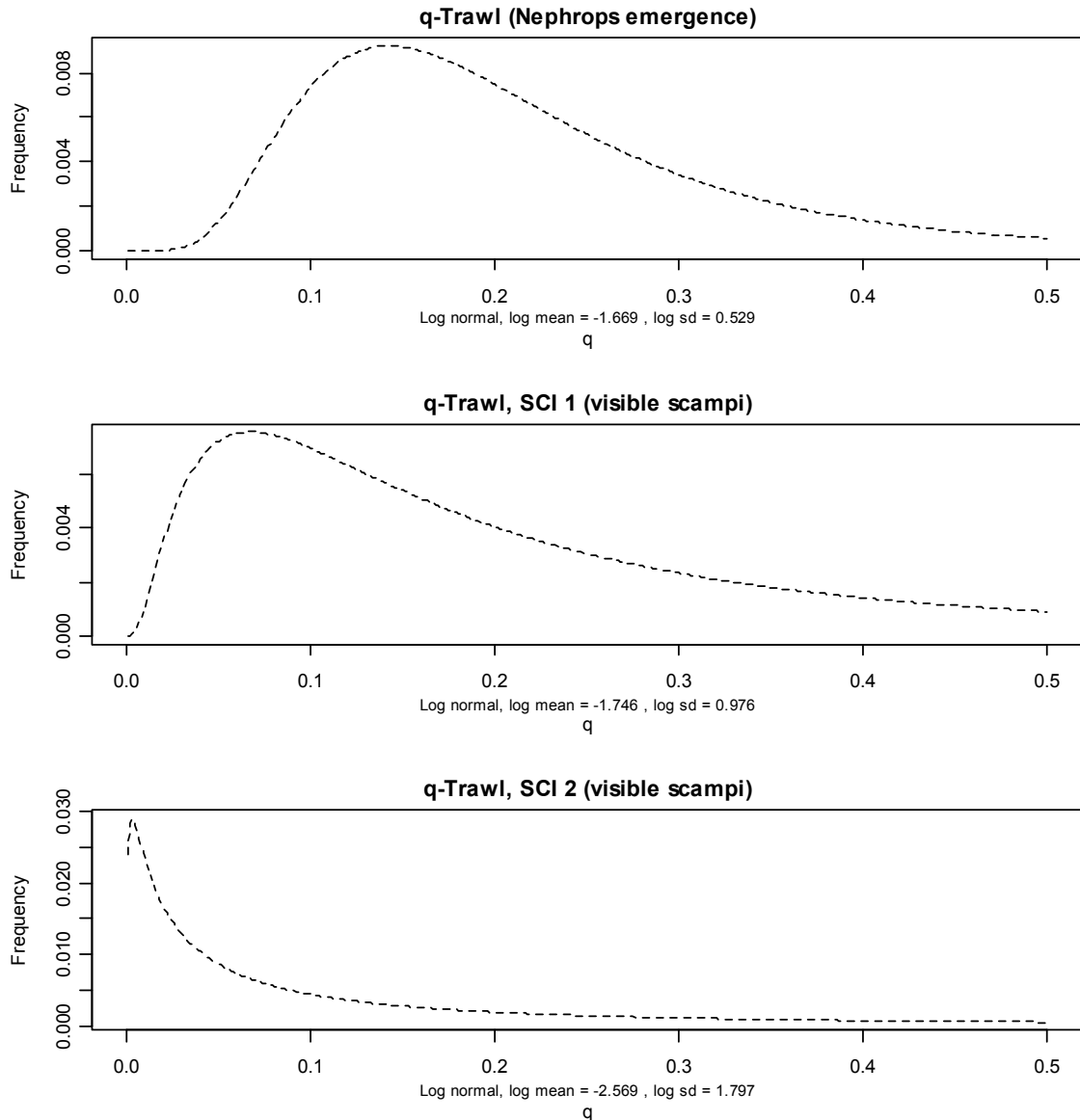
Figure 23: Estimated distributions for availability (proportion of scampi available to trawl gear) for SCI 1 and SCI 2.

Relative density of scampi in the surveyed area compared to the unsurveyed area is discussed above for the photo survey (section 2.6.1), and a similar approach is adopted for trawl surveys. Trawl survey and observer data were combined, and for each stratum or combination used within the model, catch rate (numbers.h^{-1}) for time step 1 was estimated relative to the overall average (for time step 1). Using the same data source, the relative catch rate in the different time steps was also estimated, and within the CASAL model, *q* values in other time steps were constrained relative to the *q* in time step 1 using the *ratio_qs_penalty*, with the prior on the ratio estimated from the ratio of the respective relative availabilities shown in Figure 24.

Relative availability of scampi in the surveyed area represents relative differences in emergence between strata. As discussed above, while there is evidence that emergence may vary with latitude, even within management areas (Tuck 2010), given that we have no relative emergence data outside the photo survey area, we assume that emergence rate is constant over space and between years. Between time step differences in emergence are incorporated into the estimates of relative density between time steps from the trawl and observer catch rate data.

Relative availability step 1

Relative availability step 2

Normal, mean = 0.804 , sd = 0.181

Normal, mean = 0.622 , sd = 0.2

Relative availability step 3

Normal, mean = 1.574 , sd = 0.267
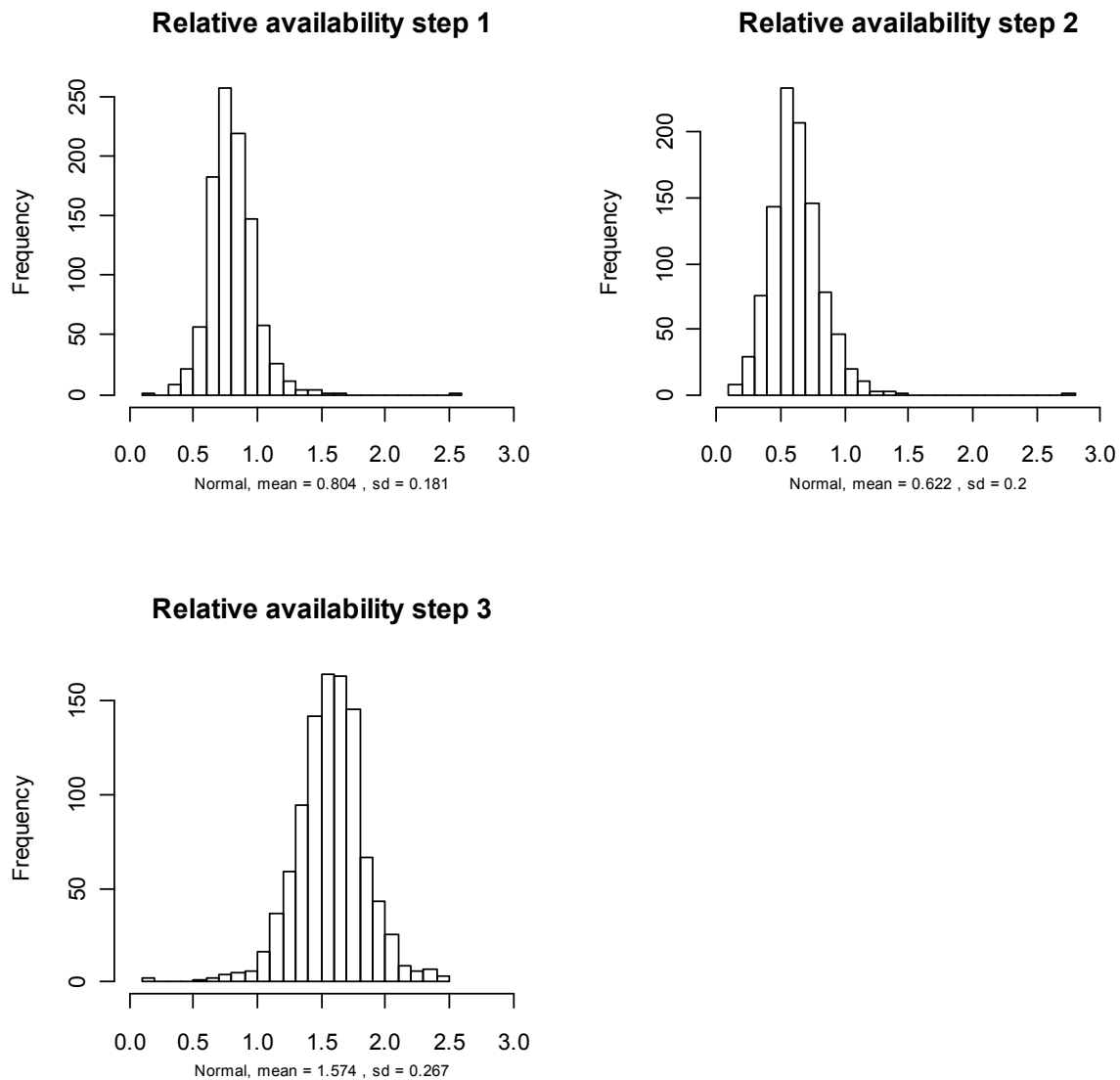
Figure 24: Availability of scampi by time step, relative to the annual average.

2.6.3. Model runs

For each fishery, model runs were examined over a range of combinations of structure complexity and sets of data included.

Model complexities were:

1. Stratification on basis of time step (numbered 4 for SCI 2, and 7 for SCI 6A).
2. Stratification on basis of depth (e.g. 202 combined with 3/402) and time step (numbered 5 for SCI 2, and 8 for SCI 6A).
3. Stratification on basis of survey strata (depth and latitude), time step (numbered 6 for SCI 2, not relevant for SCI 6A).

Data combinations were:

A. Photo survey index only.
B. Photo survey and trawl index only.
C. Photo survey, CPUE and trawl index.

Each of these data combinations was examined using the relevant abundance indices, and associated length frequency data. For length frequency data, effective multinomial sample sizes were estimated for each series of data using the *Neff.multinomial* function (Francis 2011) (details provided in Appendix 7). Despite the fact that the at-length data cover relatively few years (less than 10), method 2 (based on mean length) has been adopted, as the correlations between length proportions in the same year invalidate method 1.

Previous implementations of the model (with more constrained YCS) have estimated process error for the abundance indices, and this has led to large process error estimates for the CPUE indices (~ 40%), and low weighting within the model. Given the relatively consistent patterns observed in CPUE (between time steps and strata), model runs have also been examined where instead of estimating process error, it has been fixed at 15% (also examined for 10% and 20%) for the CPUE abundance indices, and effectively no additional error added to the trawl or photo survey data, so that the overall c.v.s of the various abundance indices observations are more similar.

3. MODEL RESULTS

3.1. SCI 1

For SCI 1, allowing the model to estimate process error for the CPUE indices resulted in relatively large process error estimates for these data (typically 0.3–0.4), for each of the levels of spatial stratification, resulting in poor fits to these series. Therefore, for models including the CPUE indices, process error was fixed, and model fits were examined across a range of values. As the fixed process error was reduced, fits to the CPUE indices improved, and model estimates of B_0 and SSB/B_0 decreased. On the assumption that the CPUE indices are providing useful information about stock abundance, for these models process error was fixed at an intermediate value of 0.15, to provide similar c.v. values to the trawl survey indices.

Estimated key parameters and quantities for the matrix of model runs for SCI 1 are presented in Table 20. These models range from the most simple, fitting only to the photographic survey abundance index (1A) with no spatial stratification, to the most complex, fitting to the photographic survey, commercial CPUE and trawl survey abundance indices, with stratification over depth and latitudinal strata (3C). Plots of the time series of B, SSB/B_0 and year class strength for each model are also presented in Figure 25.

Estimates of B_0 for the MPD fits for the various models ranged from 1700–6800 t, although only most of the models had B_0 values within the range of 1700–3300 t. There was some evidence of consistency in stock trajectory within models fitting the same data, but there were differences in the estimated B_0 between some of the levels of model stratification within data type. The time series of the ratio of $SSB:B_0$ appears more consistent between models fitting the same types of data, and models including the CPUE indices suggest SSB declined in the late 1980s, increased rapidly to a peak in the mid 1990s, declined steadily to the early 2000s, and has declined more slowly since then, with current SSB 40–50% of B_0. The models excluding CPUE generally show a slight increase in SSB to about 1990, followed by either a steady decline, or a decline to the late 1990s, followed by a more stable period, with current SSB 50–90% of B_0. There is very little signal in the estimates of year class strength, although models fitting CPUE indices estimated higher recruitment round 1990.

Table 20: Estimated key parameters and quantities from MPD fits for SCI 1 models.

	B_0	SSB_{2010}	SSB_{2010}/B_0	*q-Photo*	*q-Trawl*
1A	2005	1075	0.54	1.72	
1B	3325	2420	0.73	0.90	0.29
1C	2311	1177	0.51	2.56	0.23
2A	1977	1016	0.51	1.77	
2B	6309	5601	0.89	0.44	0.20
2C	1771	776	0.44	4.47	0.32
3A	2632	1744	0.66	1.19	
3B	6839	6256	0.91	0.42	0.19
3C	1697	717	0.42	4.76	0.38
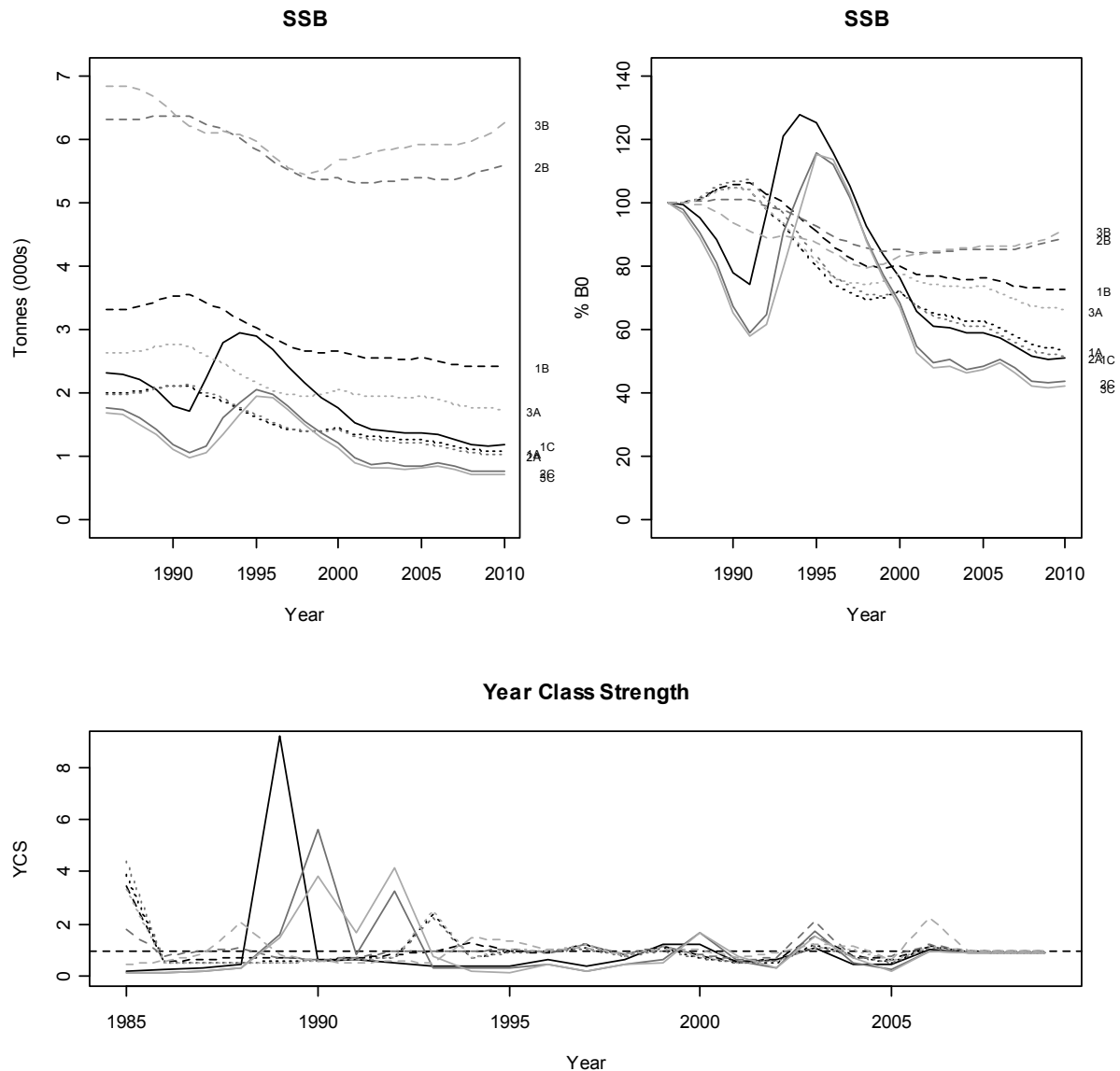
Figure 25: Plots of SSB, SSB as a percentage of B_0, and year class strength for MPD fits for SCI 1 models. Dotted lines represent A models (photo only), dashed lined represent B models (photo and trawl survey), solid lines represent C models (photo, trawl survey and CPUE). Black lines represent model 1 (stratified by time step), dark grey lines represent model 2 (stratified by time step and depth), light grey lines represent model 3 (stratified by time step and survey strata).

Fits to the CPUE indices were generally reasonable for all SCI 1 models in which they were included, and varied slightly along with the fits to the other indices and proportions at length with additional spatial complexity (stratification by depth and latitude). Fits excluding the CPUE indices did not fit the trawl or photo series particularly well. Of the models fitting the CPUE data, models "2C" (stratification on basis of time step and depth) and "3C" (stratification on basis of time step and survey strata), produced very similar outputs, and therefore, models "1C" (stratification on basis of time step) and "2C" are presented for SCI 1. Description of the model fits are provided below, with plots provided in Appendix 1 (model 1C) and Appendix 2 (model 2C).

Model "1C" (figures in Appendix 1)

Model 1C estimated a B_0 of 2311 t, with the SSB in 2010 51% of B_0. The trajectory of SSB and YCS are shown in A1.1. SSB is estimated to have declined through the late 1980s (with the start of the fishery), increased from 1991 to 1995, and then declined steadily until 2002. Since this time, SSB has declined at a slower rate, and appears more stable in the most recent years. The model estimates very high year class strength in 1989. The estimated photo survey abundance index follows the general pattern of the observed values, but does not match the inter-year variability observed, and *qPhoto* was estimated to be 2.56.

Fits to the CPUE indices do not quite reach the observed high levels of the index in the mid to late 1990s, but do match the pattern prior to and after this period well. The fits to the trawl survey indices were reasonable, following the increase to 1995, and the decline and the more stable period after this (A1.2). The trawl survey catchability *q-Trawl* was estimated to be 0.23.

Fits to the trawl survey proportions at length were reasonable in some years of the series, but poorer in others (A1.3 and A1.4). The fits to the observer proportions at length (A1.5 – A1.7) were variable, and generally not as good as the fits to the trawl survey proportions at length. The estimated commercial fishing and trawl survey selectivity ogives appear reasonable (A1.8), and reflect the seasonal changes in sex ratio apparent in catches. Fits to the proportions at length of recaptures were variable (A1.9), and generally better for the combinations of release and recapture containing more animals (e.g. release 96-2 recapture 97-1, release 96-3 recapture 97-3, release 97-1 recapture 97-3). Estimated growth increments at 20 mm and 40 mm were 8.7 mm and 1.5 mm for males, and 8.6 mm and 0.0 mm for females.

The likelihood profile when B_0 is fixed in the model is shown in A1.10. The overall profile shows a clear minimum at a B_0 of about 2300 t. The abundance indices, and in particular the CPUE series, appear to have the greatest influence on the estimates of B_0, although other data also show a similar pattern.

The MCMC was started at the base case MPD and run for 5 million simulations, with every two thousandth sample saved, giving a set of 1500 samples, the first 1000 being considered the burn in. For diagnostics, we first used the trace for each parameter, and second, a plot of the running median and 5th and 95th quantiles, along with the moving average over 50 samples. Trace plots for some of the key parameters are presented in A1.11, with the diagnostic plots presented in A1.12. The traces appear quite stable, and are quite well mixed. MCMC jump statistics (A1.13) show no evidence of non-convergence in most parameters. Geweke convergence diagnostics are provided in A1.14 and Appendix 6 for each of the parameters. The MPD estimates are located reasonably within the posterior distribution (A1.15). The posterior distributions of the q parameters for which priors were provided (*q-Trawl*, *q-Trawl* ratio step1:step2 and *q-Photo*) fit within the prior distributions (A1.16). The posterior trajectory of SSB suggests biomass declined slightly to 1991, increased to 1995, declined to about the 1991 level by 2000, and has continued to decline, but at a slower rate stable since this time (A1.17). The 5th and 95th quantiles of the 2010 SSB are 46% and 59% of B_0, respectively.

Model "2C" (figures in Appendix 2)

Model 2C estimated a B_0 of 1771 t, with the SSB in 2010 44% of B_0. The trajectory of SSB and YCS are shown in A2.1. SSB follows a very similar pattern to model "1C", but at a slightly lower level. Rather than a single exceptional year of recruitment, the model estimates a series of years between 1989 and 1992 with high year class strength. The estimated photo survey abundance index follows the pattern of the observed values slightly better than model "1C", and *q-Photo* was estimated to be 4.47.

As with model "1C", fits to the CPUE indices do not quite reach the highest observed levels of the index in the mid to late 1990s, but do match the pattern prior to and after this period well (A2.2). The fits to the trawl survey indices were good for the shallower strata, but did not follow the observed pattern in the deeper strata quite as well (A2.3). The trawl survey catchability *q-Trawl* was estimated to be 0.32.

As with model "1C", fits to the trawl survey proportions at length were reasonable in some years of the series, but poorer in others (A2.4 and A2.5). The fits to the observer proportions at length were variable (A2.6 – A2.10). The estimated commercial fishing and trawl survey selectivity ogives generally reflect the seasonal changes in sex ratio apparent in catches although the selectivity for the trawl survey in deeper strata does not match the pattern shown by the others (A2.11). Fits to the proportions at length of recaptures appeared similar to other models, and generally better for the combinations of release and recapture containing more animals (A2.12). Estimated growth increments at 20 mm and 40 mm were 12.2 mm and 2.0 mm for males, and 11.5 mm and 0.0 mm for females.

The likelihood profile when B_0 is fixed in the model is shown in A2.13. The overall profile shows a clear minimum at a B_0 of about 1 800 t, and as with model "1C", the abundance indices, and in particular the CPUE series, appear to have the greatest influence on the estimates of B_0.

The MCMC was started at the base case MPD and run for 5 million simulations, with every two thousandth sample saved, giving a set of 2500 samples, the first 1000 being considered the burn in. For diagnostics, we first used the trace for each parameter, and second, a plot of the running median and 5th and 95th quantiles, along with the moving average over 50 samples. Trace plots for some of the key parameters are presented in A2.14, with diagnostic plots presented in A2.15. The traces appear stable, and are quite well mixed. MCMC jump statistics (A2.16) show no evidence of non-convergence in most parameters. Geweke convergence diagnostics are provided A2.17 and Appendix 6 for each of the parameters. The MPD estimates are located reasonably within the posterior distribution (A2.18). The posterior distributions of the q parameters for which priors were provided (*q-Trawl*, *q-Trawl* ratio step1:step2 and *q-Photo*) fit within the prior distributions, although the *q-Photo* distribution is towards the upper tail (A2.19). The posterior trajectory of SSB suggests that biomass declined to 1991, increased to 1995, declined to about the 1991 level by 2002, and has remained relatively stable since this time (A2.20). The 5th and 95th quantiles of the 2010 SSB are 40% and 51% of B_0, respectively.

3.2. SCI 2

For SCI 2, allowing the model to estimate process error for the CPUE indices resulted in more moderate estimates than for SCI 1 (about 0.2), and fits to the series were better. It was therefore decided to estimate process error rather than fix it.

Estimated key parameters and quantities for the matrix of model runs for SCI 2 are presented in Table 21. These models range from the most simple, fitting only to the photographic survey abundance index (4A) with no spatial stratification, to the most complex, fitting to the photographic survey, commercial CPUE and trawl survey abundance indices, with stratification over depth and latitudinal strata (6C). Plots of the time series of B, SSB/B_0 and year class strength for each model (single growth period versions) are also presented in Figure 26.

Estimates of B_0 for the MPD fits for the various models ranged from 1950–5950 t, although only the 6A model (photo data only, model stratification by time step and survey strata) had an estimated B_0 greater than 2350 t. The trajectories for SSB, the ratio of SSB:B_0 and relative YCS were very consistent for the three models including the CPUE series, but more variable between the models excluding these data. Most of the models suggest a current SSB:B_0 ratio between 40–50%, although the models including the CPUE series suggest that biomass declined in the early 1990s, before returning to B_0 levels in the mid 1990s, while the models excluding the CPUE generally suggest that biomass exceeded B_0 in the early 1990s. There was very little signal in the estimates of year class strength, other than some years of high recruitment in the late 1980s and early 1990s.

Table 21: Estimated key parameters and quantities from MPD fits for SCI 2 models.

	B_0	SSB_{2010}	SSB_{2010}/B_0	*q-Photo*	*q-Trawl*
4A	2258	951	0.42	4.00	
4B	2120	566	0.27	5.87	0.16
4C	2294	1029	0.45	5.00	0.13
5A	2328	975	0.42	3.94	
5B	1946	618	0.32	6.16	0.35
5C	2183	1000	0.46	5.83	0.20
6A	5943	5435	0.91	0.86	
6B	2008	808	0.40	5.14	0.18
6C	2131	976	0.46	6.15	0.15
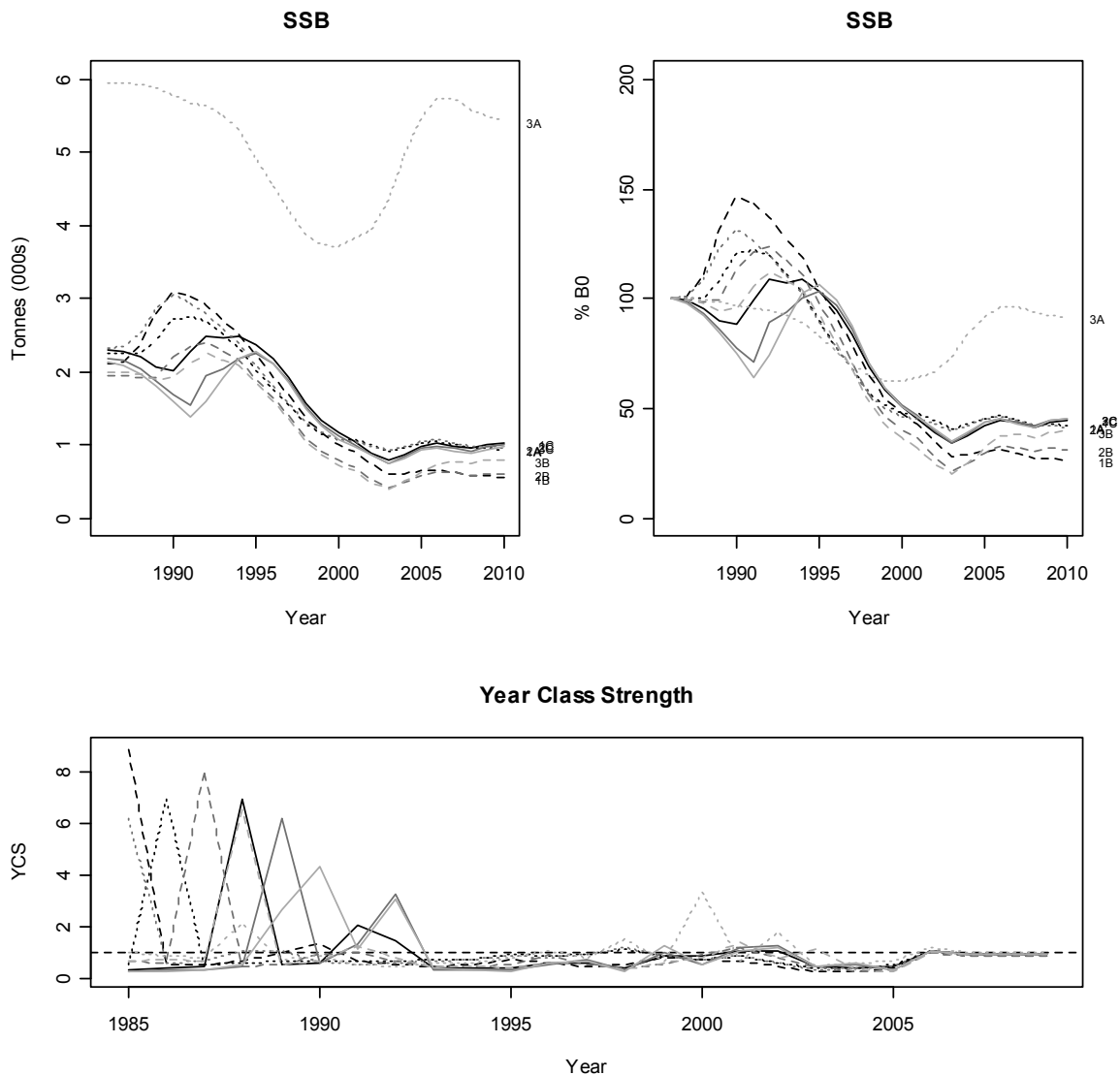
Figure 26: Plots of SSB, SSB as a percentage of B0, and year class strength for MPD fits for SCI 2 models. Dotted lines represent A models (photo only), dashed lined represent B models (photo and trawl survey), solid lines represent C models (photo, trawl survey and CPUE). Black lines represent model 4 (stratified by time step), dark grey lines represent model 5 (stratified by time step and depth), light grey lines represent model 6 (stratified by time step and survey strata).

Fits to the CPUE indices were generally good for all SCI 2 models in which they were included, and the fits to the other indices and proportions at length were not noticeably improved by adding additional spatial complexity (stratification by depth and latitude). Therefore, model "4C" (stratification on basis of time step, with the CPUE, photo survey and trawl surveys abundance indices) is presented for SCI 2. Description of the model fits are provided below, with plots provided in Appendix 3.

Model "4C" (figures in Appendix 3)

Model 4C estimated a B_0 of 2294 t, with the SSB in 2010 45% of B_0. The trajectory of SSB and YCS are shown in A3.1. SSB is estimated to have declined through the late 1980s (with the start of the fishery), increased from 1991 to 1995, and then declined steadily until 2003. Between 2003 and 2006 SSB appears to have increased slightly, and remained relatively stable in recent years. The model estimates very high year class strengths in 1989 and 1992. The estimated photo survey abundance index follows the pattern of the observed values, but does not match the inter-year variability observed, and *q-Photo* was estimated to be 5.00.

Fits to the CPUE indices do not quite match the observed decline and increase in the early 1990s, but do follow the decline observed after this. The fits to the trawl survey indices were reasonable, following the observed decline to the early 2000s, and the more stable period after this (A3.2). The trawl survey catchability *q-Trawl* was estimated to be 0.13.

Fits to the trawl survey proportions at length (A3.3 and A3.4) were good in the early years of the series (particularly in time step 1), when the data were collected from dedicated trawl surveys containing a large number of stations (an average of 27 stations.yr^{-1}), and reasonable in more recent years, when sampling intensity has been lower. The fits to the observer proportions at length (A3.5 – A3.7) were not as good as the fits to the trawl survey proportions at length, but better than those observed to the observer proportions at length in the two time step scampi model reported previously (Tuck & Dunn 2006). The estimated commercial fishing and trawl survey selectivity ogives appear reasonable (A3.8), and reflect the seasonal changes in sex ratio apparent in catches. Fits to the proportions at length of recaptures (A3.9) were variable, and generally better for the combinations of release and recapture containing more animals (e.g. release 96-2 recapture 97-1, release 96-3 recapture 97-3, release 97-1 recapture 97-3). Estimated growth increments at 20 mm and 40 mm were 9.18 mm and 1.6 mm for males, and 9.08 mm and 0.0 mm for females.

The likelihood profile when B_0 is fixed in the model is shown inA3.10. The overall profile shows a clear minimum at a B_0 of about 2300 t. The abundance indices, and in particular the CPUE series, appear to have the greatest influence on the estimates of B_0, although other data also show a similar pattern.

The MCMC run was started at the base case MPD and run for 5 million simulations, with every two thousandth sample saved, giving a set of 2500 samples, with the first 1000 considered a burn in. Within the MCMC run the process error for the abundance indices fixed at the MPD estimate. For diagnostics, we first used the trace for each parameter, and second, a plot of the running median and 5th and 95th quantiles, along with the moving average over 50 samples. Trace plots for some of the key parameters are presented inA3.11, with the diagnostic plots presented in A3.12. The traces appear reasonably stable, and are quite well mixed. MCMC jump statistics are plotted in A3.13, and show no evidence of non-convergence. Geweke convergence diagnostics are provided in A3.14 and Appendix 6 for each of the parameters displayed in A3.11. Posterior distributions of these parameters are shown in A3.15. The MPD estimates (also plotted in A3.15) are located within the posterior distribution. The posterior distributions of the q parameters for which priors were provided (*q-Trawl*, *q-Trawl* ratio step1:step2 and *q-Photo*) are plotted along with the prior distributions in A3.16. The posterior distributions fit within the prior distributions, although the *q-Photo* distribution is towards the upper tail. The posterior trajectory of SSB (A3.17) suggests a relatively stable period until the mid 1990s (with SSB possibly increasing slightly), followed by a steady decline in biomass during the late 1990s, a slight increase in the early 2000s, and a

stable period since this time. The 5th and 95th quantiles of the 2010 SSB are 38% and 50% of B_0, respectively.

3.3.   SCI 6A

For SCI 6A, model runs were compared with *q-Scampi* fixed at 1, or estimated, with a prior of 1, and a c.v. of 0.2 (Section 2.6.1), on the basis of our understanding of the use of scampi burrows in this area. In addition, as with the other stocks, models were compared with process error for the CPUE indices fixed (at 0.15), or estimated. Within each combination of data and spatial stratification, the model results were very similar between these comparisons, and therefore the models presented are those with both *q-Scampi* and process error for the CPUE are estimated.

Estimated key parameters and quantities for the matrix of model runs for SCI 6A are presented in Table 22. These models range from the most simple, fitting only to the photographic survey abundance index (7A) with no spatial stratification, to the most complex, fitting to the photographic survey, commercial CPUE and trawl survey abundance indices, with stratification over depth and latitudinal strata (8C). Plots of the time series of B, SSB/B_0 and year class strength for each model are also presented in Figure 27.

Estimates of B_0 for the MPD fits for the various models ranged from 2640–5060 t, although only one model had an estimated B_0 greater than 4000 t. The trajectories for SSB, the ratio of SSB:B_0 and relative YCS were relatively consistent for the two models including the CPUE series, but more variable between the models excluding these data. These models including CPUE estimated a current SSB:B_0 ratio of 40–49%, while estimates for other models ranged from 15–58%. The models including CPUE suggest that biomass declined in the early 1990s, and has fluctuated around this lower level since this time. Models excluding the CPUE generally suggest increases in biomass in the early years of the series, followed by more rapid declines. There was very little signal in the estimates of year class strength, other than some years of high recruitment in the early 1990s and early 2000s.

Table 22: Estimated key parameters and quantities from MPD fits for SCI 6A models.

	B0	SSB$_{2010}$	SSB$_{2010}$/B_0	*q-Scampi*	*q-Trawl*
7A	3636	537	0.15	1.12	
7B	5066	2925	0.58	0.89	0.57
7C	2641	1065	0.40	0.91	0.83
8A	2836	630	0.22	1.11	
8B	3586	1555	0.43	0.85	0.49
8C	3055	1490	0.49	0.85	0.64
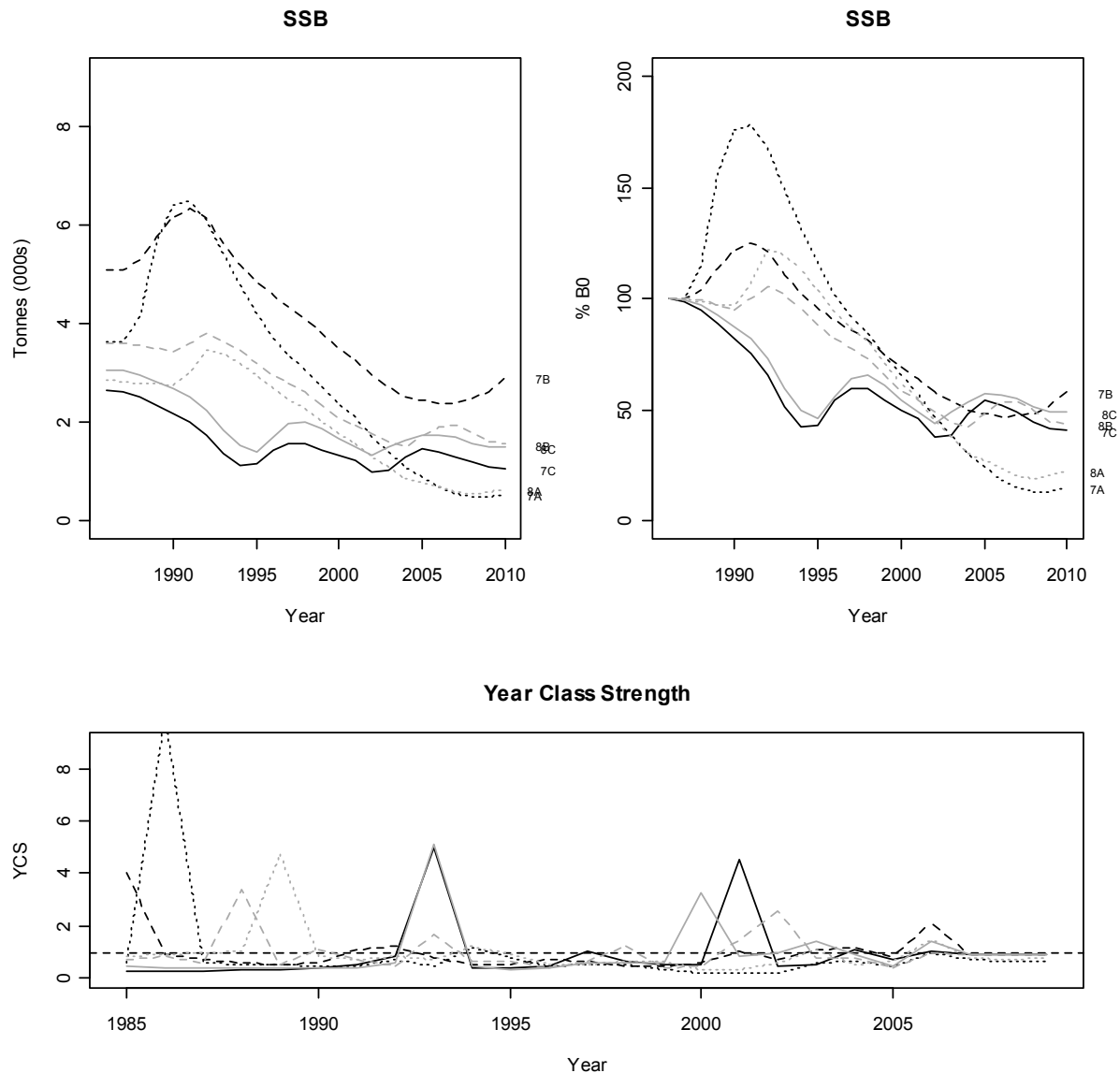
Figure 27: Plots of SSB, SSB as a percentage of B_0, and year class strength for MPD fits for SCI 6A models. Dotted lines represent A models (photo only), dashed lined represent B models (photo and trawl survey), solid lines represent C models (photo, trawl survey and CPUE). Black lines represent model 7 (stratified by time step), light grey lines represent model 8 (stratified by time step and survey strata).

Fits to the CPUE indices were generally good for all SCI 6A models in which they were included, and the fits to the other indices and proportions at length were not noticeably improved by adding additional spatial complexity (stratification by depth and latitude). The more complex model "8C" estimated a slightly larger B_0 and SSB_{2010}, but followed a very similar trajectory to the "7C" model. Both model "7C" (stratification on basis of time step) and model "8C" (stratification on basis of time step and survey strata) are presented for SCI 6A. Description of the model fits are provided below, with plots provided in Appendix 4 (model 7C) and Appendix 5 (model 8C).

Model "7C" (figures in Appendix 4)

Model 7C estimated a B_0 of 2641 t, with the SSB in 2010 40% of B_0. The trajectory of SSB and YCS are shown in A4.1. SSB is estimated to have declined through the early 1990s (with the start of the fishery),

and fluctuated at this lower level since this time. The model estimates strong class strengths in 1993 and 2001. The estimated photo survey scampi abundance index declines over time, as do the observed values, but the estimated rate of decline does not match that observed. *q-Scampi* was estimated to be 0.91.

Fits to the CPUE indices are good, matching the decline in the early part of the series, and the more recent fluctuations. The fits to the trawl survey indices followed the overall decline, but did not match the increase in 2008 (A4.2). The trawl survey catchability *q-Trawl* was estimated to be 0.83.

Fits to the trawl survey proportions at length (A4.3) were good, generally matching the observed size range and sex ratio observed. The fits to the observer proportions at length (A4.4 – A4.6) were not as good as the fits to the trawl survey proportions at length, and were generally worse for time steps 2 and 3, where less data are available. The estimated commercial fishing and trawl survey selectivity ogives (A4.7) reflect the seasonal changes in sex ratio apparent in catches (females more prevalent in time step 1), but even at this time, male selection is higher than females. Fits to the proportions at length of recaptures (A4.8) were variable, and generally better for the combinations of release and recapture containing more animals. Estimated growth increments at 20 mm and 40 mm were 10.6 mm and 2.4 mm for males, and 13.7 mm and 0.0 mm for females.

The likelihood profile when B_0 is fixed in the model is shown in A4.9. The overall profile shows a clear minimum at a B_0 of about 2500 t. The abundance indices, and in particular the CPUE series, appear to have the greatest influence on the estimates of B_0.

The MCMC was started at the base case MPD and run for 3 million simulations, with every two thousandth sample saved, giving a set of 1500 samples. For diagnostics, we first used the trace for each parameter, and second, a plot of the running median and 5th and 95th quantiles, along with the moving average over 50 samples. Trace plots for some of the key parameters are presented in A4.10, with the diagnostic plots presented in A4.11. The traces appear reasonably stable, and are quite well mixed. MCMC jump statistics are plotted in A4.12, and show no evidence of non-convergence in most parameters. Posterior distributions of these parameters are shown in A4.13. The MPD estimates (also plotted in A4.13) are mostly located within the posterior distribution, with the exception of the *q-Trawl* parameter. The posterior trajectory of SSB (A4.14) suggests a decline in biomass during the early 1990s, fluctuating around this lower level since this time, and the 5th and 95th quantiles of the 2010 SSB are 33% and 44% of B_0, respectively.

Model "8C" (figures in Appendix 5)

Model 8C estimated a B_0 of 3055 t, with the SSB in 2010 49% of B_0. The trajectory of SSB and YCS are shown in A5.1. As with model 7C, SSB is estimated to have declined through the early 1990s (with the start of the fishery), and fluctuated at this lower level since this time. The model estimates strong year class strengths in 1993 and 2001. The estimated photo survey scampi abundance index declines over time, as do the observed values, but the estimated rate of decline does not match that observed. *q-Scampi* was estimated to be 0.85.

Fits to the CPUE indices are good, matching the decline in the early part of the series, and the more recent fluctuations (A5.2 – A5.5). The fits to the trawl survey indices followed the overall decline, but did not match the increase in 2008 (A5.6). The trawl survey catchability *q-Trawl* was estimated to be 0.64.

Fits to the trawl survey proportions at length (A5.7 and A5.8) were good, generally matching the observed size range and sex ratio. The fits to the observer proportions at length (A5.9 – A5.16) were not as good as the fits to the trawl survey proportions at length, and were generally worse for time steps 2 and 3, where less data are available. The estimated commercial fishing and trawl survey selectivity ogives (A5.17 and A5.18) generally reflect the seasonal changes in sex ratio apparent in catches (females more prevalent in time step 1), but some curves (particularly for commercial fishing) did not appear realistic, and as with model 7C, even at this time, male selection is higher than females. Fits to the proportions at

length of recaptures (A5.19) were variable, and generally better for the combinations of release and recapture containing more animals. Estimated growth increments at 20 mm and 40 mm were 10.5 mm and 2.6 mm for males, and 11.9 mm and 0.0 mm for females.

The likelihood profile when B_0 is fixed in the model is shown in A5.20. The overall profile shows a clear minimum at a B_0 of about 3000 t. The abundance indices, and in particular the CPUE series, appear to have the greatest influence on the estimates of B_0.

The MCMC was started at the base case MPD and run for 3 million simulations, with every two thousandth sample saved, giving a set of 1500 samples. For diagnostics, we first used the trace for each parameter, and second, a plot of the running median and 5th and 95th quantiles, along with the moving average over 50 samples. Trace plots for some of the key parameters are presented in A5.21, with the diagnostic plots presented in A5.22. The traces appear reasonably stable, and are quite well mixed. MCMC jump statistics are plotted in A5.23, and show some evidence of non-convergence in a few parameters (generally abundance indices process error and some selectivity parameters). Posterior distributions of these parameters are shown in A5.24. The MPD estimates (also plotted in A5.24) are located within the posterior distribution. The posterior trajectory of SSB (A5.25) suggests a decline in biomass during the early 1990s, fluctuating around this lower level since this time, and the 5th and 95th quantiles of the 2010 SSB are 41% and 53% of B_0, respectively.

3.4. Estimation of natural mortality within model

In the model runs described above, M is fixed at 0.2, on the basis of the estimate of the K parameter from a von Bertalanffy growth curve (Cryer & Stotter 1999) using a correlative method (Pauly 1980, Charnov et al. 1983). In previous presentations of the assessment model, members of the SFAWG have suggested estimating M within the model to more fully account for uncertainty within the MCMCs. This was attempted for models 1C (SCI 1) and 4C (SCI 2), both models including all indices, and stratification only on the basis of time step.

A comparison of key parameters from models with M fixed or estimated is provided in Table 23. Comparison of the model outputs between models with M fixed or estimated provided similar results for both stocks, with B_0 and the SSB trajectory estimated at higher levels when M is estimated. Fits to the abundance indices were improved when M was estimated within the model (see for example Figure 28 and Figure 29 compared to A1.1 and A1.2), but the actual estimates of M (0.54 and 0.63, Table 23) are considered to be unrealistically high for an animal with the life history characteristics of scampi.

Table 23: Comparison of key parameters and quantities from MPD fits for SCI 1 and SCI 2 models with M fixed or estimated.

| | | | *M fixed (0.2)* | | | | | | *M estimated* | | |
	B_0	SSB_{2010}	SSB_{2010}/B_0	*q-Photo*	*q-Trawl*	B_0	SSB_{2010}	SSB_{2010}/B_0	*q-Photo*	*q-Trawl*	*M*
1C	2311	1177	0.51	2.56	0.23	2493	1767	0.71	1.24	0.38	0.63
4C	2294	1029	0.45	5.00	0.13	3185	2331	0.73	2.30	0.14	0.54

In addition, for the models presented for SCI 1 and SCI 2, the sensitivity to the assumption (0.2) was examined through fixing M at 0.15 and 0.3. Key parameters from the MPD fits to these sensitivity runs are tabulated in Table 24.

Figure 29: Fits and q-q diagnostic plots to CPUE and trawl survey abundance indices for SCI 1 from model 1C (M estimated).

Figure 28: Spawning stock biomass trajectory (a), year class strength (b) fits (c) and q-q diagnostic plots (d) to photo survey abundance index for SCI 1 from model 1C (M estimated).

Table 24: Estimated key parameters and quantities from MPD fits for SCI 1 models.

	Model	M	B_0	SSB_{2010}	SSB_{2010}/B_0	*q-Photo*	*q-Trawl*
SCI 1	1C	0.2	2311	1177	0.51	2.56	0.23
SCI 1	2C	0.2	1771	776	0.44	4.47	0.32
SCI 2	4C	0.2	2294	1029	0.45	5.00	0.13
SCI 1	1C	0.15	2992	1571	0.52	1.33	0.31
SCI 1	2C	0.15	2350	1079	0.46	3.32	0.24
SCI 2	4C	0.15	2729	1179	0.43	3.70	0.11
SCI 1	1C	0.3	1651	861	0.52	3.32	0.35
SCI 1	2C	0.3	1353	634	0.47	5.10	0.47
SCI 2	4C	0.3	1800	898	0.50	6.03	0.22
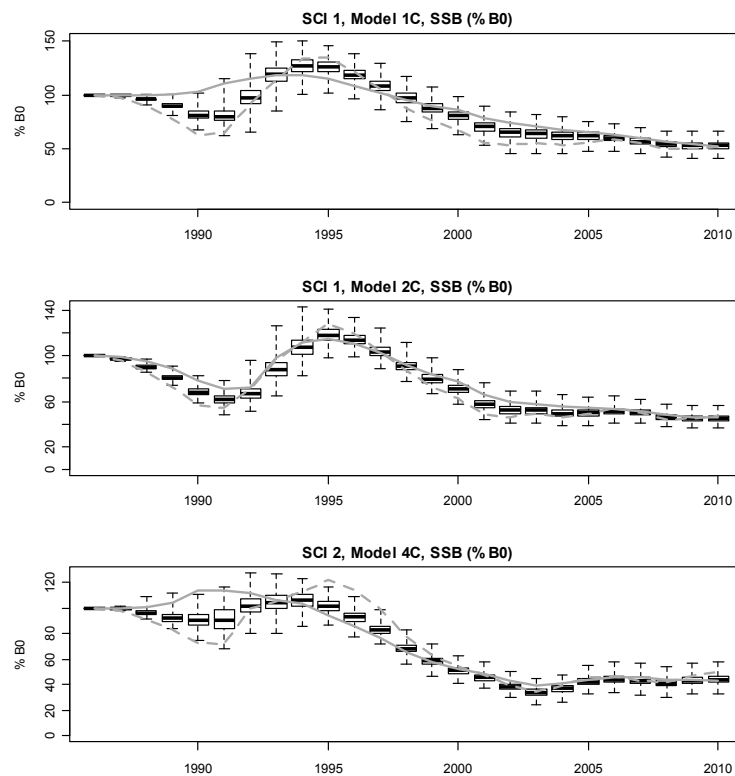
Figure 30: Posterior trajectories of SSB as a % of B_0 for each of the base models, with trajectories of the MPD fits to M sensitivity runs overlayed. Solid grey line – M 0.15, dashed grey line – M 0.3.

For MPD runs with M fixed at 0.3, B_0 and SSB_{2010} were lower than the base runs (M fixed at 0.2), and q values were higher. The opposite was the case when M was fixed at 0.15. Plots of the posterior trajectories of the SSB as a % of B_0 are presented for each of the base models in Figure 30, along with trajectories from the MPD fits for the M sensitivity runs. It can be seen that when M was fixed at 0.15, the overall stock trajectory was flatter, with the decline in biomass estimated in the late 1980s and early 1990s either reduced, or not apparent at all, and the peak in biomass occurring earlier in the time series, and to a lower level. The trajectory for M fixed at 0.3 generally showed the opposite. For both sensitivity runs, SSB_{2010}/B_0 was well within the range observed in the MCMC traces for the base models.

3.5. Projections for SCI 1 and SCI 2

The assessments reported B_0, and $B_{current}$ and used the ratio of current and projected spawning stock biomass ($B_{current}$ and B_{2015}) to B_0 as preferred indicators. Projections were conducted up to 2015 on the basis of a range of catch scenarios (slightly above and below catch in most recent year or recent average catch, and also TACC if this differs from the previous catch levels). In both stocks, recent recruitment is estimated to have been lower than the long term average, and projections have been conducted on the basis of both long term and recent (last decade) recruitment scenarios. The probability of exceeding the default Harvest Strategy Standard target and limit reference points are reported.

For SCI 1, model outputs suggest that spawning stock biomass (SSB) decreased until the early 1990s, increased to a peak in about 1995, declined to the early 2000s, and has remained relatively stable since this time. The SSB in SCI 1 in 2010 is estimated to be 40%–50% of B_0 (Table 25), depending on the model selected and the recruitment scenario. For SCI 2, model outputs suggest that spawning stock biomass (SSB) in SCI 2 decreased until 1990, increased to a peak in about 1994, declined to the early 2000s, increased slightly until about 2005, and has remained relatively stable since this time. The SSB in SCI 2 in 2010 is estimated to be about 40% of B_0 (Table 27) for both recruitment scenarios.

The default management target for scampi of 40% B_0 is within the range of % B_0 estimated for both stocks. On the basis of the outputs from model 1C, and annual catches at the TACC (120 tonnes), the probability of SSB in SCI 1 being below either of the limits by 2015 is very low (Table 26), irrespective of the recruitment scenario applied. Model 2C suggests the probability of SSB in SCI 1 being below the limits is greater, particularly for the recent recruitment scenario. For SCI 2, on the basis of outputs from model 4C, and annual catches at the TACC (200 tonnes), the probability of SSB being below the 20% B_0 limit is 63% and 29% for the recent and long term recruitment scenarios, respectively. For annual catches at the level of 2009-10 (125 tonnes), the probability of SSB being below the 20% B_0 limit is 15% and 5% for the recent and long term recruitment scenarios, respectively, while for catches at the level of the average of the last 5 years (75 tonnes), the probability of being below either limit is very low, irrespective of the recruitment scenario applied (Table 28).

Table 25: Results from MCMC runs showing B_0, B_{curr} and B_{2015} estimates at varying catch levels for both models for SCI 1 for recent (R) and long term (L) recruitment scenarios.

Model	B_0	B_{curr}	B_{curr}/B_0	100 tonnes		110 tonnes (2009-10 catch)		120 tonnes (TACC)		130 tonnes	
				B_{2015}/B_0	B_{2015}/B_{curr}	B_{2015}/B_0	B_{2015}/B_{curr}	B_{2015}/B_0	B_{2015}/B_{curr}	B_{2015}/B_0	B_{2015}/B_{curr}
1C (R)	2521	1267	0.50	0.44	0.87	0.42	0.84	0.41	0.81	0.39	0.78
2C (R)	1883	772	0.41	0.32	0.77	0.30	0.72	0.28	0.67	0.26	0.63
1C (L)	2521	1297	0.50	0.50	0.94	0.48	0.92	0.47	0.88	0.45	0.86
2C (L)	1883	834	0.43	0.47	1.00	0.45	0.95	0.43	0.90	0.41	0.86

Table 26: Results from MCMC runs for SCI 1, showing probabilities of projected spawning stock biomass exceeding the default Harvest Strategy Standard target and limit reference points.

	2010		100 tonnes 2015		110 tonnes (2009-10 catch) 2015		120 tonnes (TACC) 2015		130 tonnes 2015	
	1C	2C	1C	2C	1C	2C	1C	2C	1C	2C
Recent recruitment										
P(SSB<10% B_0)	0	0	0	0.016	0	0.028	0.001	0.047	0.001	0.064
P(SSB<20% B_0)	0	0	0.005	0.134	0.007	0.183	0.013	0.235	0.020	0.297
P(SSB<40% B_0)	0.035	0.473	0.341	0.757	0.405	0.797	0.467	0.832	0.530	0.860
P(B_{2015}<B_{2010})			0.800	0.839	0.851	0.868	0.879	0.902	0.908	0.929
Long term recruitment										
P(SSB<10% B_0)	0	0	0	0.014	0	0.027	0	0.041	0	0.059
P(SSB<20% B_0)	0	0	0.008	0.097	0.011	0.127	0.020	0.151	0.028	0.185
P(SSB<40% B_0)	0.041	0.377	0.300	0.402	0.335	0.432	0.373	0.463	0.401	0.493
P(B_{2015}<B_{2010})			0.570	0.506	0.605	0.540	0.621	0.575	0.638	0.611

Table 27: Results from MCMC runs showing B_0, B_{curr} and B_{2015} estimates at varying catch levels for SCI 2 for recent (R) and long term (L) recruitment scenarios.

Model	B_0	B_{curr}	B_{curr}/B_0	75 tonnes (average last 5 years)		100 tonnes		125 tonnes (2009-10 catch)		200 tonnes (TACC)	
				B_{2015}/B_0	B_{2015}/B_{curr}	B_{2015}/B_0	B_{2015}/B_{curr}	B_{2015}/B_0	B_{2015}/B_{curr}	B_{2015}/B_0	B_{2015}/B_{curr}
4C (R)	2248	881	0.39	0.38	0.95	0.34	0.84	0.30	0.74	0.17	0.43
4C (L)	2248	938	0.41	0.50	1.15	0.46	1.06	0.41	0.96	0.29	0.67

Table 28: Results from MCMC runs for SCI 2, showing probabilities of projected spawning stock biomass exceeding the default Harvest Strategy Standard target and limit reference points.

	2010	75 tonnes (average last 5 years)	100 tonnes	125 tonnes (2009-10 catch)	200 tonnes (TACC)
	2010	2015	2015	2015	2015
Recent recruitment	4C	4C	4C	4C	4C
P(SSB<10% B_0)	0	0	0.002	0.015	0.243
P(SSB<20% B_0)	0	0.021	0.071	0.146	0.635
P(SSB<40% B_0)	0.572	0.609	0.768	0.863	0.986
P($B_{2015}<B_{2010}$)		0.614	0.799	0.919	0.999
Long term recruitment					
P(SSB<10% B_0)	0	0	0.001	0.002	0.091
P(SSB<20% B_0)	0	0.003	0.019	0.051	0.291
P(SSB<40% B_0)	0.443	0.256	0.373	0.467	0.678
P($B_{2015}<B_{2010}$)		0.303	0.433	0.551	0.771

4. DISCUSSION

For each scampi stock, models were developed with a range of data inputs and structural (including spatial) complexity, developed on the basis of discussions within SCI200803W (Tuck & Dunn 2009). Changes to the model structure, and fixing abundance indices process error (for SCI 1) have improved fits to the CPUE series considerably, compared to previous models. Increasing model complexity did not generally improve fits greatly, or alter perceptions of overall stock trajectory, but did result in some changes in the level of B_0 and SSB_{2010}. For each fishery, one or two (if results were not consistent) models fitting all the abundance indices were examined further, and have been presented as base model options. The MCMC simulations had reasonable diagnostics, and the MCMC results were similar to the MPD estimates.

For SCI 1, the models stratified on the basis of depth or survey strata estimated a slightly smaller B_0 than the simplest model, but all followed a very similar trajectory. MPD estimates of B_0 from the base models were 1800–2300 t, and the likelihood profiles showed clear minima at these values. The abundance indices appear most influential from the likelihood profiles. The stock trajectory relative to B_0 appears reasonably consistent between the models presented, initially declining to the early 1990s, increasing to the mid 1990s, declining again until the early 2000s, and then remaining more stable, with the models suggesting that SSB in 2010 was between 40 and 60% of B_0, depending on assumptions about recent recruitment. Models 1C and 2C were accepted by the Working Group.

For SCI 2, the models including the CPUE indices were very consistent, and the model with the simplest spatial stratification was presented. The MPD estimate of B_0 was about 2300 t, and as with the SCI 1 models, the likelihood profiles showed a clear minimum, and the abundance indices appeared most influential. The stock trajectory relative to B_0 appears to have remained stable (or slightly increased) until the mid 1990s, declined until the late 1990s, increased slightly, and then remained stable since the early 2000s. The model suggests that SSB in 2010 was between 38 and 50% of B_0, depending on assumptions about recent recruitment. Model 4C was accepted by the Working Group.

For SCI 6A, the model stratified on the basis of depth estimated a slightly greater B_0 than the simplest model, but all followed a very similar trajectory. MPD estimates of B_0 from the base models were 2600 – 3000 t, and the likelihood profiles showed clear minima at these values. As with the models for other areas, the abundance indices appear most influential from the likelihood profiles. The stock trajectory relative to B_0 appears very consistent between the models presented, initially declining in the early 1990s, and subsequently fluctuating around this level. The model suggests that SSB in 2010 was between 33 and 53% of B_0. These models were not accepted by the Working Group.

Scampi observer length frequency data

The Ministry of Fisheries observer data collected from commercial voyages provides the only information on the length and sex distribution of removals from the fishery. These are generally not well fitted within the current length based model, or previous implementations (Cryer et al. 2005, Tuck & Dunn 2006, Tuck & Dunn 2009). A previous examination of scampi observer data noted that coverage of the fishery is patchy, and concluded that the length and sex composition of scampi catches was sometimes poorly described (Hartill & Cryer 2000), and we have no reason to suggest the situation has changed since this study. A more recent investigation (based on a limited data set) identified a clear discrepancy between the observer samples and length distributions based on stratified sampling of scampi grades (Hartill & Tuck 2010), possibly introduced by the sampling procedure utilised on that occasion, and implying that the observer sample may have been biased. It is currently unclear how representative observer data is of the fishery removals, and any potential bias introduced by the sampling process may

partly explain the poor fits to the observer length distributions within the models. Fits to trawl survey length frequency data (where either the whole scampi catch, or a large subsample is measured) are far better within the models. Data on landings composition by processed size grade could be fitted within the model if these were considered more reliable, although at present only a limited time series of data are available.

5. ACKNOWLEDGEMENTS

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7.

APPENDIX 1. SCI 1 model 1C plots.
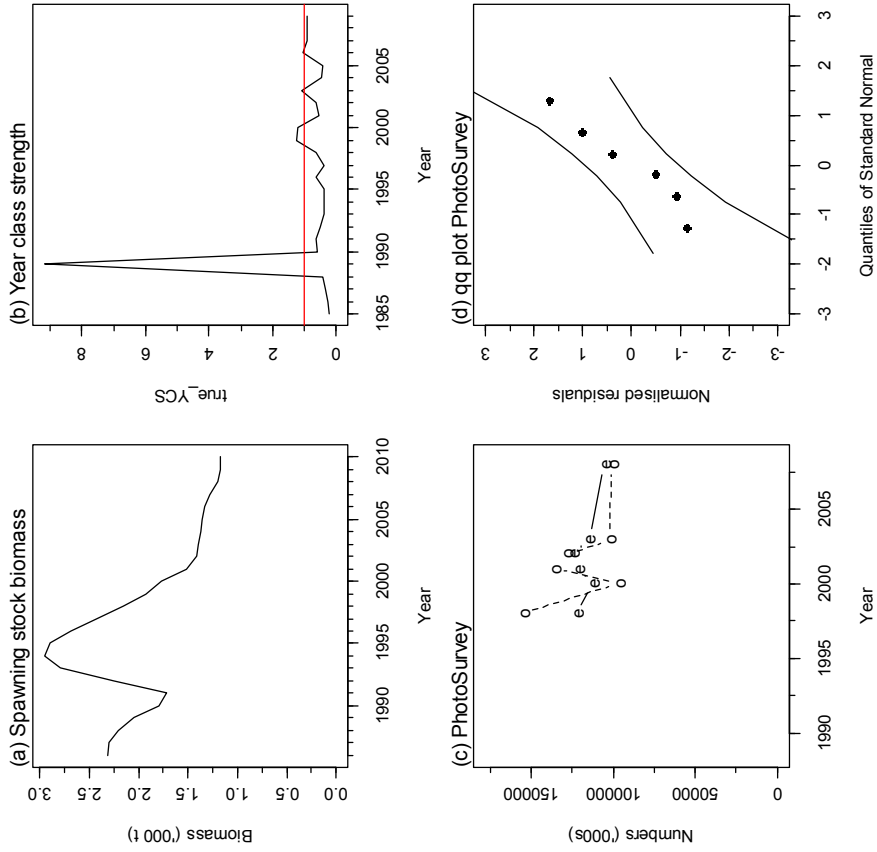
A1.1: Spawning stock biomass trajectory (a), year class strength (b) fits (c) and q-q diagnostic plots (d) to photo survey abundance index for SCI 1 from model 1C.
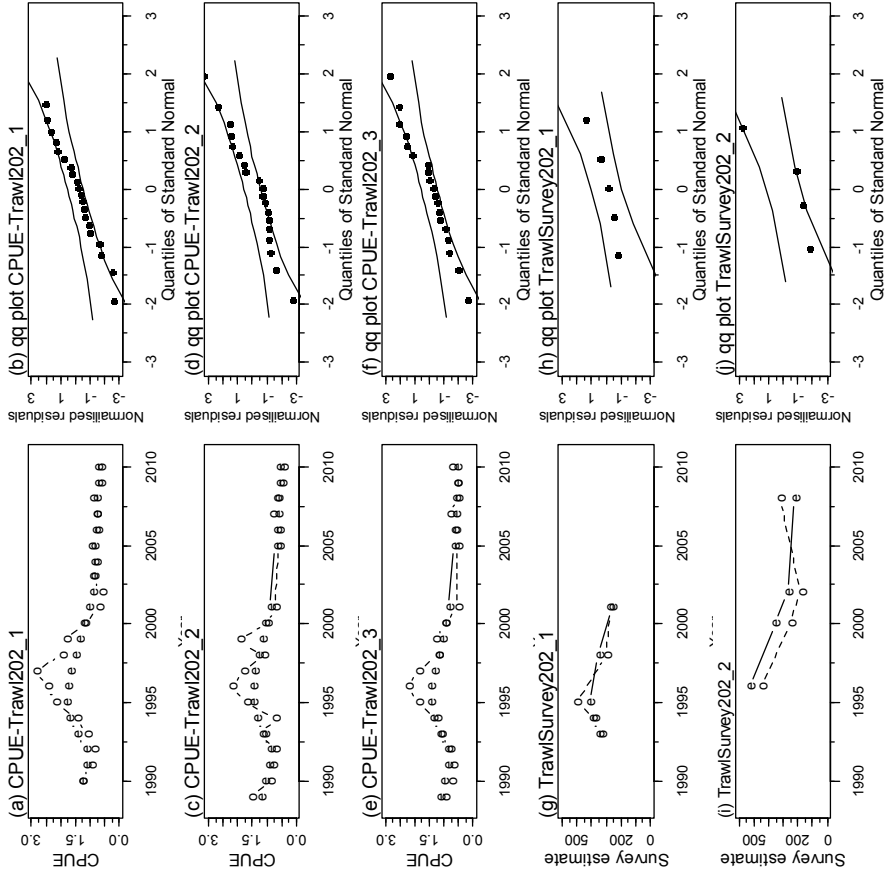

A1.2: Fits and q-q diagnostic plots to CPUE and trawl survey abundance indices for SCI 1 from model 1C.

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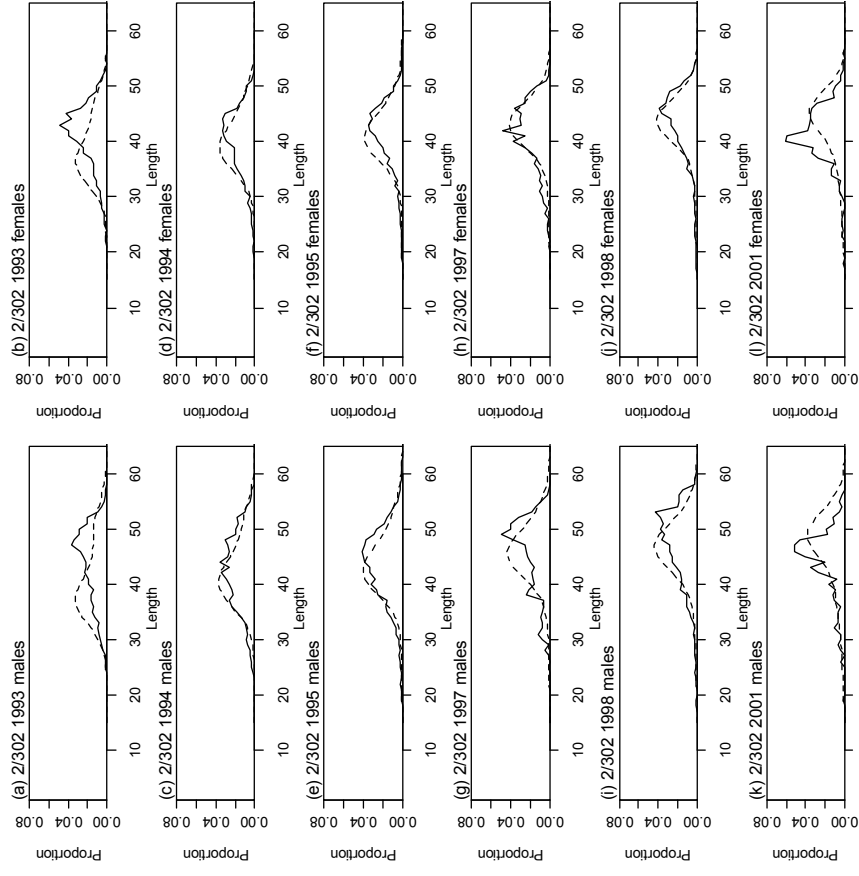
A1.4: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 2 trawl surveys for SCI 1 from model 1C.
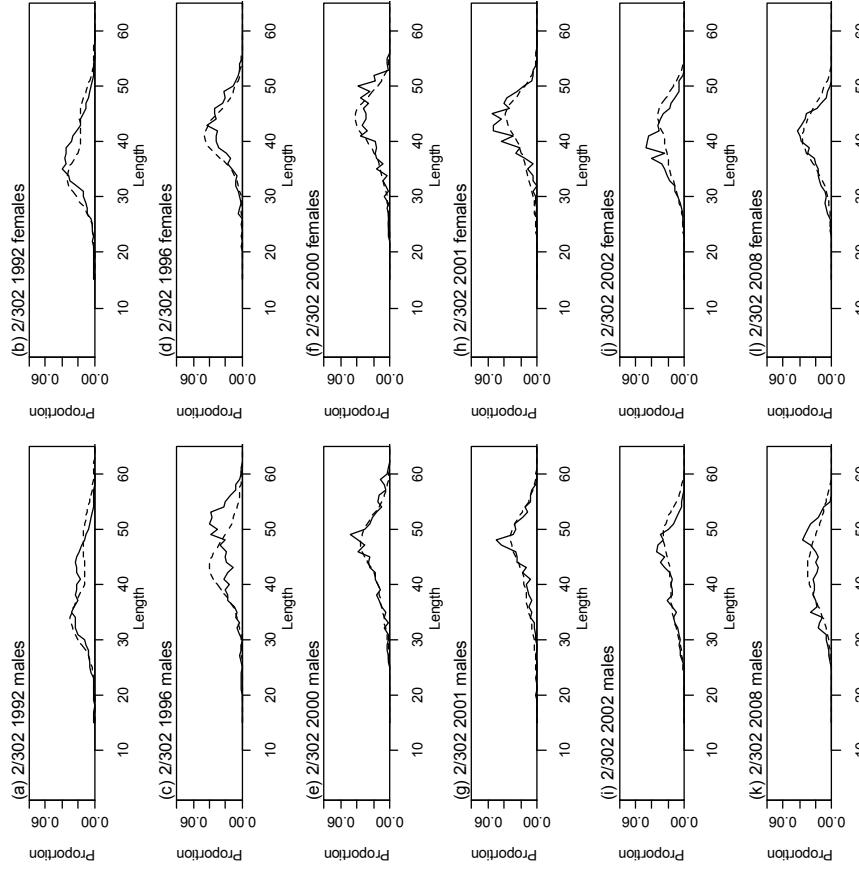
A1.3: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 1 trawl surveys for SCI 1 from model 1C.
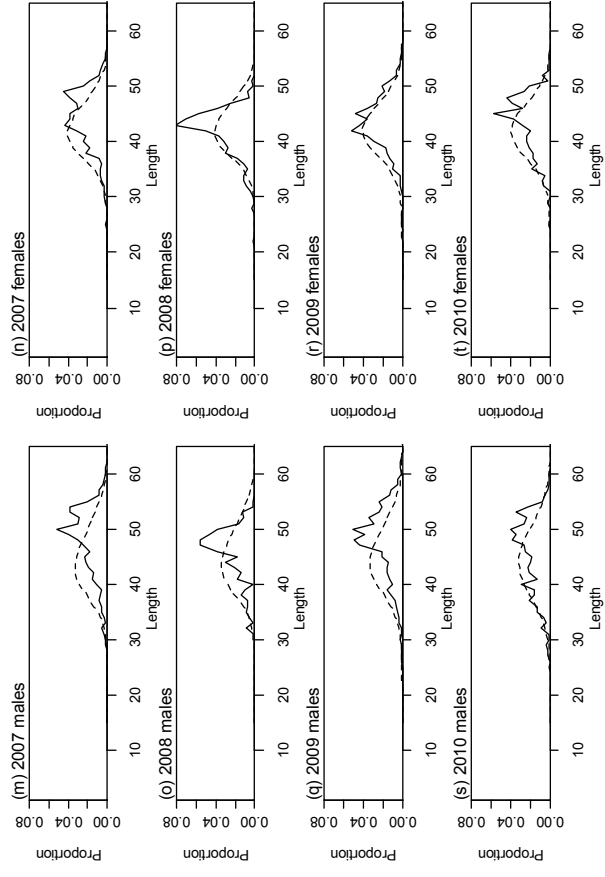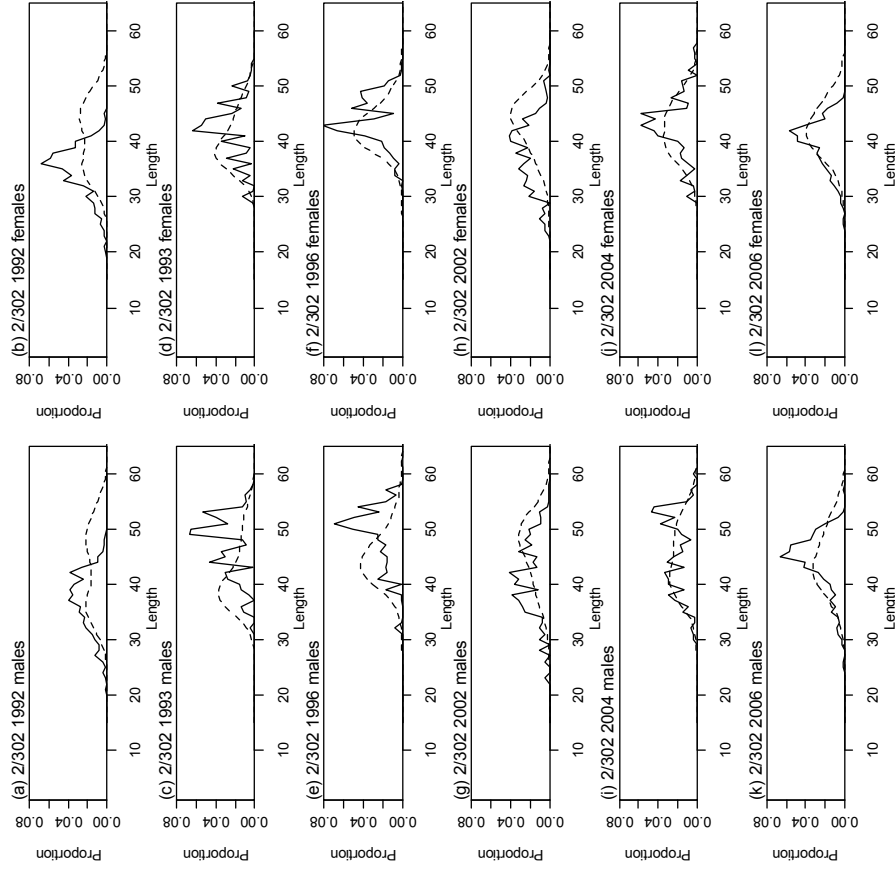
A1.5: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 1 observer samples for SCI 1 from model 1C.
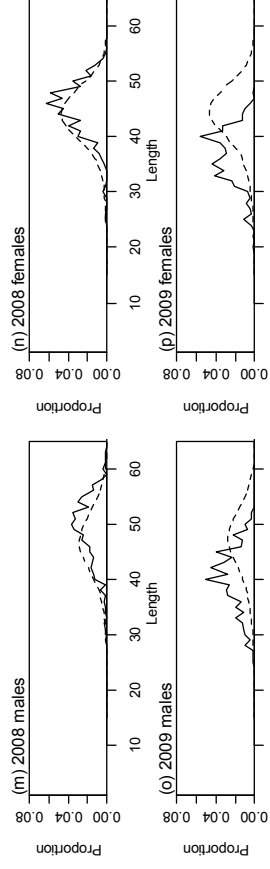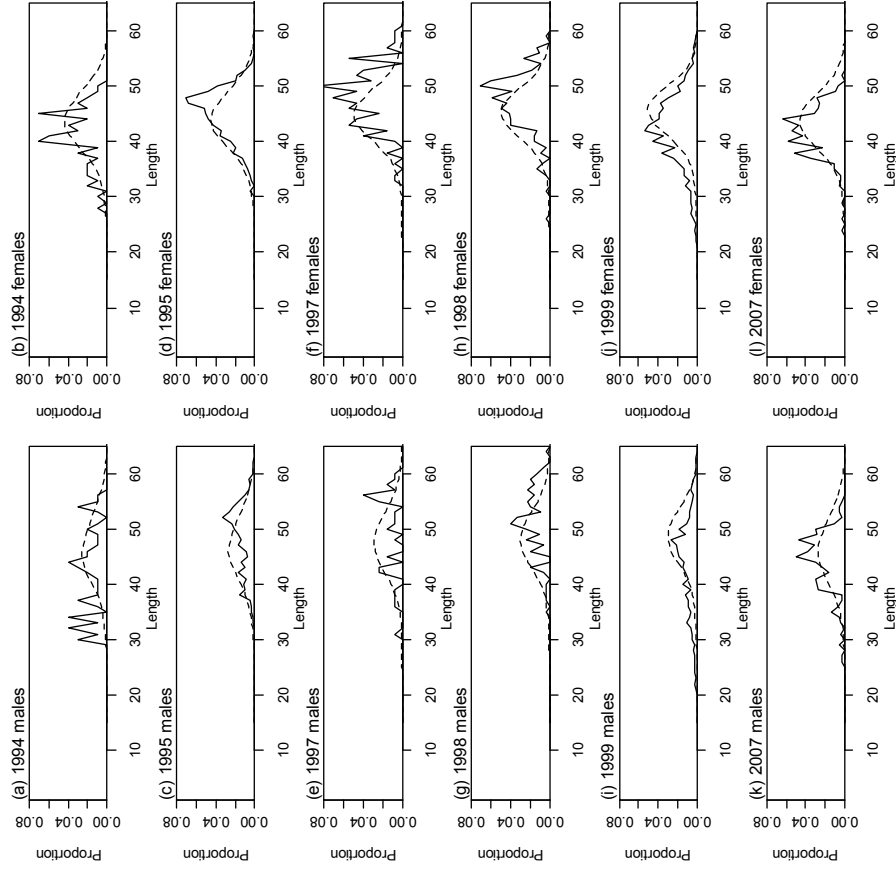
67
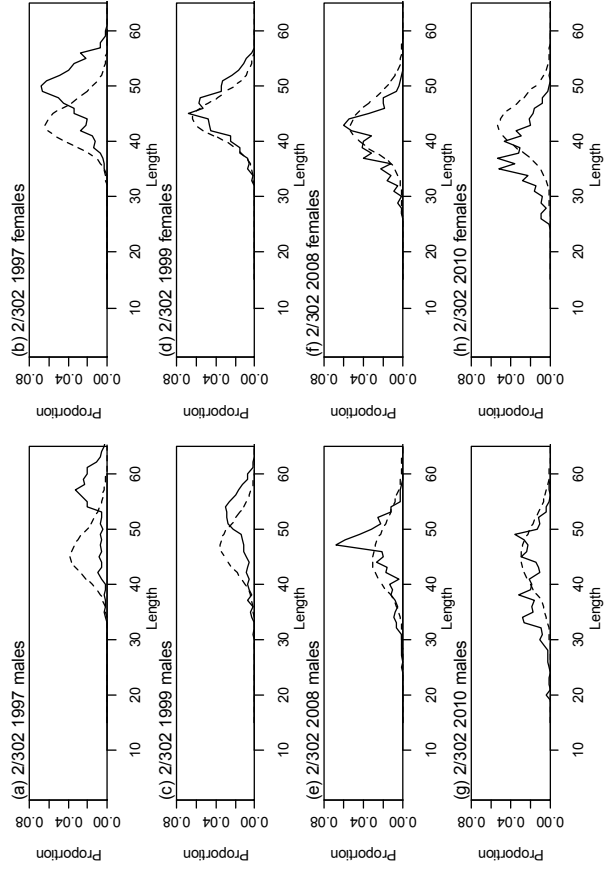
A1.6: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 2 observer samples for SCI 1 from model 1C.
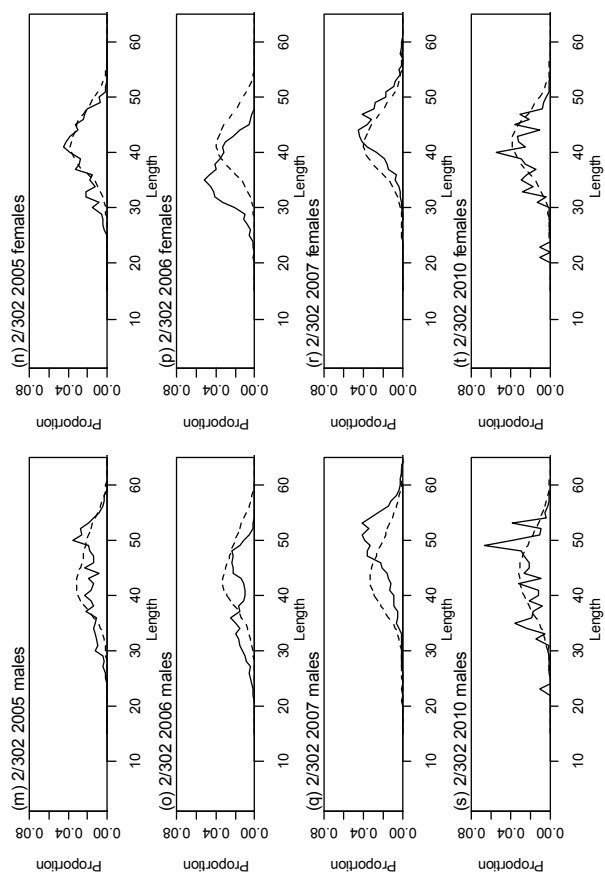
A1.7: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 3 observer samples for SCI 1 from model 1C.

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A1.9: Estimated (dotted line) and observed (points) proportion at length of recaptures from tag releases for SCI 1 from model 1C. Black solid circles represent males, grey hollow circles represent females.
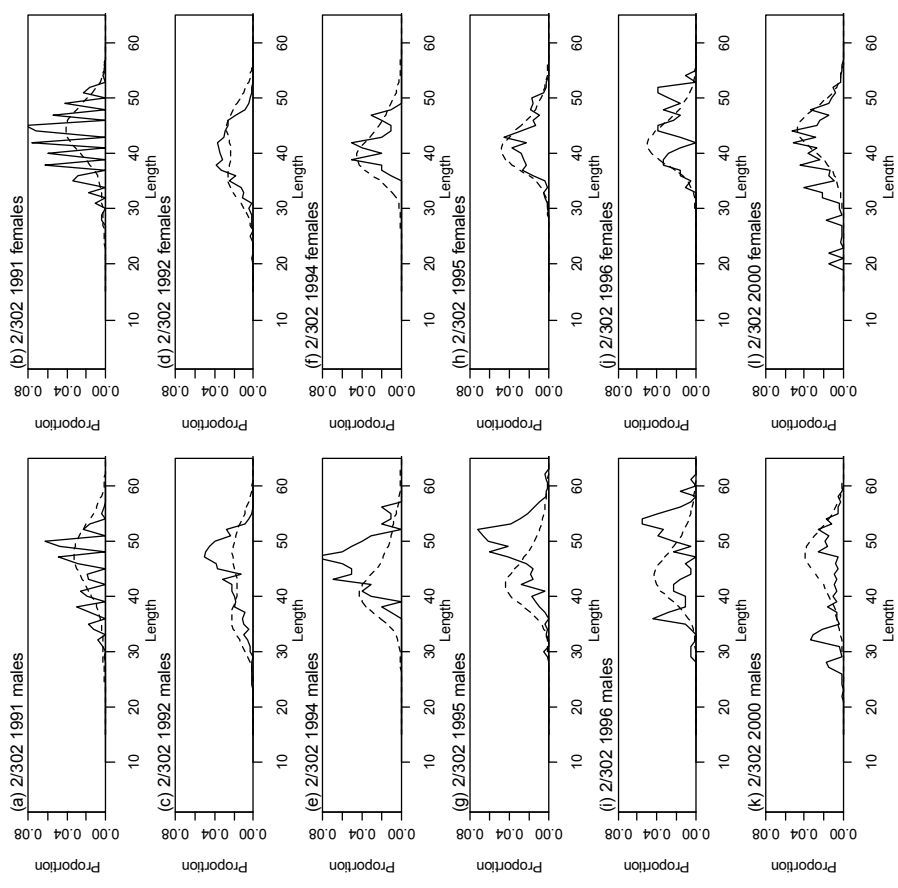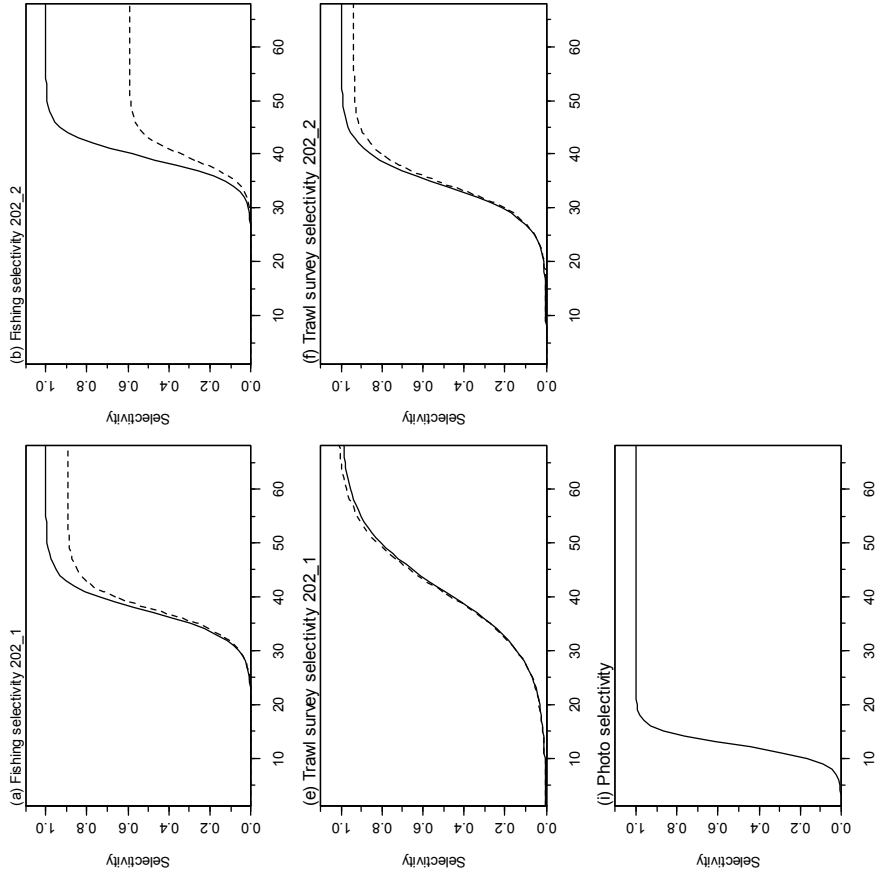
A1.8: Estimated ogives for selectivity at length for commercial trawling in time step 1 (a) and time step 2 (b), research trawling in time step 1 (c) and time step 2 (d), and the photographic survey (e) for SCI 1 from model 1C. Solid line − females, dotted line − males.

A1.11: MCMC traces for B0, SSB2010, R0, q-Trawl, q-Photo, and the four growth parameters indicated, for model 1C.

A1.10: Likelihood profiles for model 1C when B0 is fixed in the model. Figures show profiles for main priors (top left, p-priors, r – recaptures, a – abundance indices, • – proportions at length), abundance indices (top right, a - trawl survey time step 1, b – trawl survey time step 2, p – photo survey), proportion at length data (bottom left, a-trawl survey time step 1, b– trawl survey time step 2, 1 – observer time step 1, 2 – observer time step 2, 3 – observer time step 3) and priors (bottom right, b- B0, YCS - r, p- q-Photo, t – q-Trawl).

A1.13: MCMC diagnostic plot for model 1C, showing median relative jump size for all parameters (x axis, labelled 1–52). Parameter names are provided in Appendix 6.

A1.12: Diagnostic plots for parameters in A1.11..

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A1.15: Marginal posterior distribution of the parameters in A1.11.
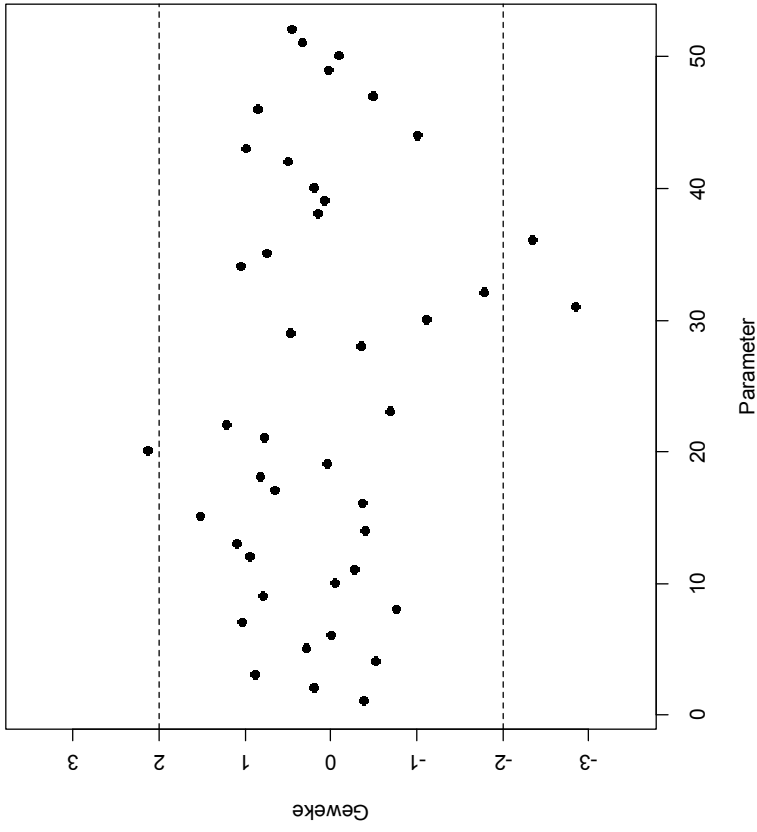
A1.14: Geweke MCMC diagnostic parameters for model 1C. Parameter names are provided in Appendix 6.
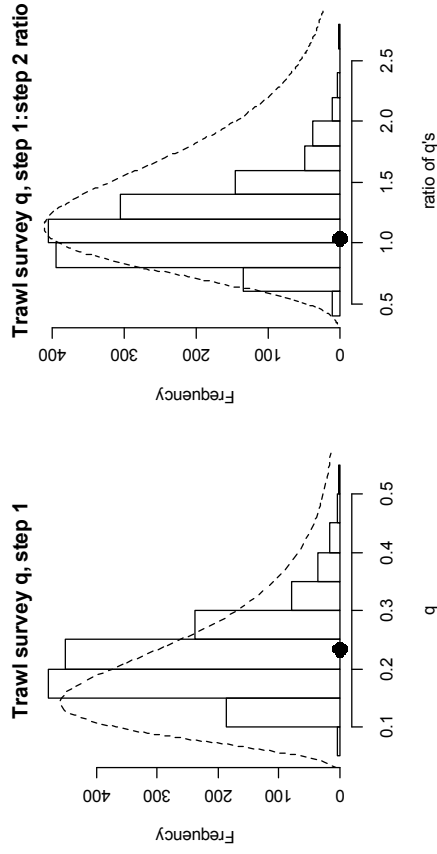
A1.17: Posterior trajectory of SSB. Upper plot shows boxplots of SSB, while lower plot shows boxplots of SSB as a percentage of B_0.

A1.16: Marginal posterior distributions (histograms), mpd estimates (solid dots) and distributions of priors (dashed lines) for parameters for which priors have been used within the model.
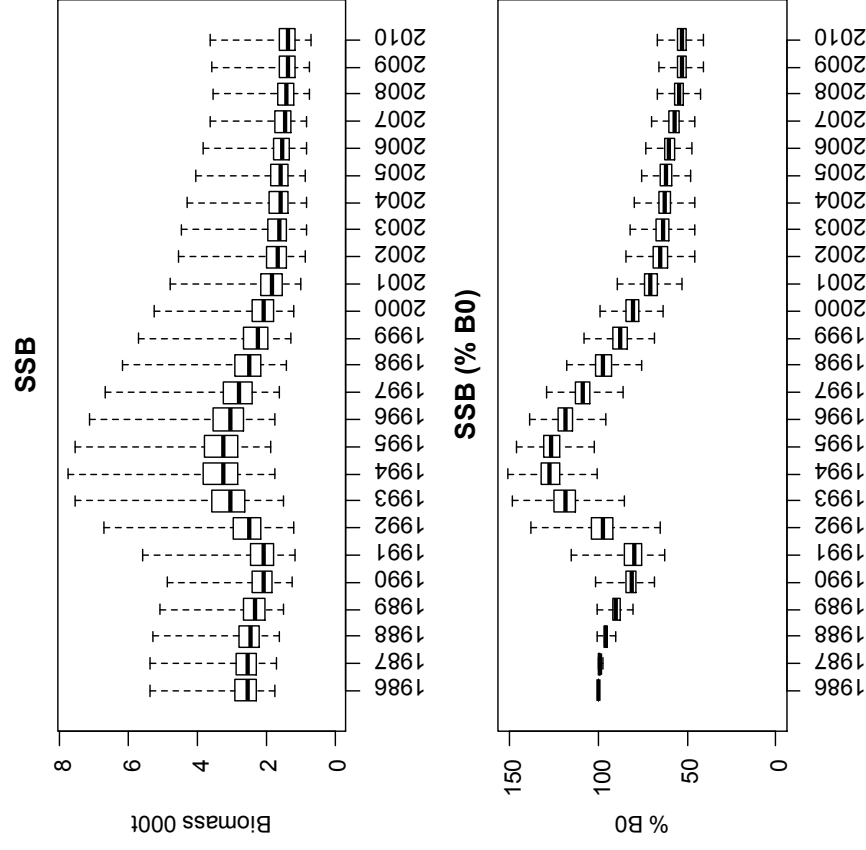
8.

APPENDIX 2. SCI 1 model 2C plots.
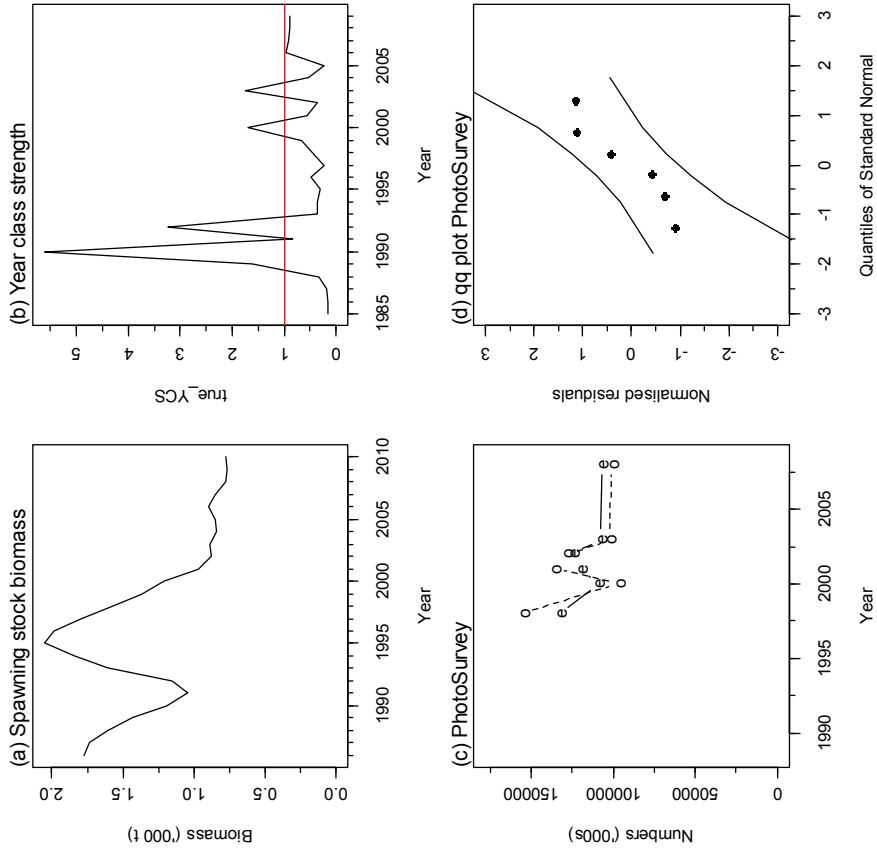
(a) Spawning stock biomass

(b) Year class strength

(c) PhotoSurvey

(d) qq plot PhotoSurvey

A2.1: Spawning stock biomass trajectory (a), year class strength (b) fits (c) and q-q diagnostic plots (d) to photo survey abundance index for SCI 1 from model 2C.

(a) CPUE-Trawl202_1   (b) qq plot CPUE-Trawl202_1

(c) CPUE-Trawl202_2   (d) qq plot CPUE-Trawl202_2

(e) CPUE-Trawl202_3   (f) qq plot CPUE-Trawl202_3

(g) CPUE-Trawl203_1   (h) qq plot CPUE-Trawl203_1

(i) CPUE-Trawl203_2   (j) qq plot CPUE-Trawl203_2

(k) CPUE-Trawl203_3   (l) qq plot CPUE-Trawl203_3
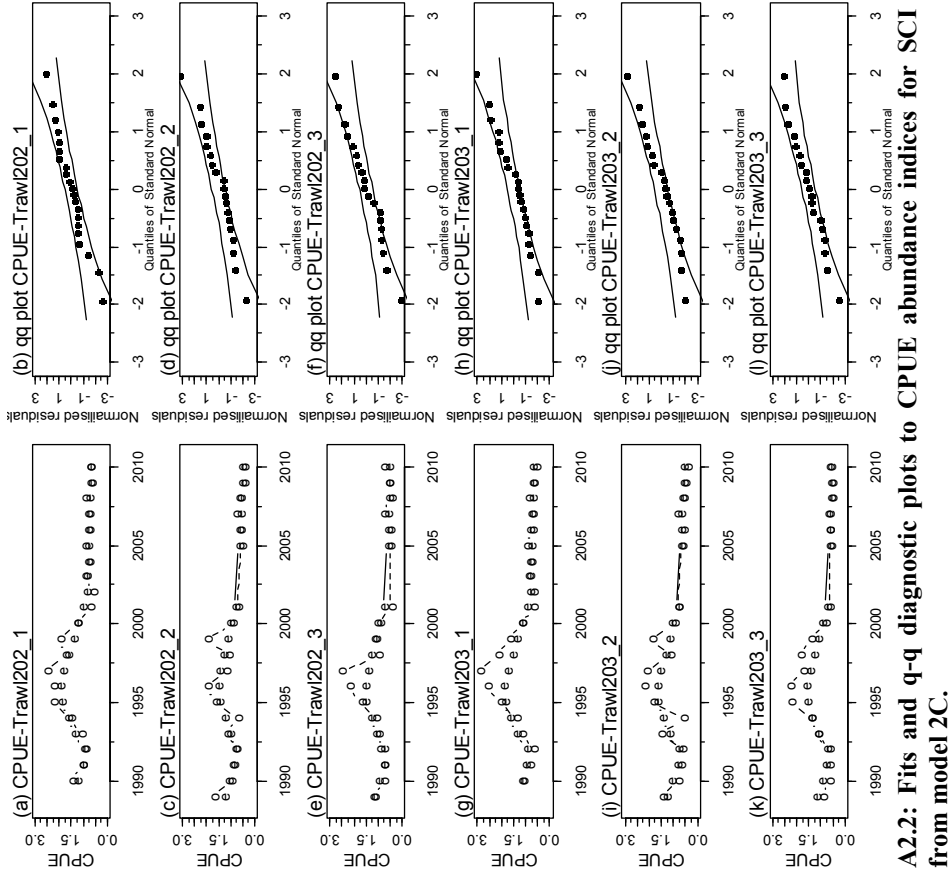
A2.2: Fits and q-q diagnostic plots to CPUE abundance indices for SCI 1 from model 2C.
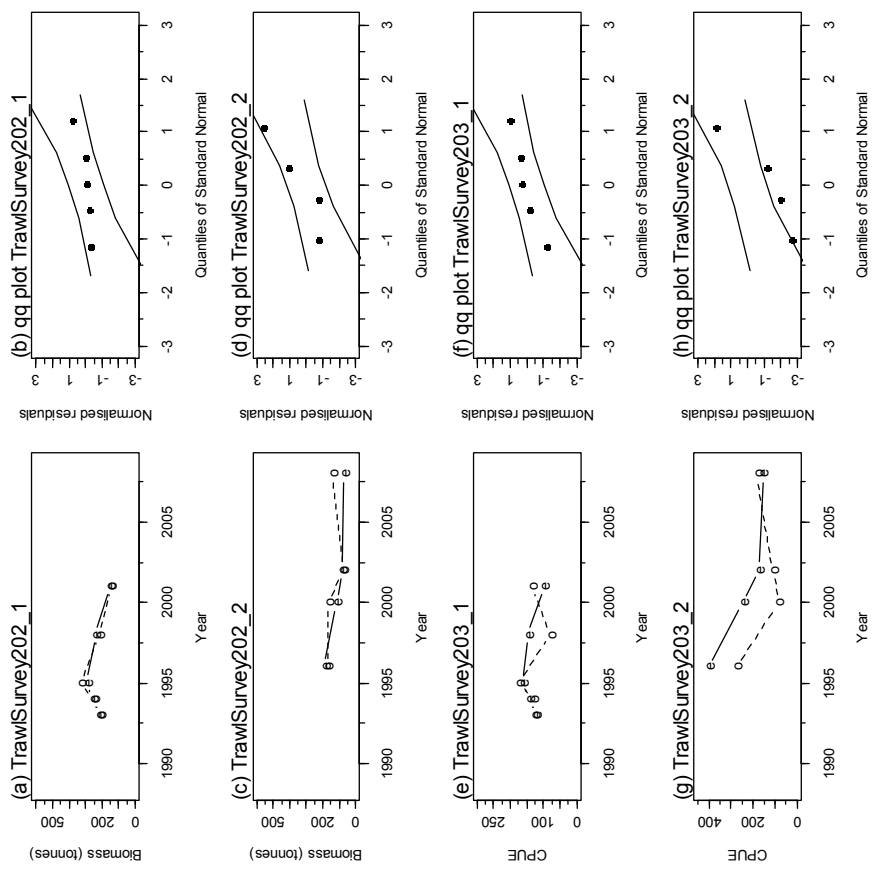
A2.3: Fits and q-q diagnostic plots to trawl survey abundance indices for SCI 1 from model 2C.
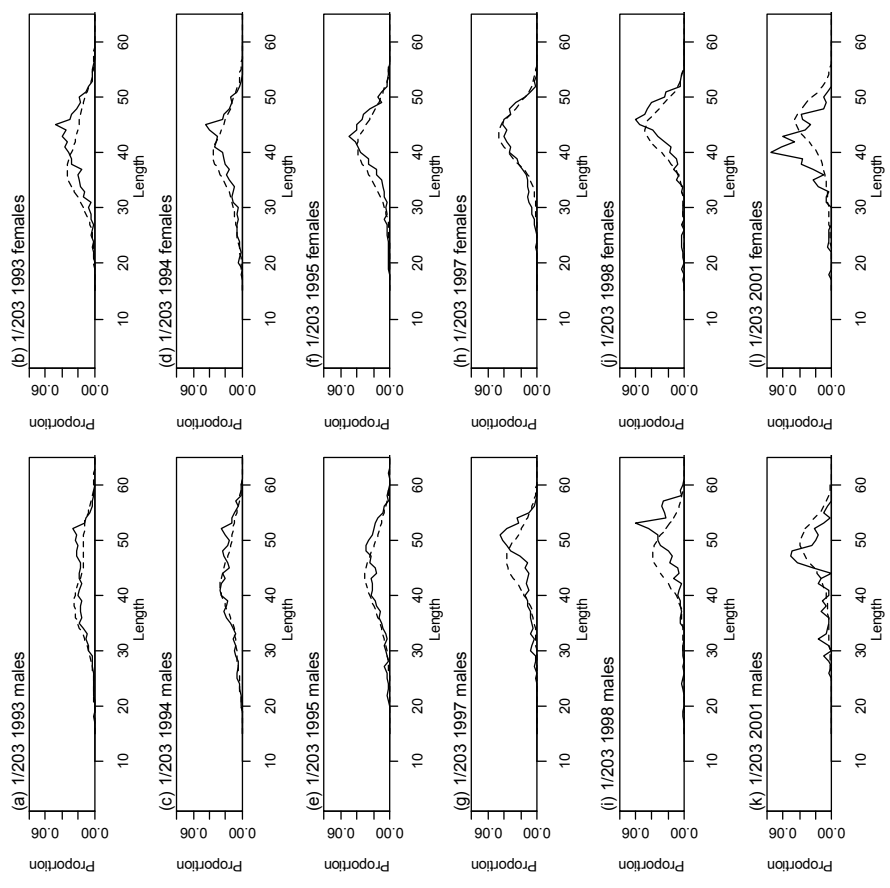
A2.4: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 1 trawl surveys for SCI 1 from model 2C.
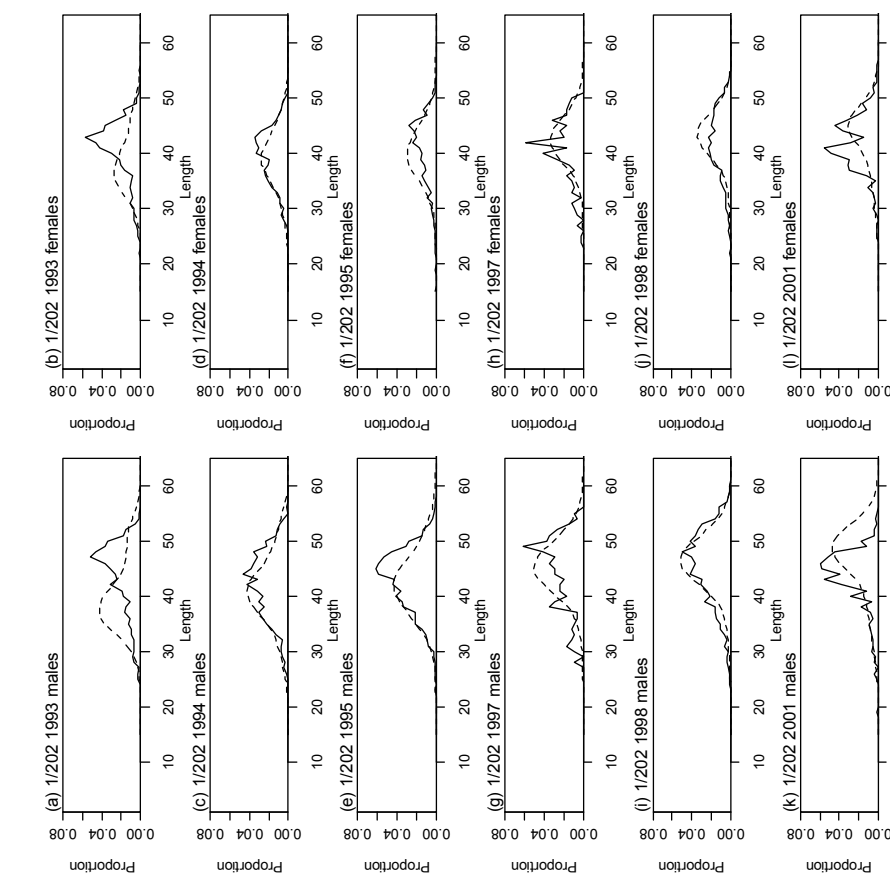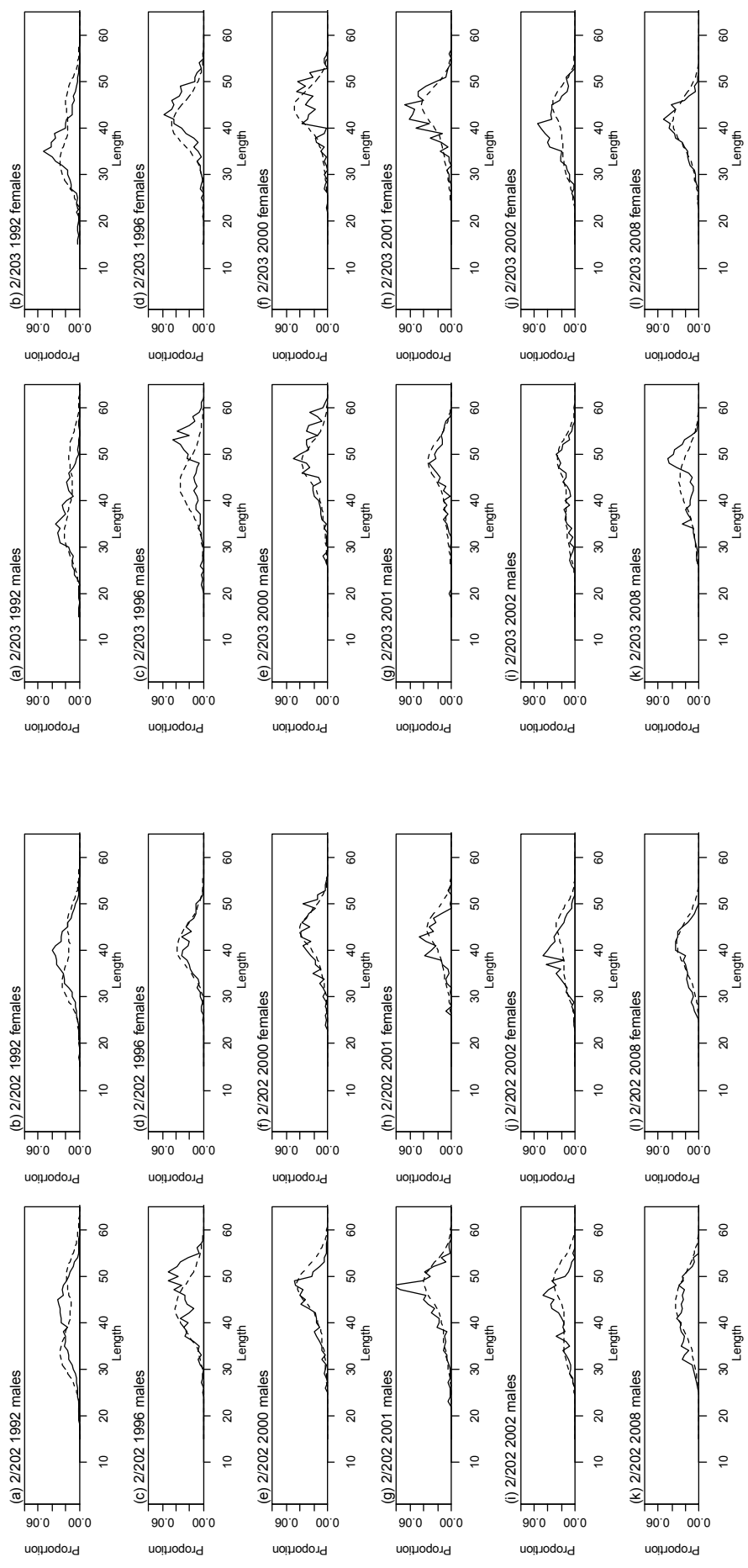
A2.5: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 2 trawl surveys for SCI 1 from model 2C.

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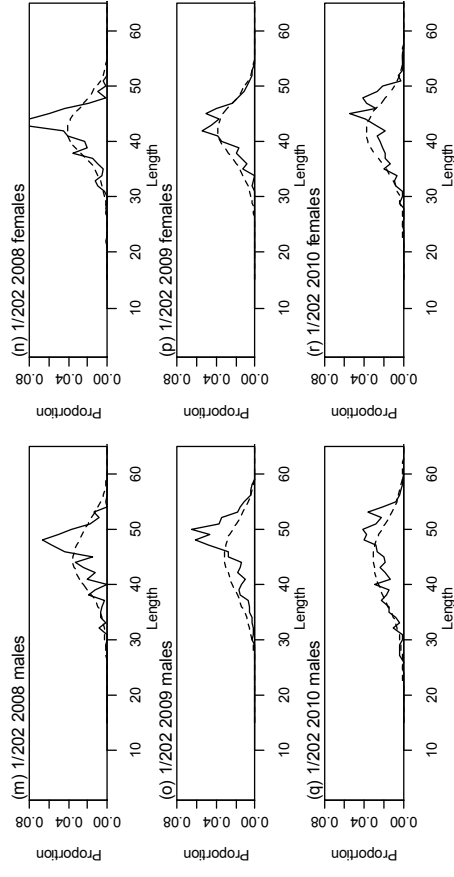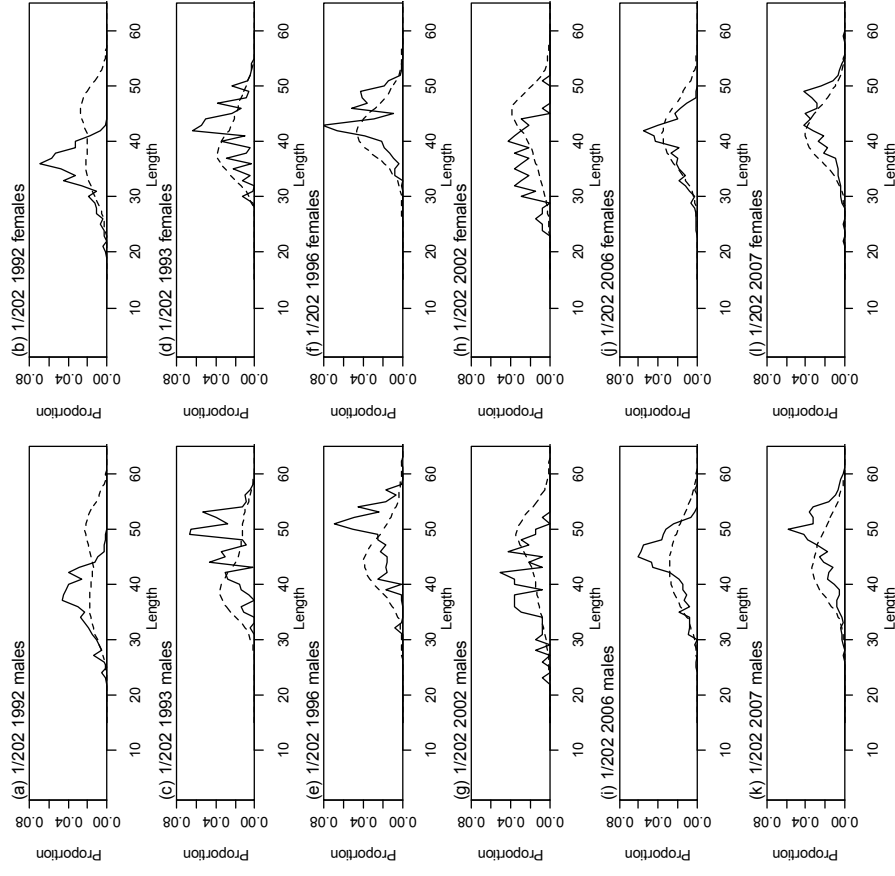
A2.6: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 1 observer samples for shallow subarea, SCI 1 from model 2C.
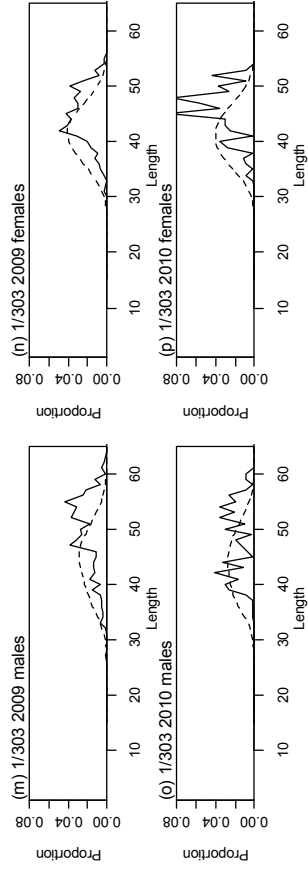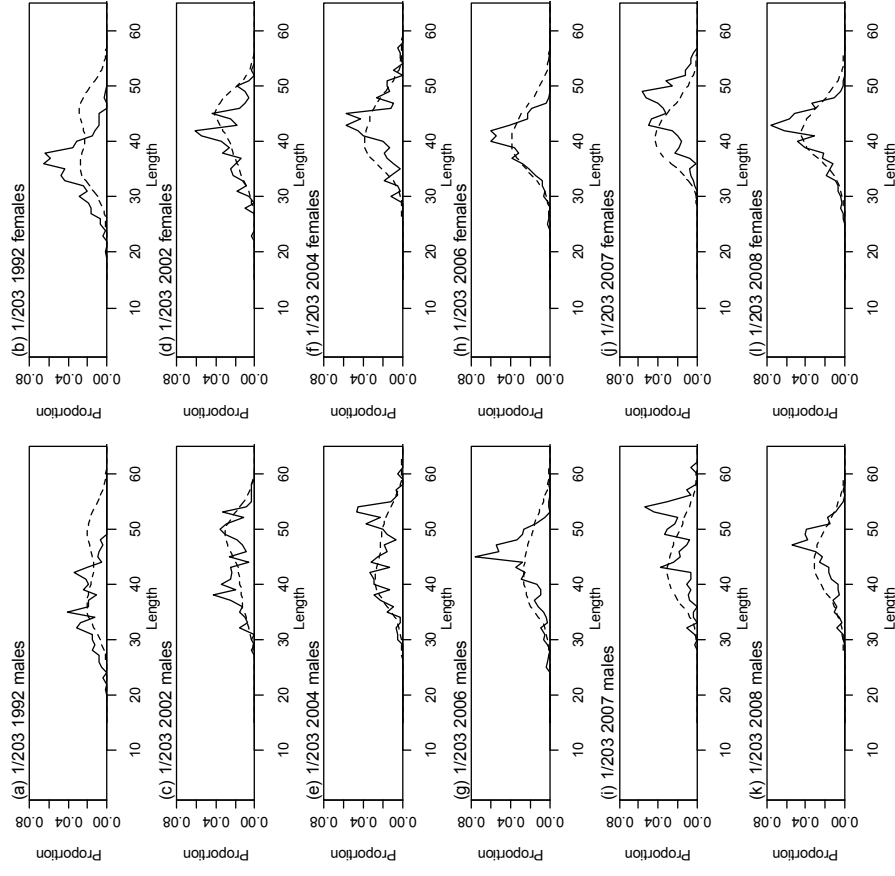
A2.7: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 1 observer samples for deep subarea, SCI 1 from model 2C.

80
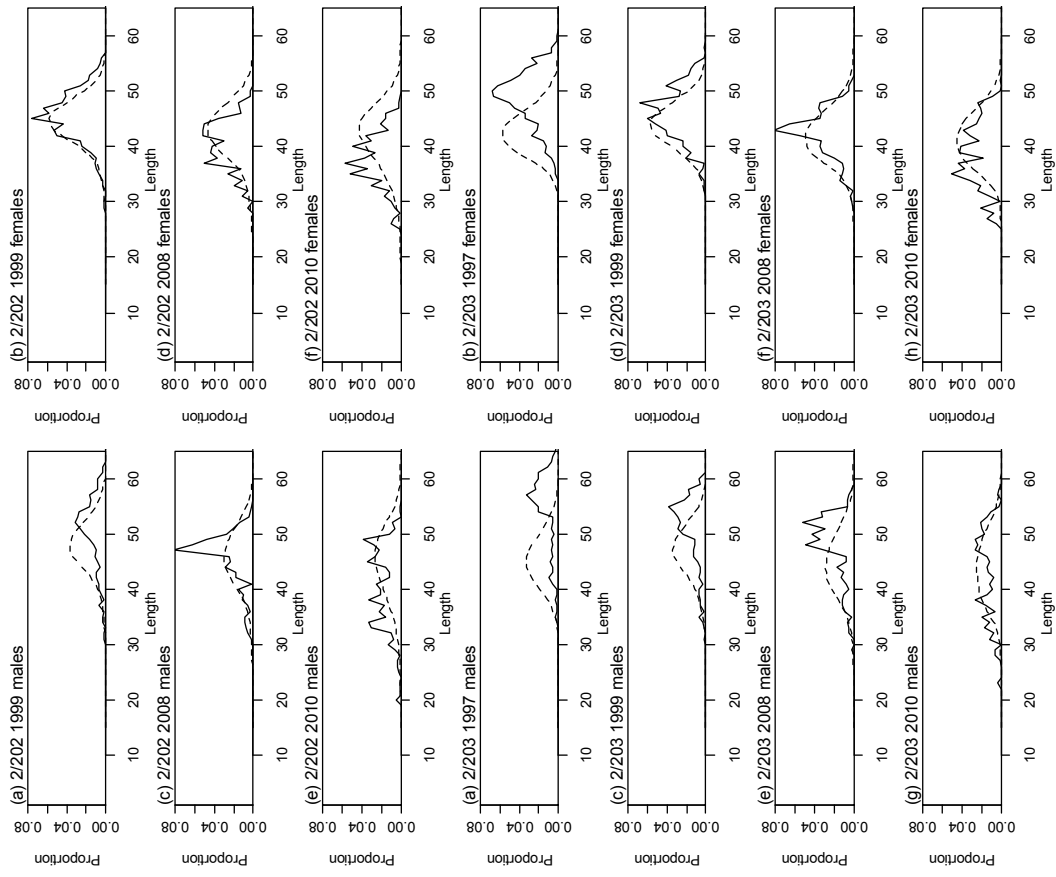
A2.8: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 2 observer samples for SCI 1 from model 2C.

A2.9: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 3 observer samples for shallow subarea, SCI 1 from model 2C.

82
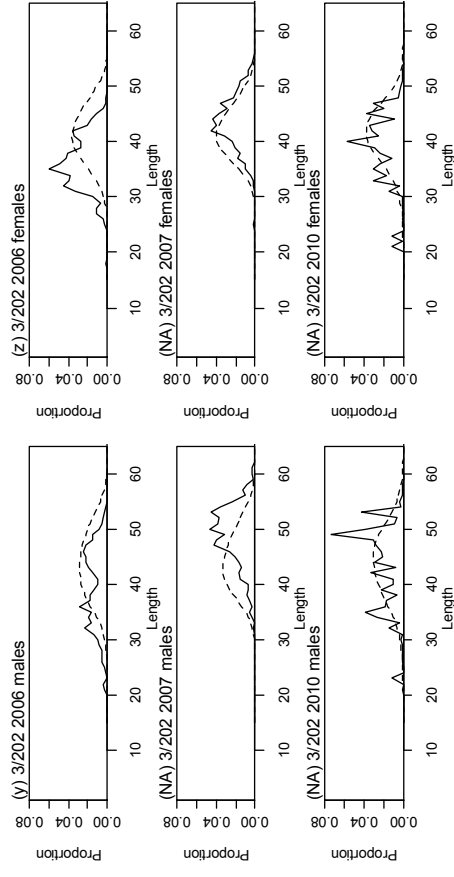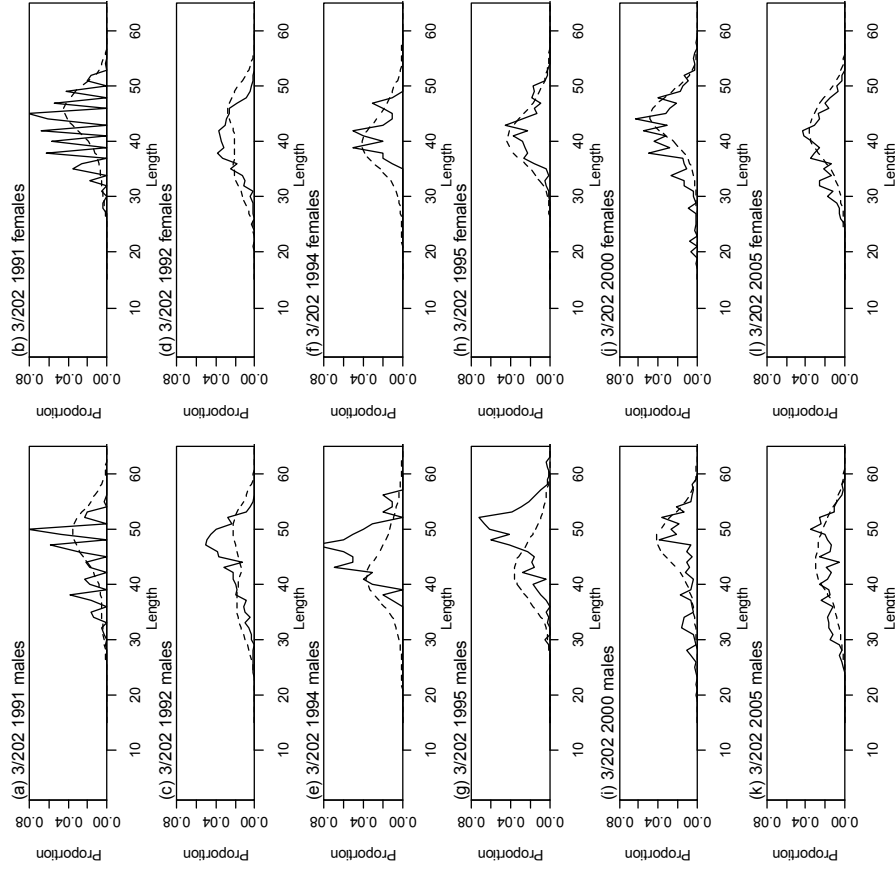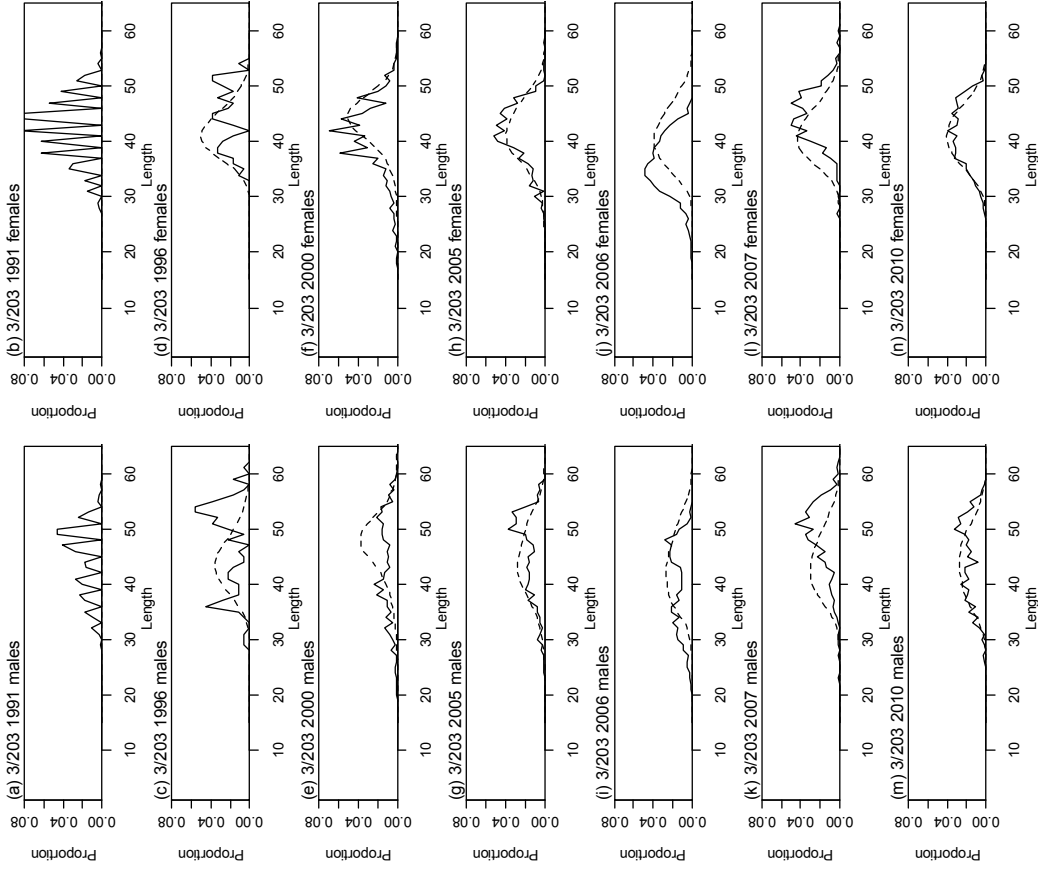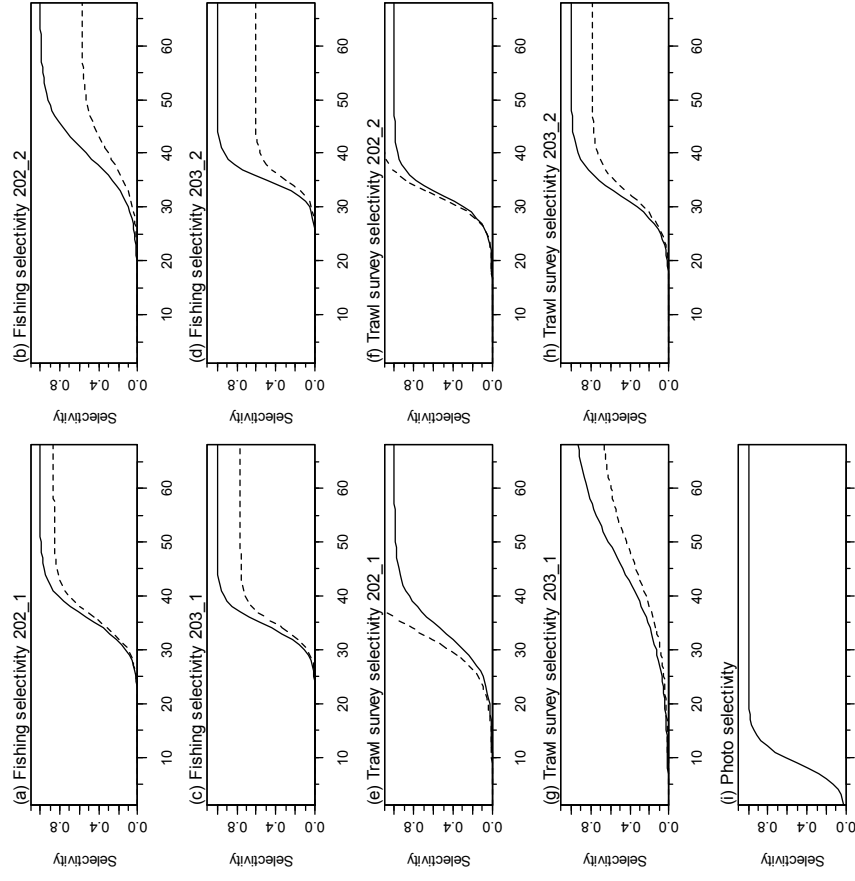
A2.11: Estimated ogives for selectivity at length for commercial trawling (a–d), research trawling (e–h), and the photographic survey (i) for SCI 1 from model 2C. Solid line – females, dotted line – males.

A2.10: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 3 observer samples for deep subarea, SCI 1 from model 2C.

A2.13: Likelihood profiles for model 2C when B₀ is fixed in the model. Figures show profiles for main priors (top left, p-priors, r – recaptures, a – abundance indices, ● – proportions at length), abundance indices (top right, a – trawl survey time step 1, b – trawl survey time step 2, p – photo survey), proportion at length data (bottom left, a-trawl survey time step 1, b- trawl survey time step 2, 1 – observer time step 1, 2 – observer time step 2, 3 – observer time step 3) and priors (bottom right, b- B₀, YCS - r, p- *q-Photo*, t – *q-Trawl*).

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A2.12: Estimated (dotted line) and observed (points) proportion at length of recaptures from tag releases for SCI 1 from model 2C. Black solid circles represent males, grey hollow circles represent females.
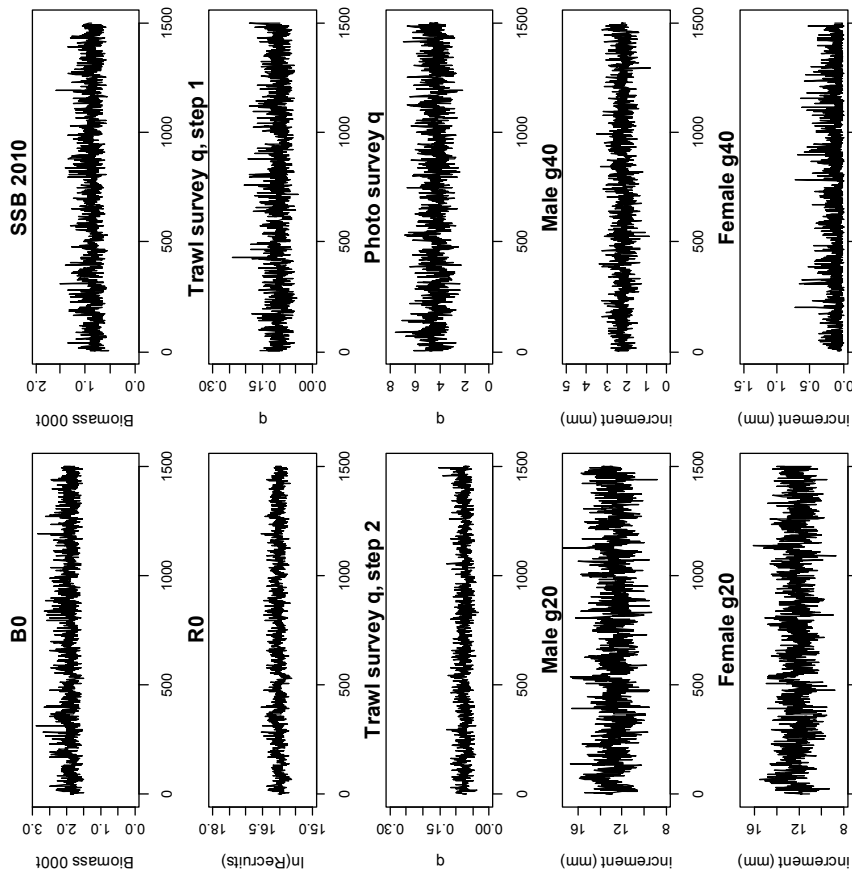
A2.14: MCMC traces for B₀, SSB₂₀₁₀, R₀, q-Trawl, q-Photo, and the four growth parameters indicated, for model 2C.
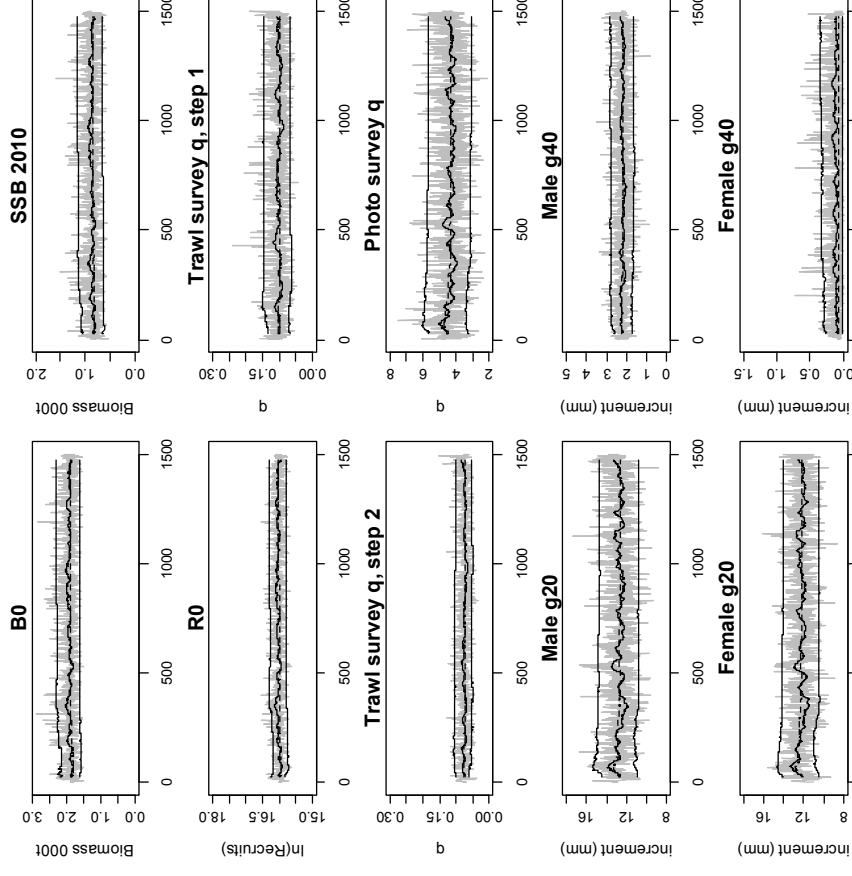
A2.15: Diagnostic plots for parameters in A2.14.

A2.17: Geweke MCMC diagnostic parameters for model 2C. Parameter names are provided in Appendix 6.
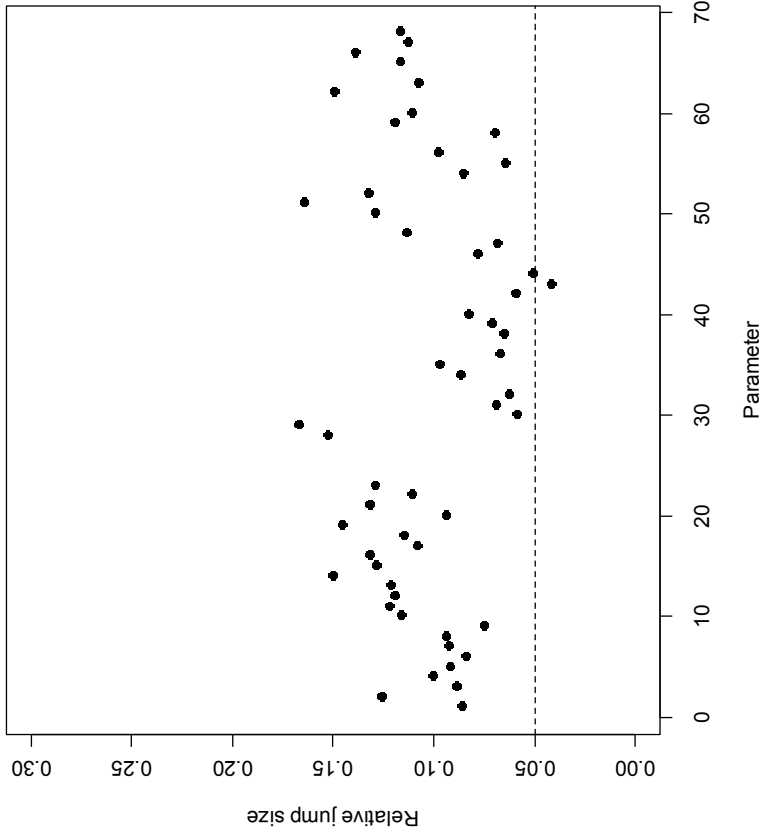
A2.16: MCMC diagnostic plot for model 2C, showing median relative jump size for all parameters (x axis, labelled 1–68). Parameter names are provided in Appendix 6.
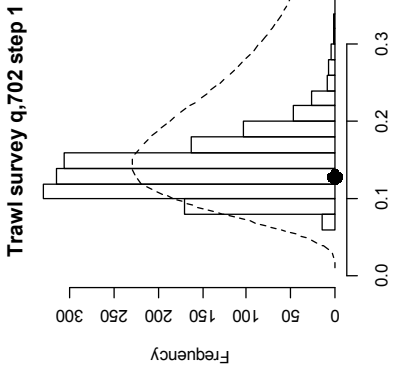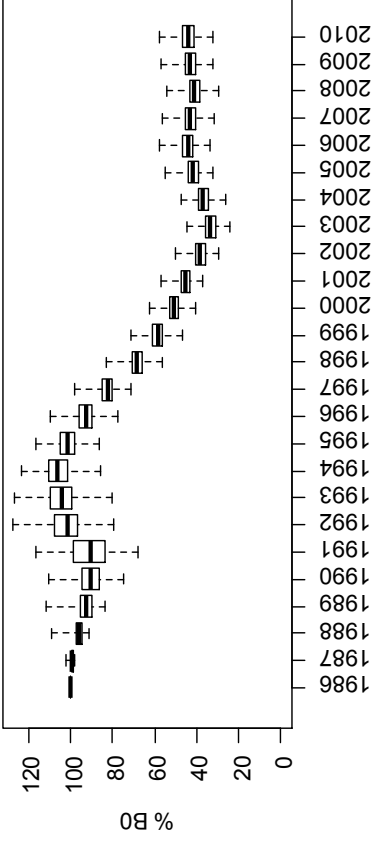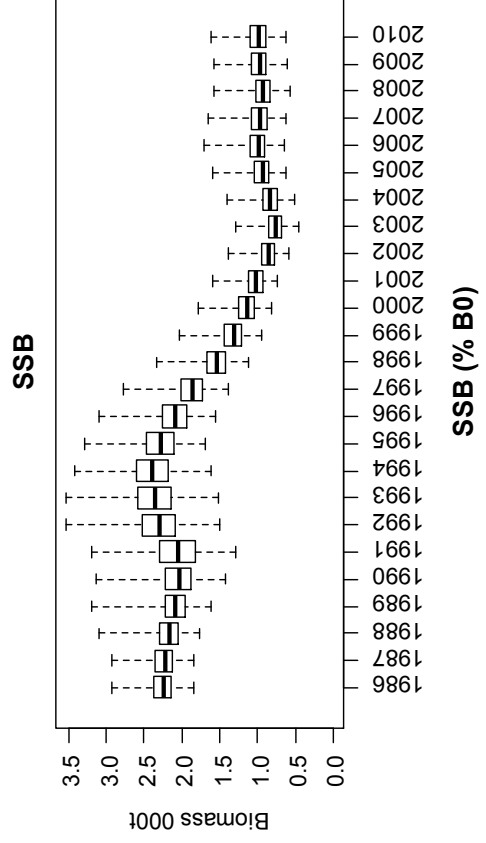
A2.19: Marginal posterior distributions (histograms), mpd estimates (solid dots) and distributions of priors (dashed lines) for parameters for which priors have been used within the model.
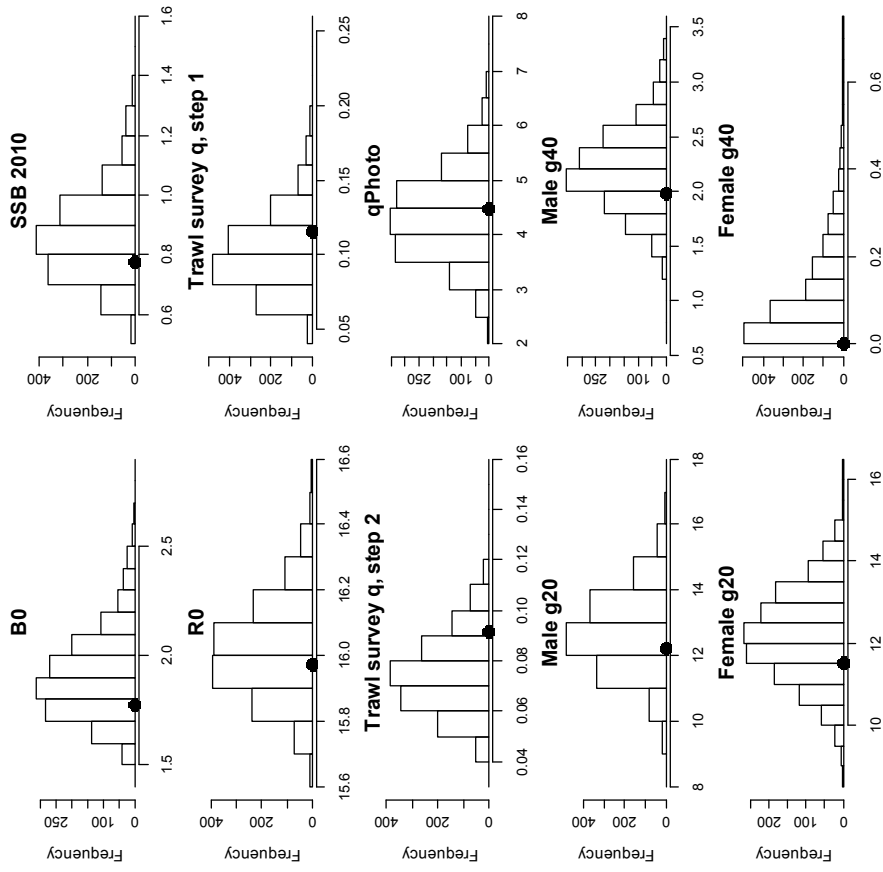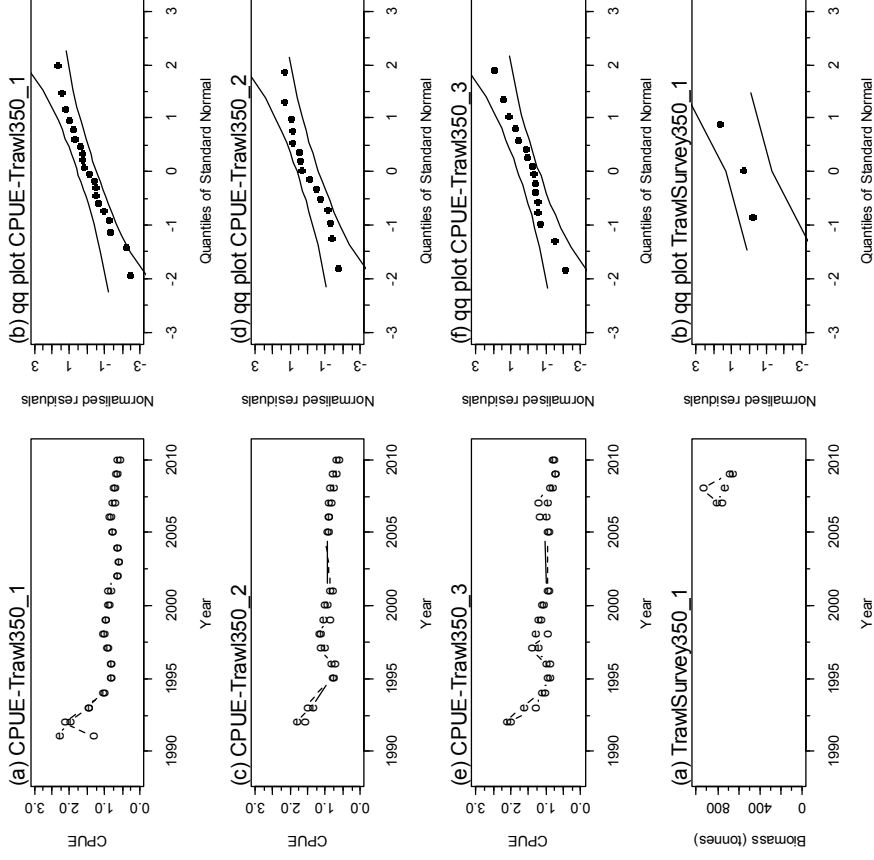
A2.18: Marginal posterior distribution of the parameters in A2.14.
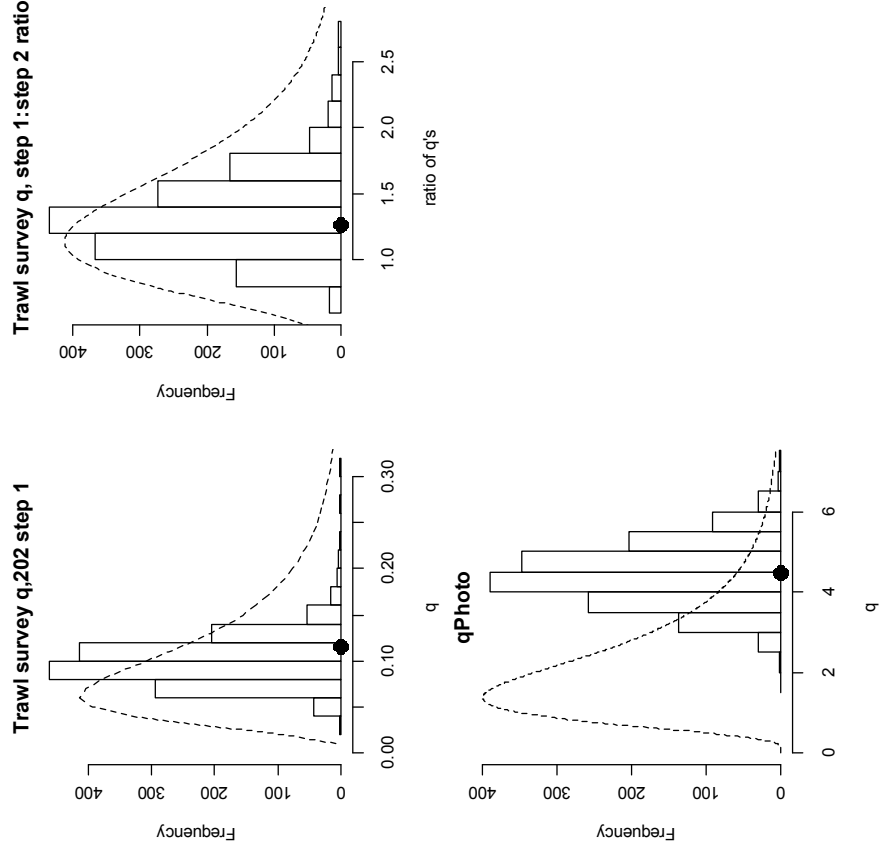
SSB

SSB (% B0)
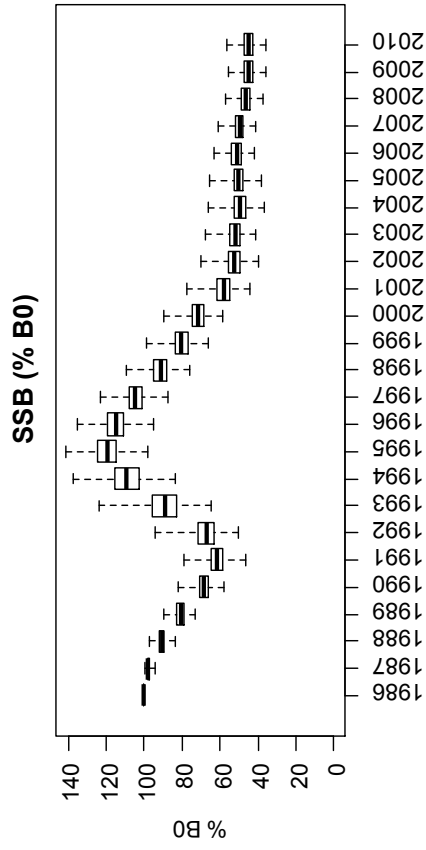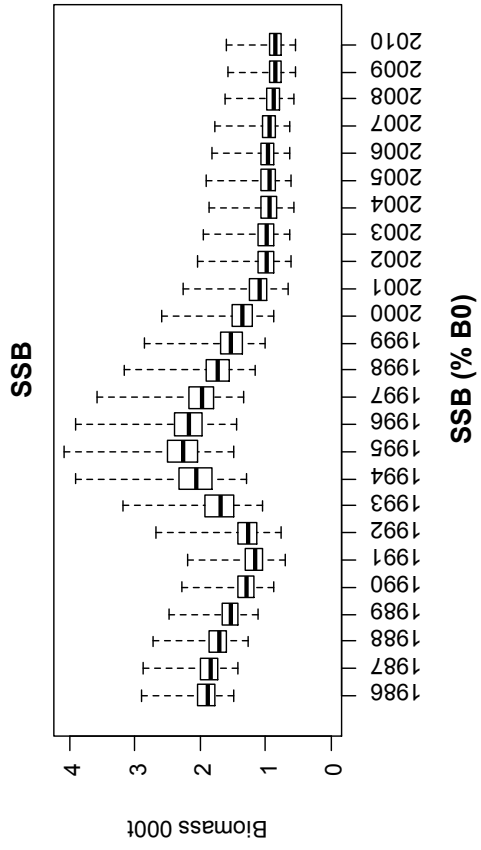
A2.20: Posterior trajectory of SSB. Upper plot shows boxplots of SSB, while lower plot shows boxplots of SSB as a percentage of B_0.

9.

**APPENDIX 3. SCI 2 model 4C plots.**

(a) Spawning stock biomass

(b) Year class strength

(c) PhotoSurvey

(d) qq plot PhotoSurvey
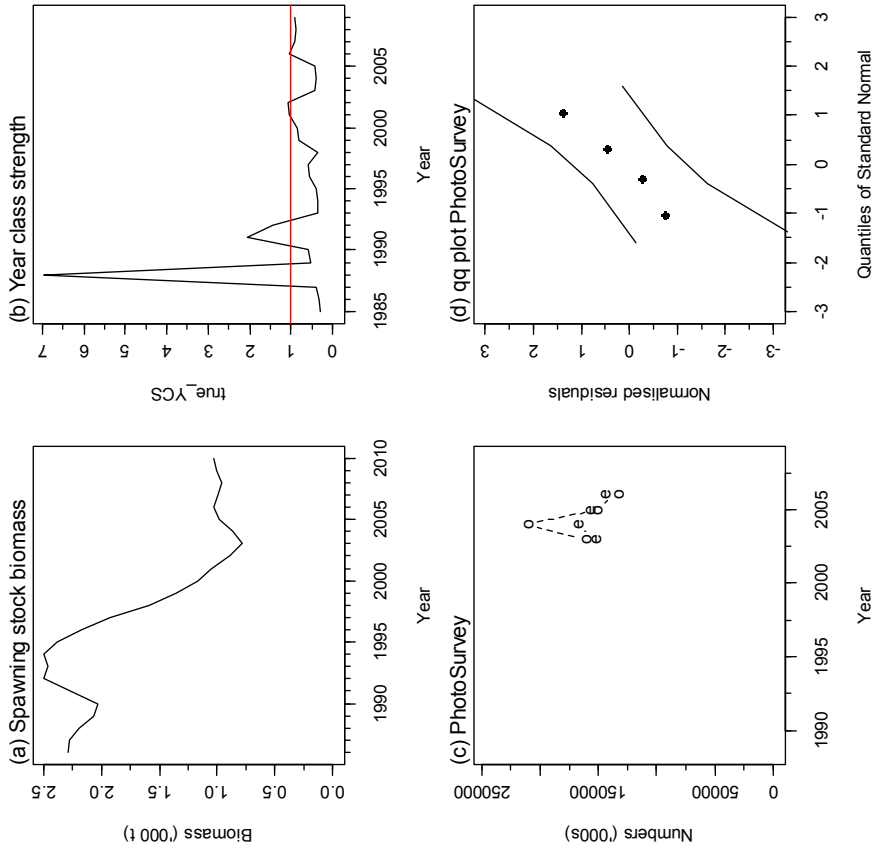
A3.1: Spawning stock biomass trajectory (a), year class strength (b) fits (c) and q-q diagnostic plots (d) to photo survey abundance index for SCI 2 from model 4C.


(a) CPUE-Trawl702_1

(b) qq plot CPUE-Trawl702_1

(c) CPUE-Trawl702_2

(d) qq plot CPUE-Trawl702_2

(e) CPUE-Trawl702_3

(f) qq plot CPUE-Trawl702_3

(g) TrawlSurvey702_1

(h) qq plot TrawlSurvey702_1

(i) TrawlSurvey702_2

(j) qq plot TrawlSurvey702_2
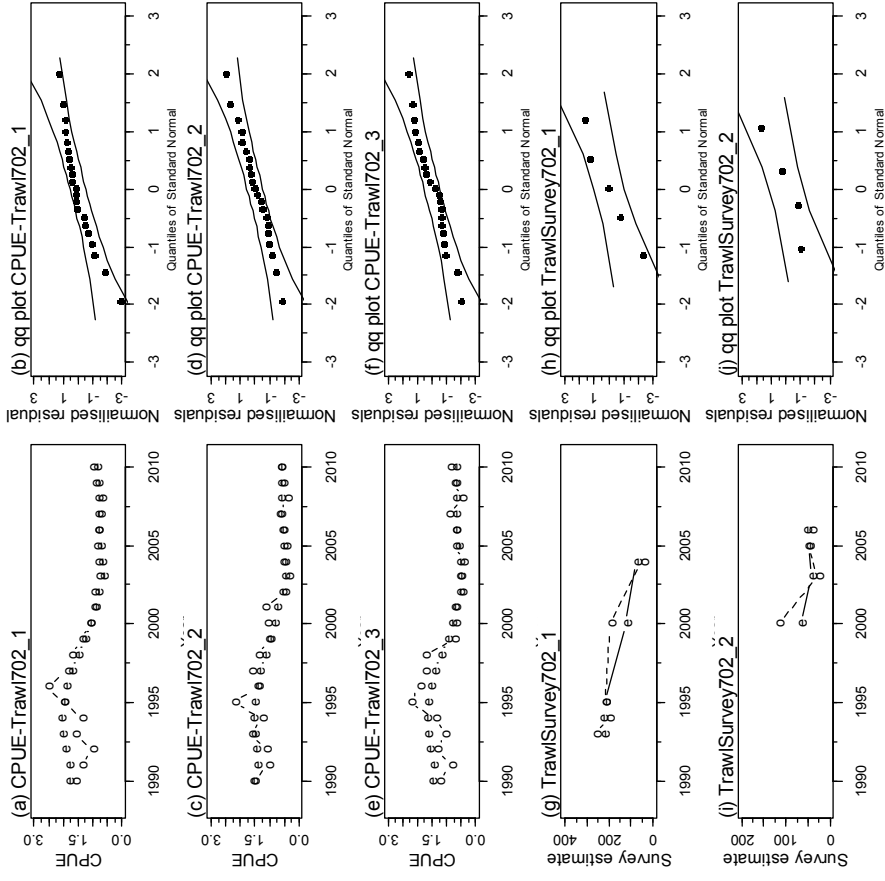
A3.2: Fits and q-q diagnostic plots to CPUE and trawl survey abundance indices for SCI 2 from model 4C.
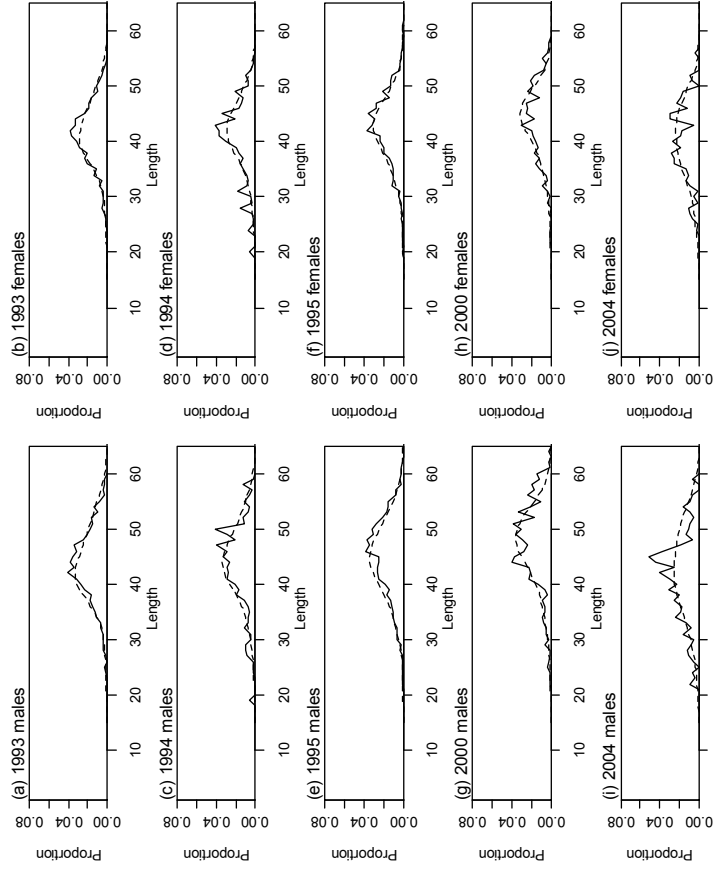
89

A3.4: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 2 trawl surveys for SCI 2 from model 4C.

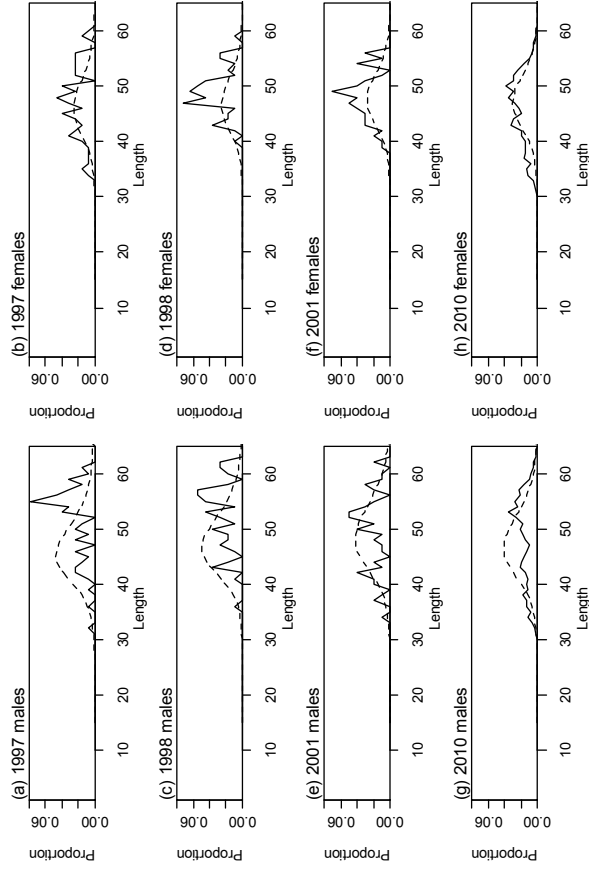**A3.3: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 1 trawl surveys for SCI 2 from model 4C.**
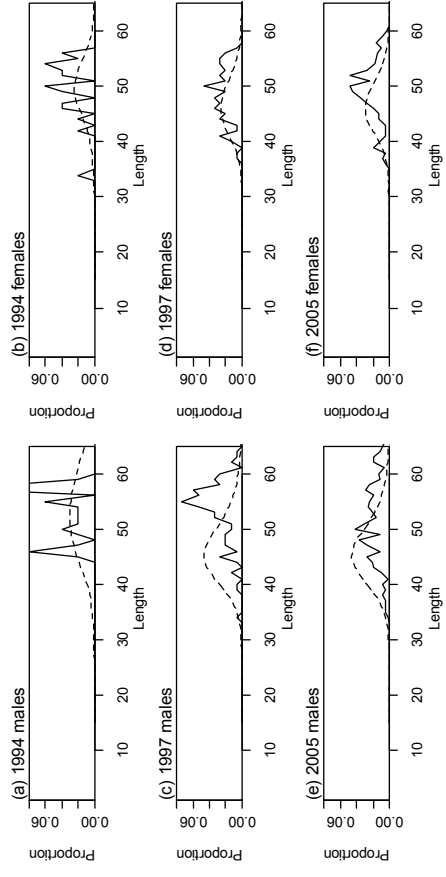
90
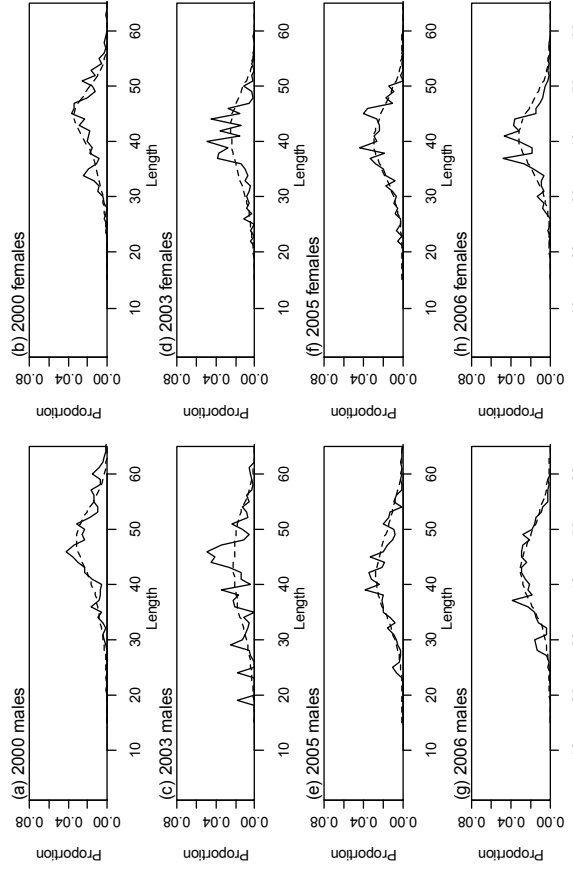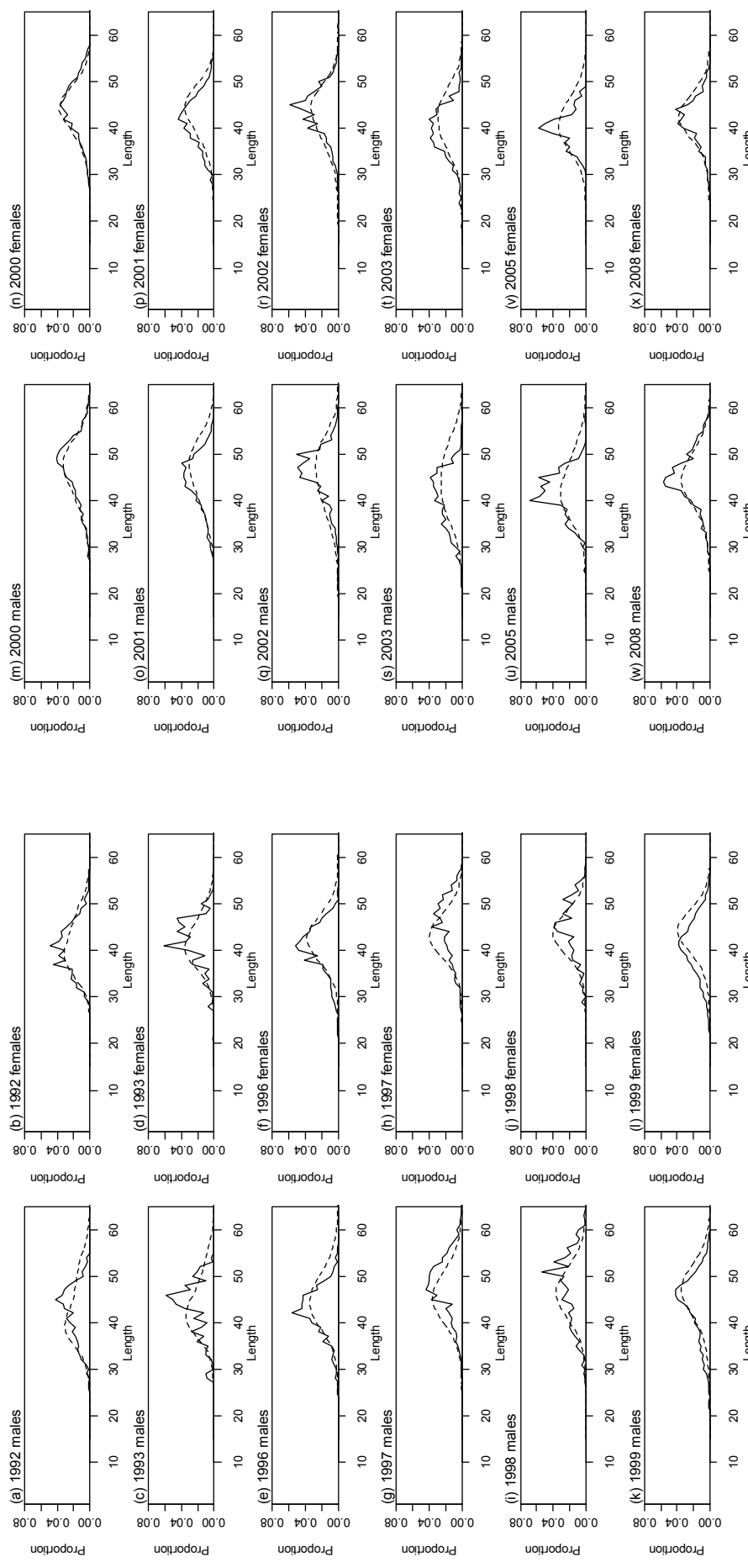
A3.5: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 1 observer samples for SCI 2 from model 4C.

A3.6: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 2 observer samples for SCI 2 from model 4C.

92
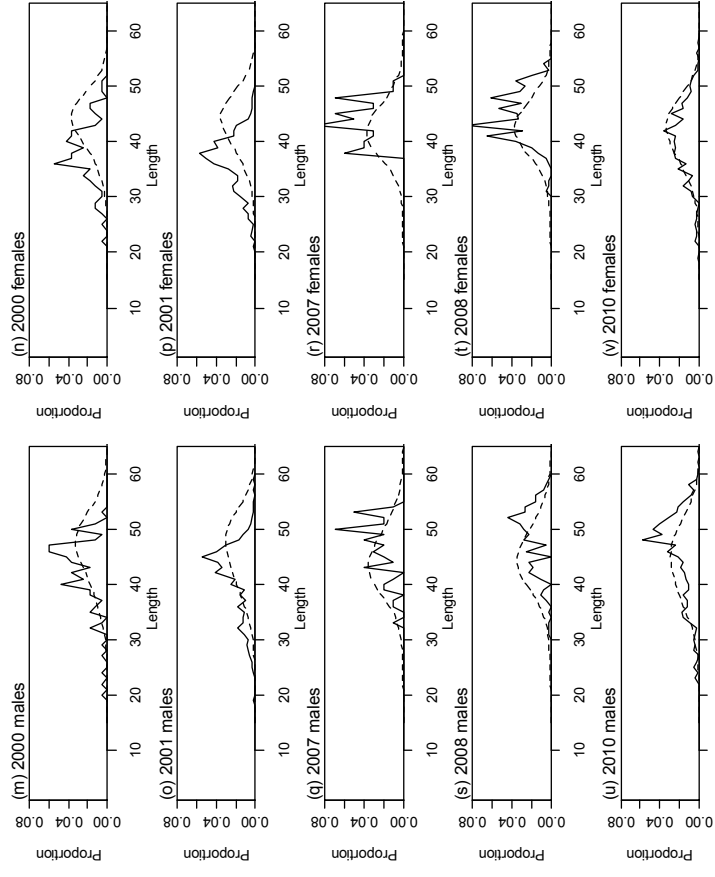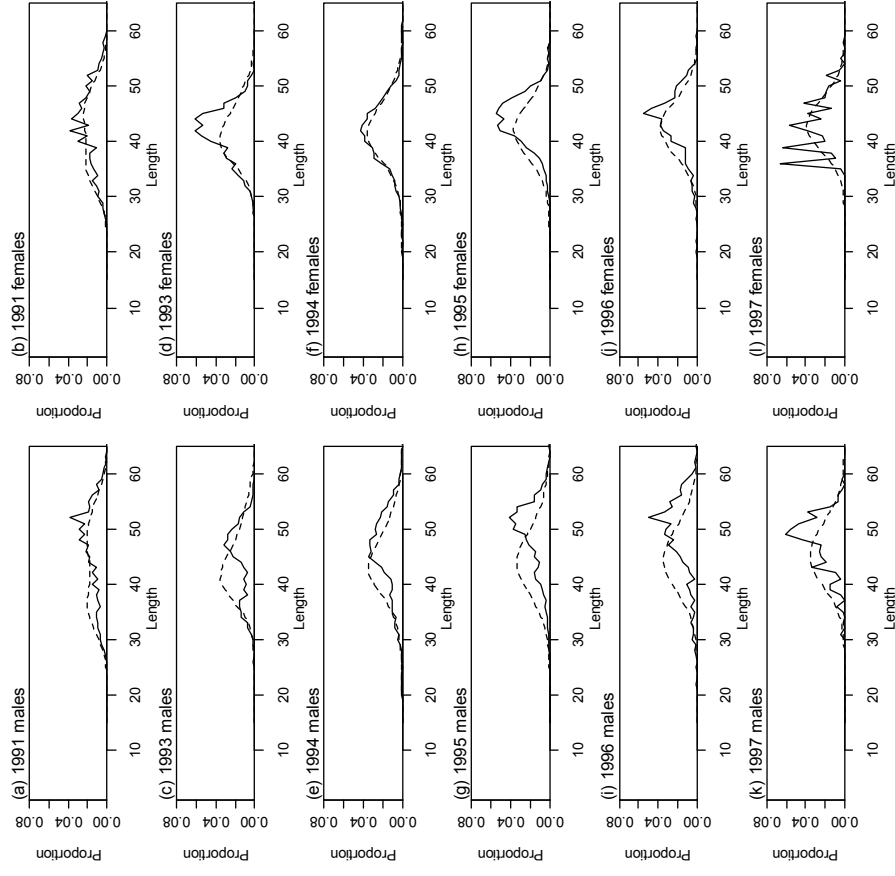
A3.7: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 3 observer samples for SCI 2 from model 4C.

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A3.9: Estimated (dotted line) and observed (points) proportion at length of recaptures from tag releases for SCI 2 from model 4C. Black solid circles represent males, grey hollow circles represent females.

94
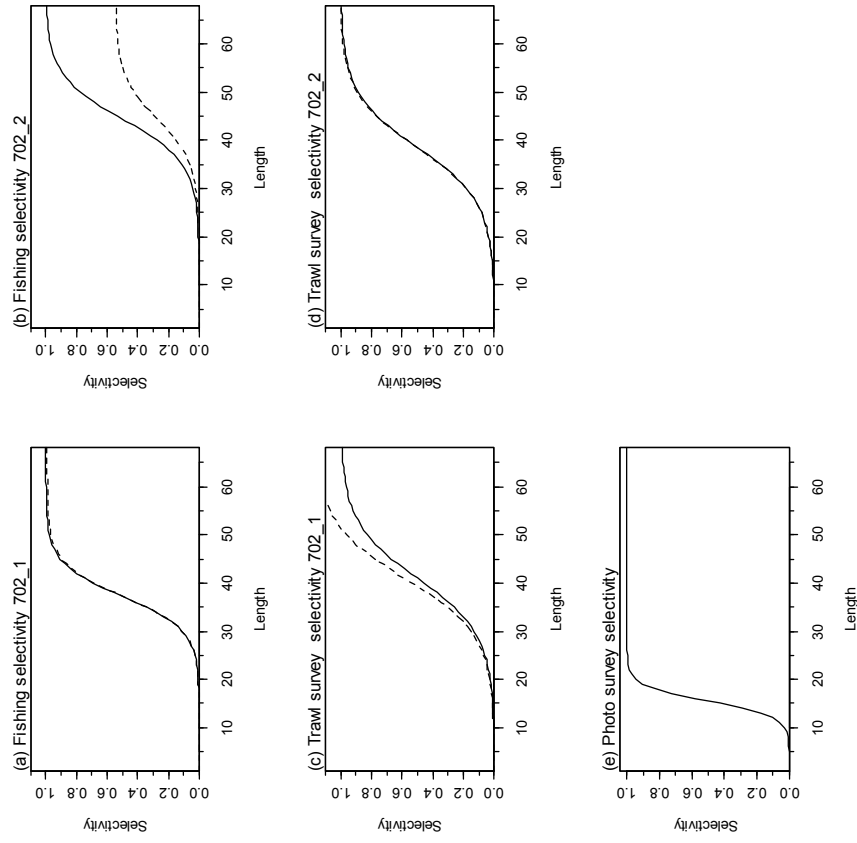
A3.8: Estimated ogives for selectivity at length for commercial trawling in time step 1 (a), time step 2 (b), and research trawling in time step 1 (c) and time step 2 (d), and the photographic survey (e) for SCI 2 from model 4C. Solid line – females, dotted line – males.
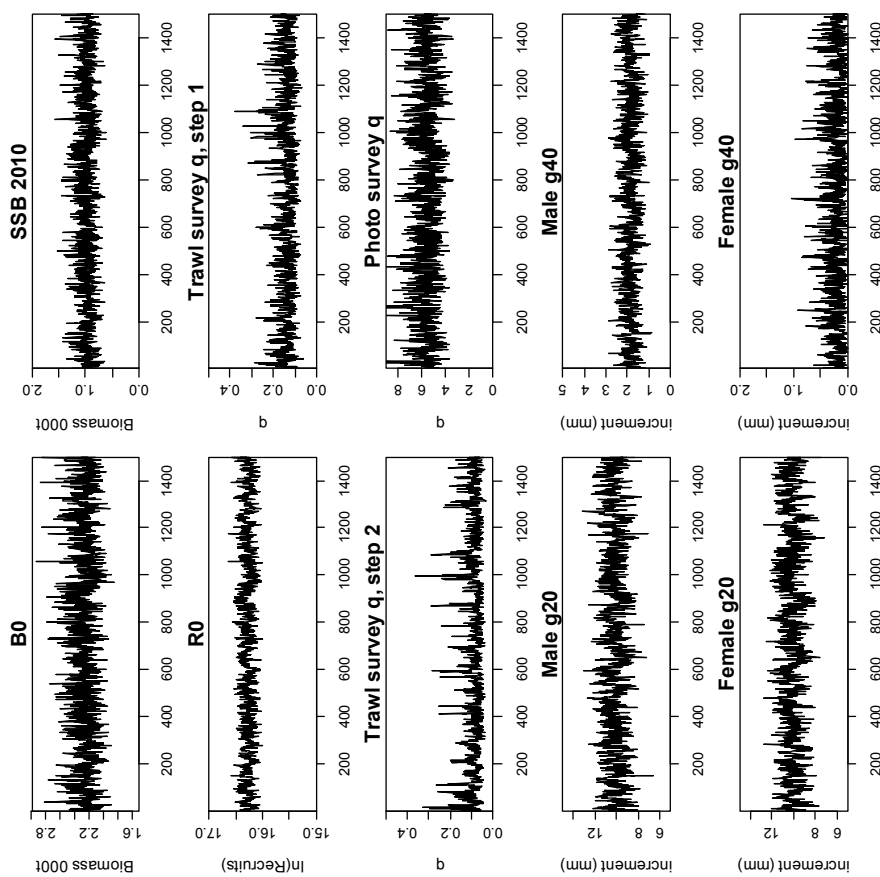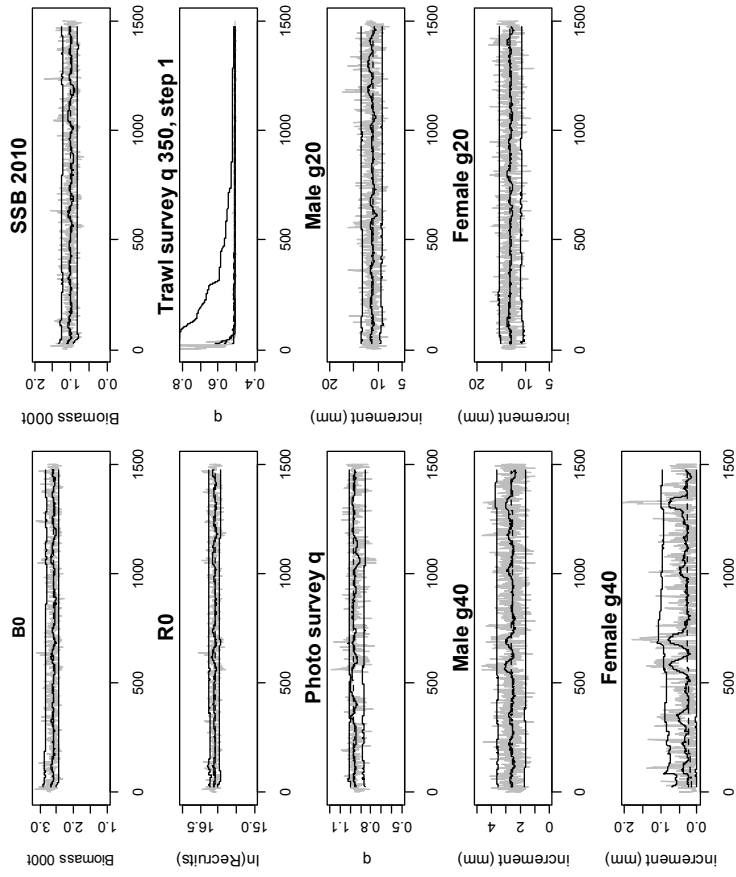
A3.11: MCMC traces for B_0, SSB_{2010}, R_0, q-Trawl, q-Photo, and the four growth parameters indicated, for model 4C.
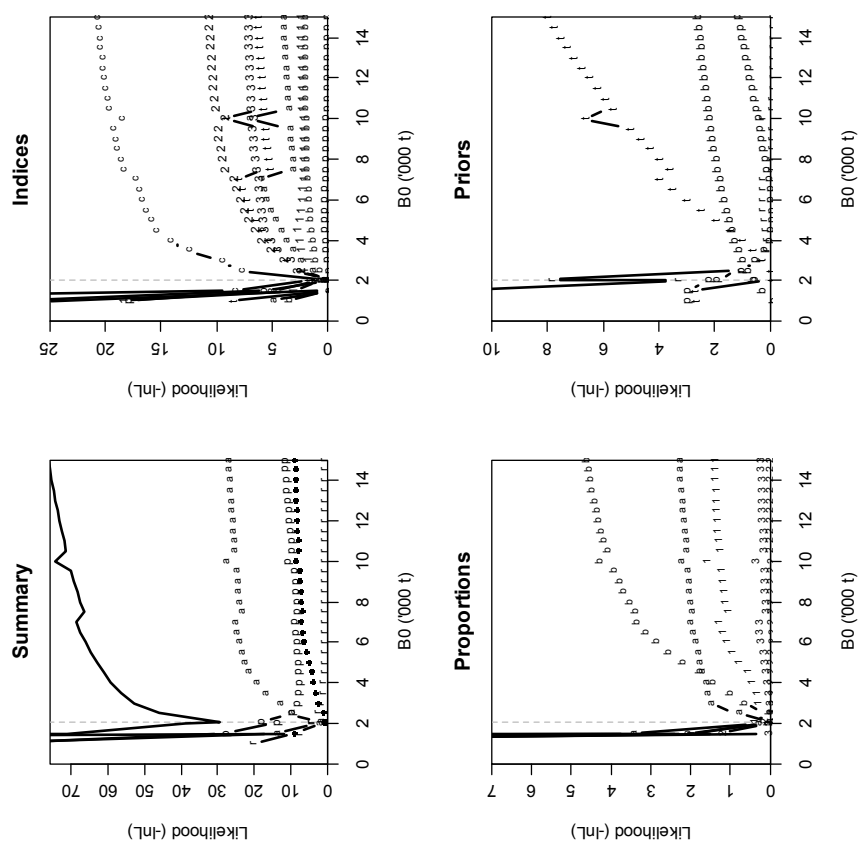
A3.10: Likelihood profiles for model 4C when B_0 is fixed in the model. Figures show profiles for main priors (top left, p–priors, r – recaptures, a – abundance indices, ● – proportions at length), abundance indices (top right, a - trawl survey time step 1, b – trawl survey time step 2, p – photo survey), proportion at length data (bottom left, a–trawl survey time step 1, b- trawl survey time step 2, 1 – observer time step 1, 2 – observer time step 2, 3 – observer time step 3) and priors (bottom right, b- B_0, YCS - r, p q-Photo, t – q-Trawl).
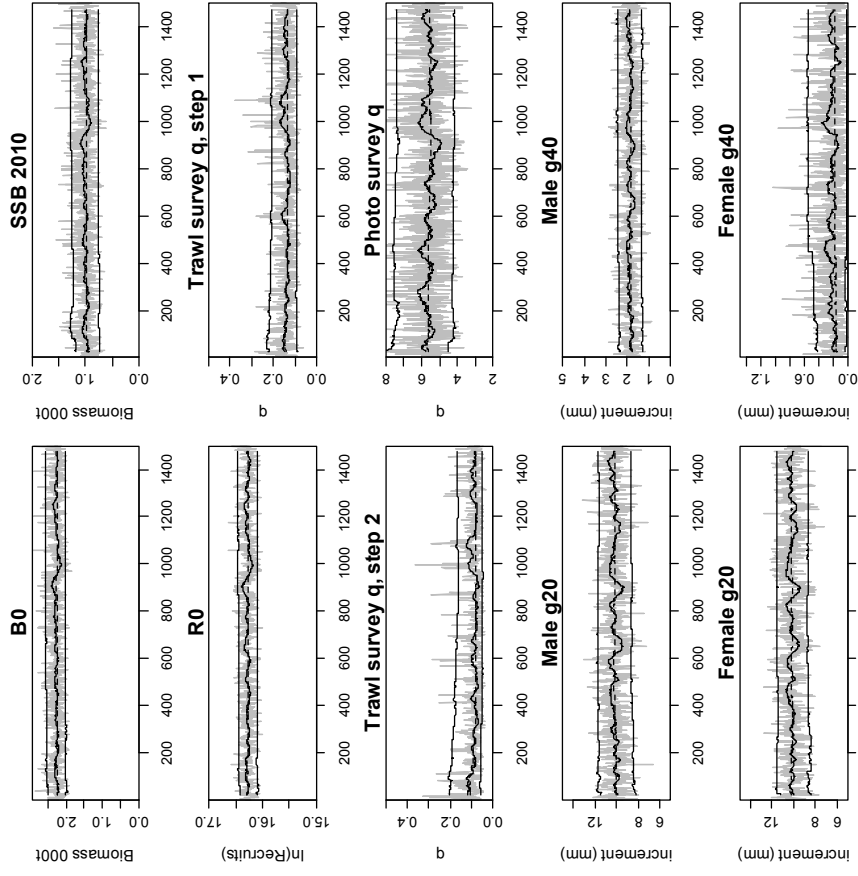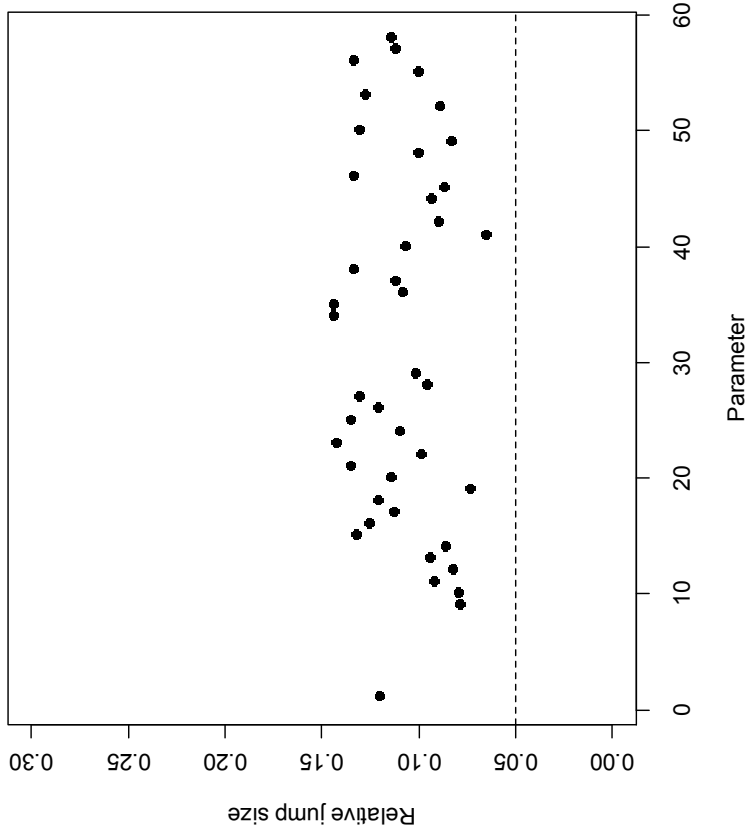
A3.13: MCMC diagnostic plot for model 4C, showing median relative jump size for all parameters (x axis, labelled 1–58). Parameter names are provided in Appendix 6.

A3.12: Diagnostic plots for parameters in A3.11.

A3.15: Marginal posterior distribution of the parameters in A3.11.
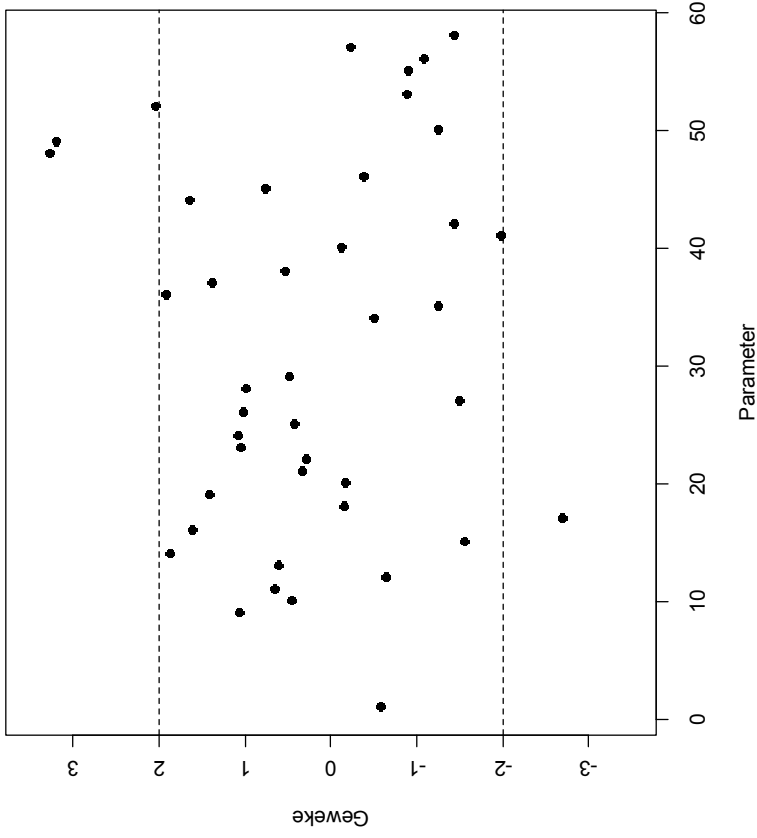
A3.14: Geweke MCMC diagnostic parameters for model 4C. Parameter names are provided in Appendix 6.
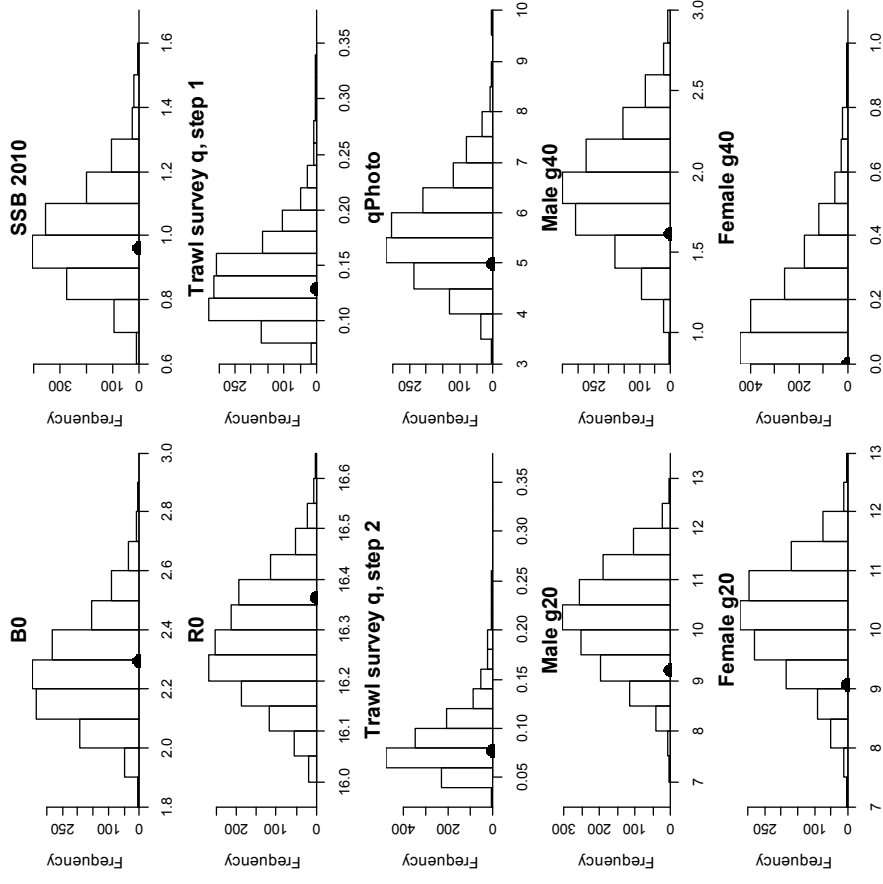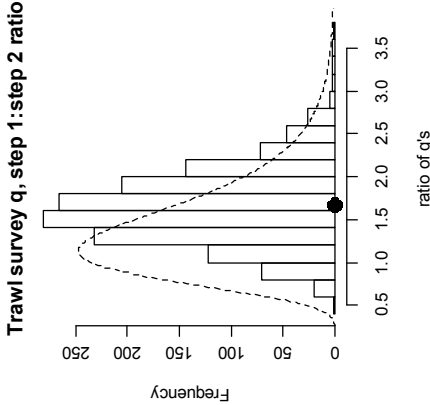
A3.17: Posterior trajectory of SSB. Upper plot shows boxplots of SSB, while lower plot shows boxplots of SSB as a percentage of B₀.

A3.16: Marginal posterior distributions (histograms), mpd estimates (solid dots) and distributions of priors (dashed lines) for parameters for which priors have been used within the model.

10. APPENDIX 4. SCI 6A model 7C plots.
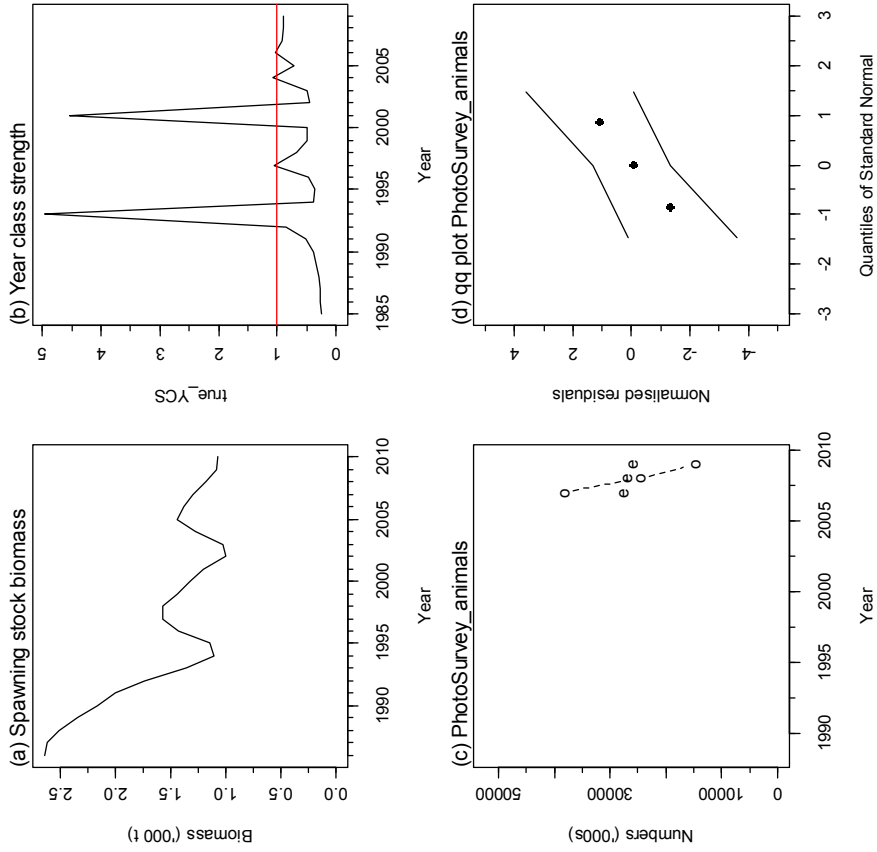
(a) Spawning stock biomass

(b) Year class strength

(c) PhotoSurvey_animals

(d) qq plot PhotoSurvey_animals

(a) TrawlSurvey350_1

(b) qq plot TrawlSurvey350_1

(c) CPUE-Trawl350_2

(d) qq plot CPUE-Trawl350_2

(e) CPUE-Trawl350_3

(f) qq plot CPUE-Trawl350_3

(a) CPUE-Trawl350_1

(b) qq plot CPUE-Trawl350_1

A4.2: Fits and q-q diagnostic plots to CPUE and trawl survey abundance indices for SCI 6A from model 7C.

A4.1: Spawning stock biomass trajectory (a), year class strength (b) fits (c) and q-q diagnostic plots (d) to photo survey abundance index for SCI 6A from model 7C.
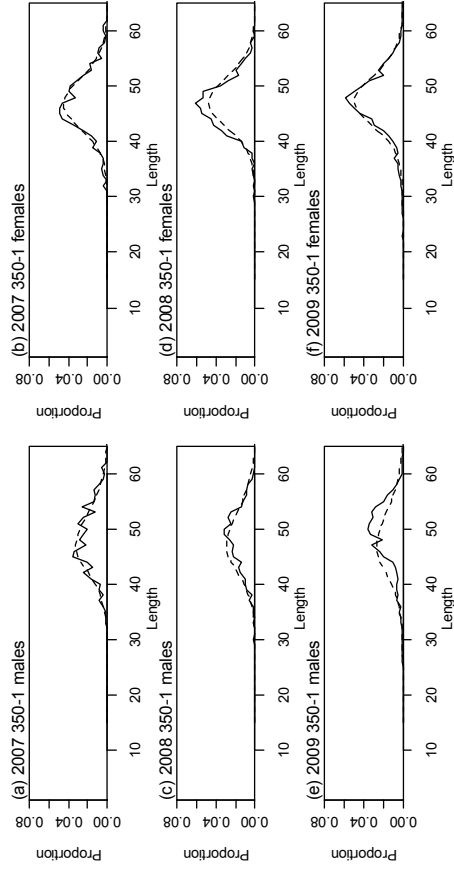
A4.3: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 1 trawl surveys for SCI 6A from model 7C.

100
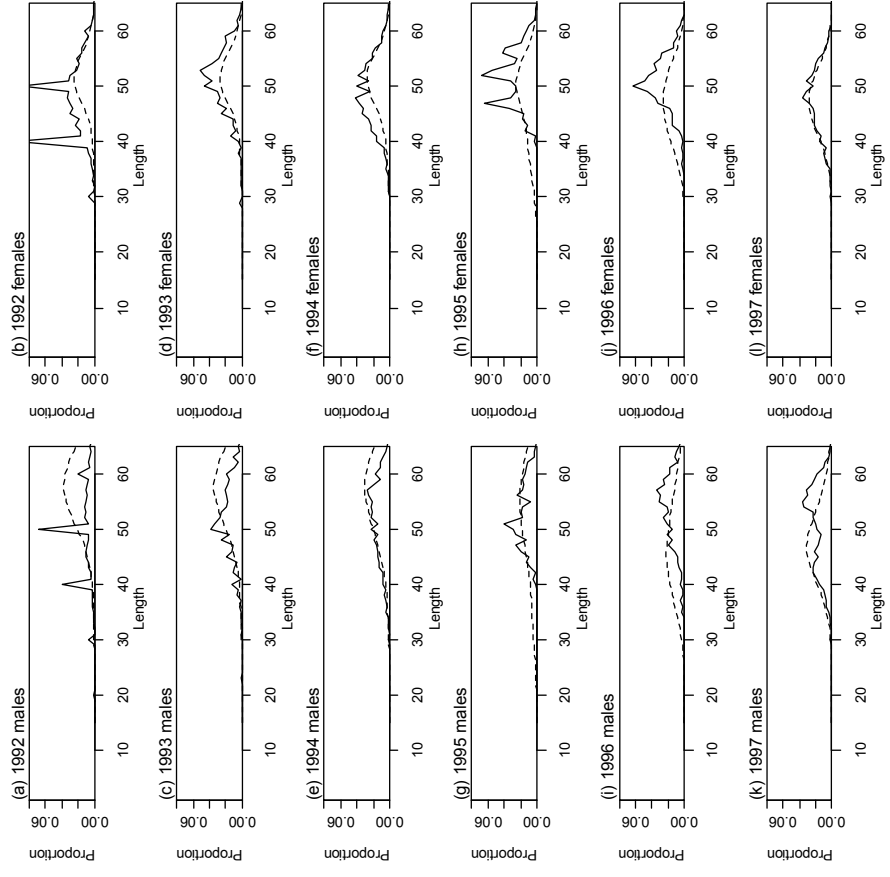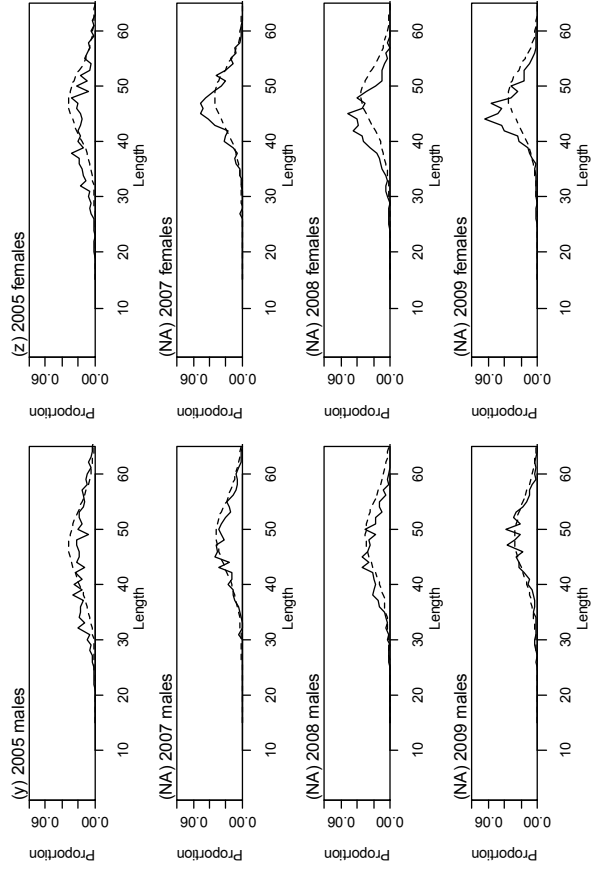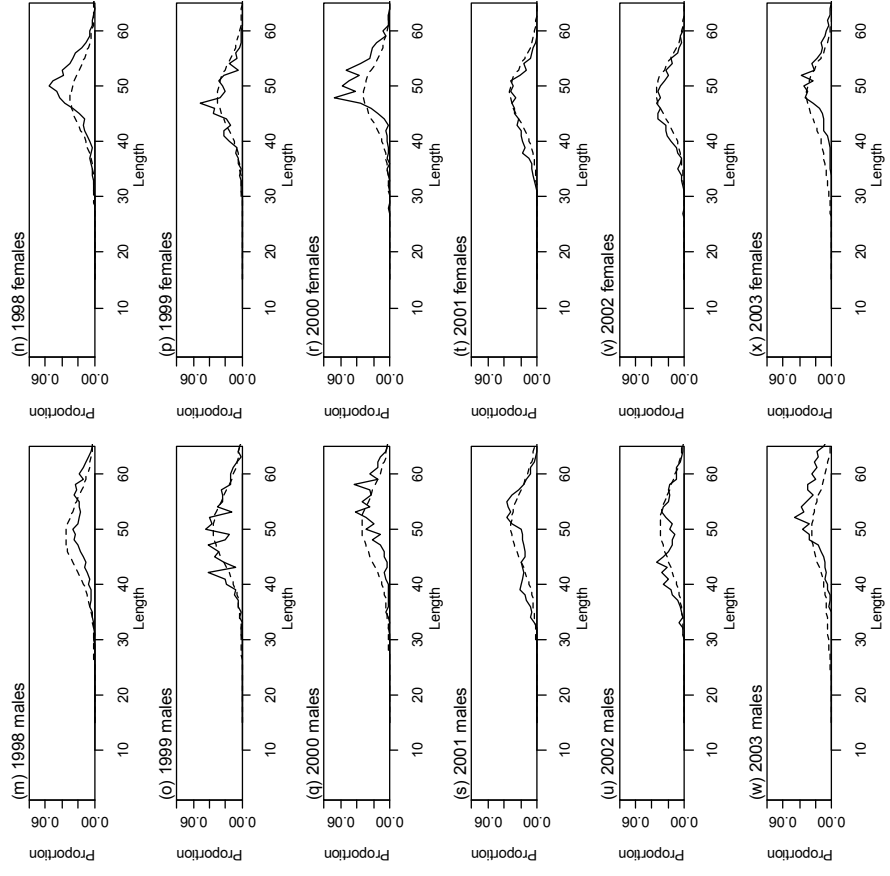
A4.4: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 1 observer samples for SCI 6A from model 7C.

A4.6: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 3 observer samples for SCI 6A from model 7C.

A4.5: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 2 observer samples for SCI 6A from model 7C.
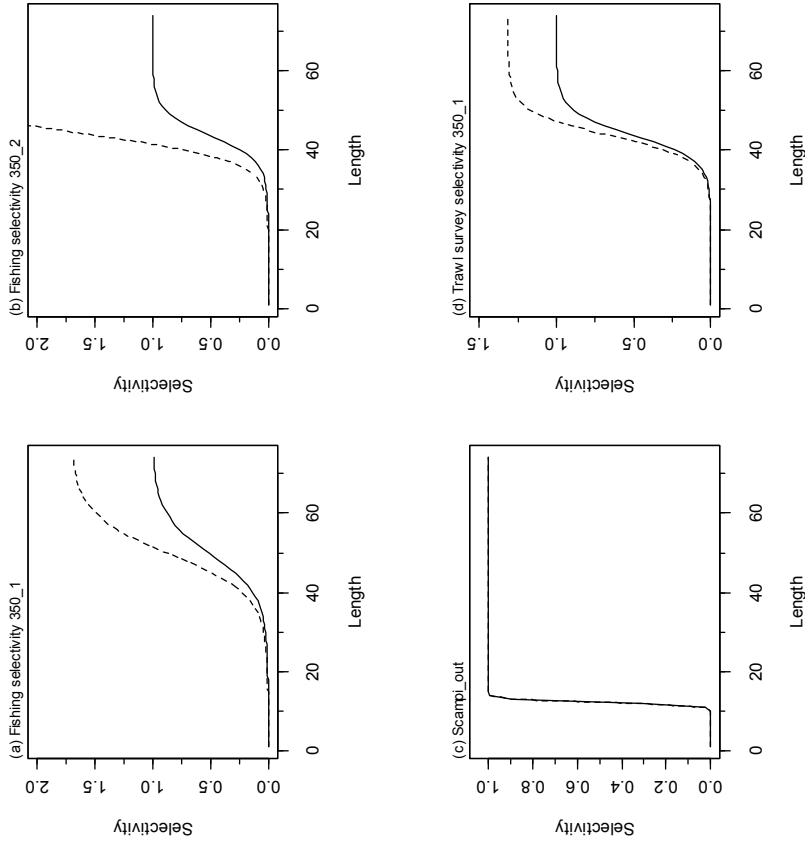
A4.7: Estimated ogives for selectivity at length for commercial trawling in time step 1 (a) and time step 2 (b), research trawling in time step 1 (c) and time step 2 (d), and the photographic survey (e) for SCI 6A from model 7C. Solid line – females, dotted line – males.
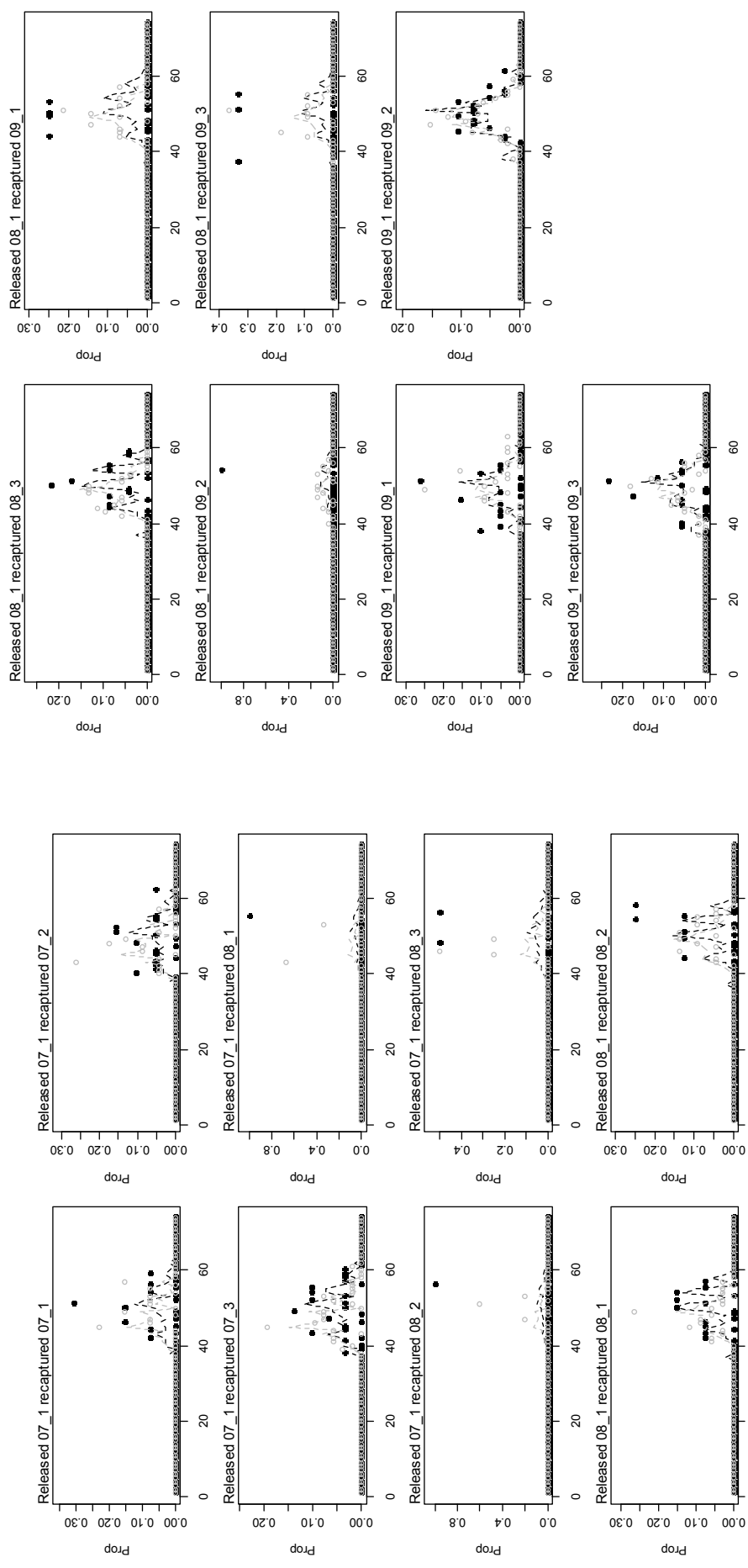
A4.8: Estimated (dotted line) and observed (points) proportion at length of recaptures from tag releases for SCI 6A from model 7C. Black solid circles represent males, grey hollow circles represent females.
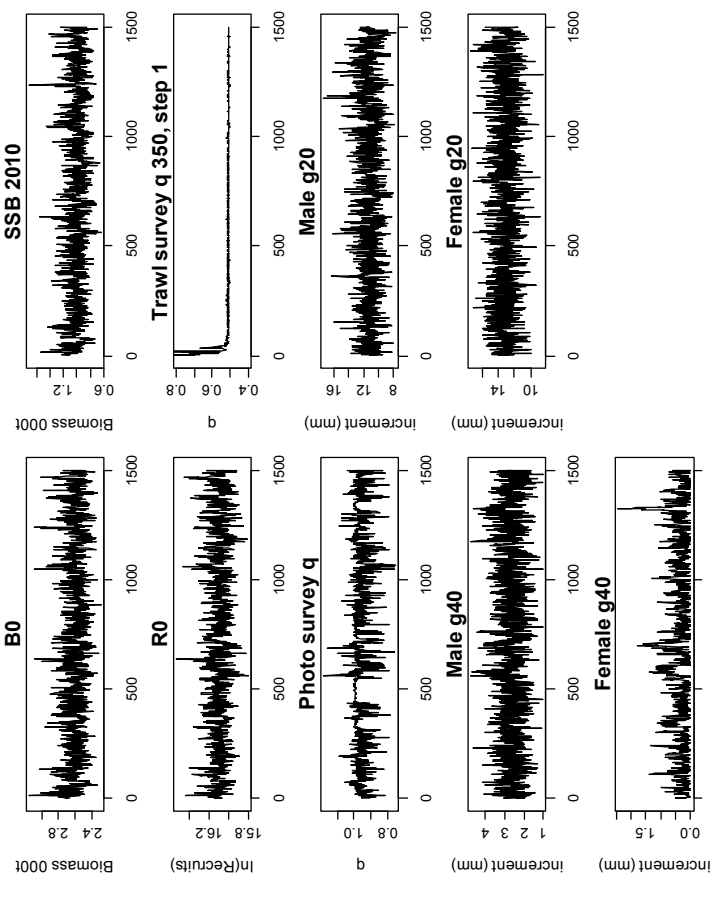
A4.10: MCMC traces for B_0, SSB$_{2010}$, R_0, q-Trawl, q-Photo, and the four growth parameters indicated, for model 7C.
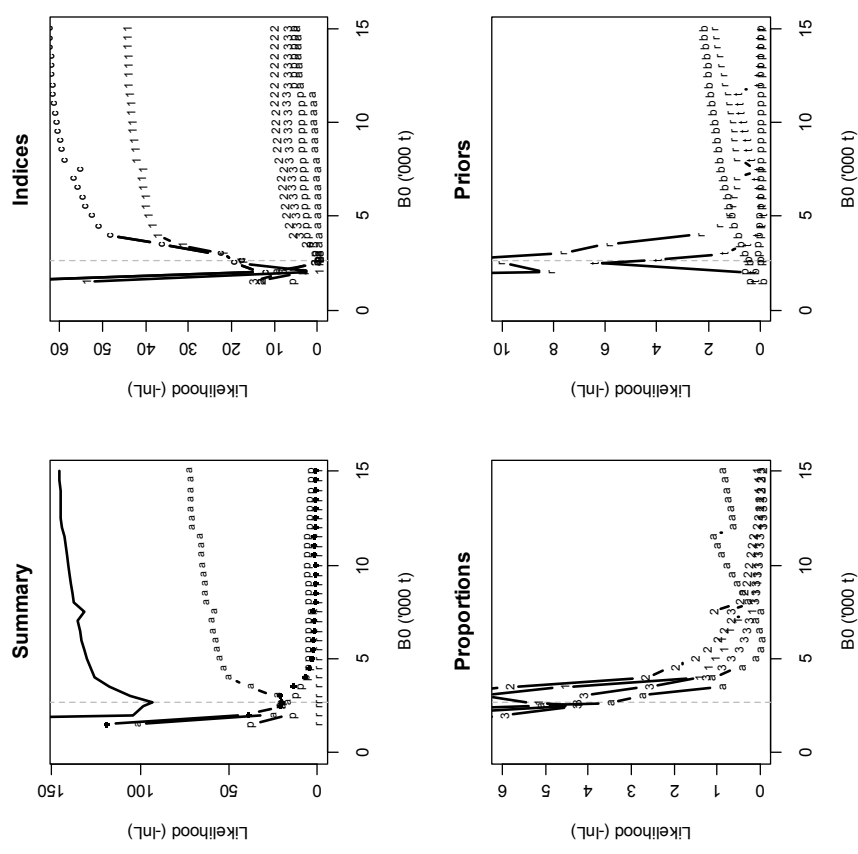
A4.9: Likelihood profiles for model 7C when B_0 is fixed in the model. Figures show profiles for main priors (top left, p-priors, r – recaptures, a – abundance indices, ● – proportions at length), abundance indices (top right, t – trawl survey, 1 - CPUE time step 1, 2 – CPUE time step 2, 3 – CPUE time step 3, p – photo survey), proportion at length data (bottom left, a-trawl survey time step 1, 1 – observer time step 1, 2 – observer time step 2, 3 – observer time step 3) and priors (bottom right, b- B_0, YCS - r, p- q-Photo, t – q-Trawl).

A4.12: MCMC diagnostic plot for model 7C, showing median relative jump size for all parameters (x axis, labelled 1–52). Parameter names are provided in Appendix 6.

A4.11: Diagnostic plots for parameters in A4.10.

A4.14: Posterior trajectory of SSB. Upper plot shows boxplots of SSB, while lower plot shows boxplots of SSB as a percentage of B_0.
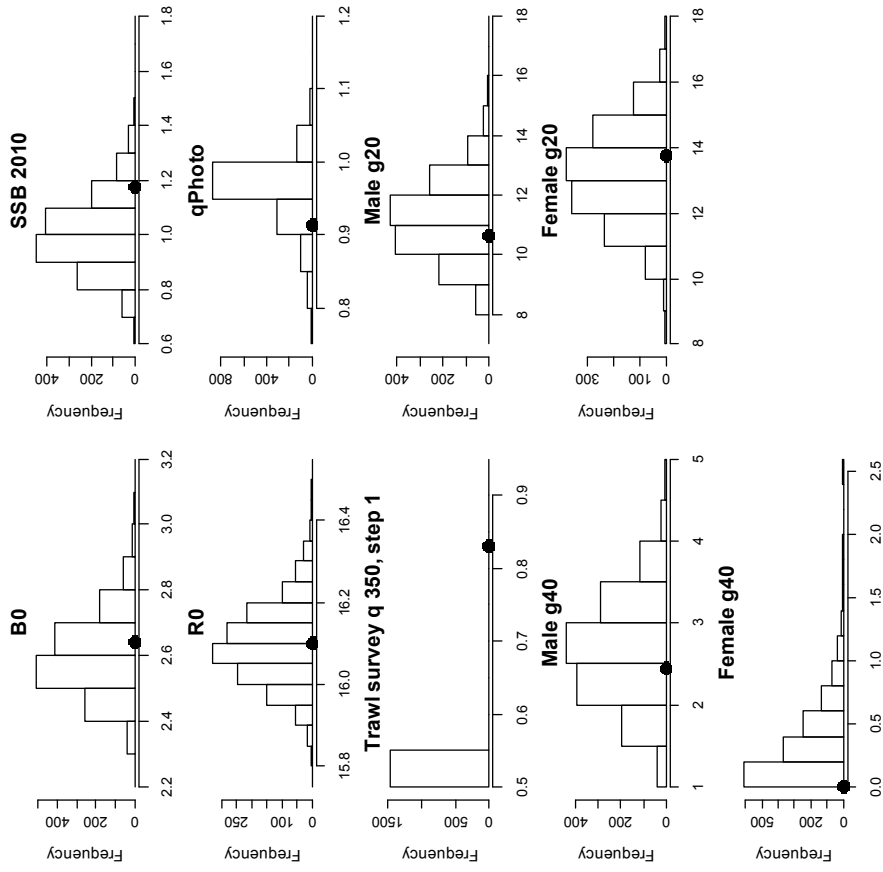
A4.13: Marginal posterior distribution of the parameters in A4.10
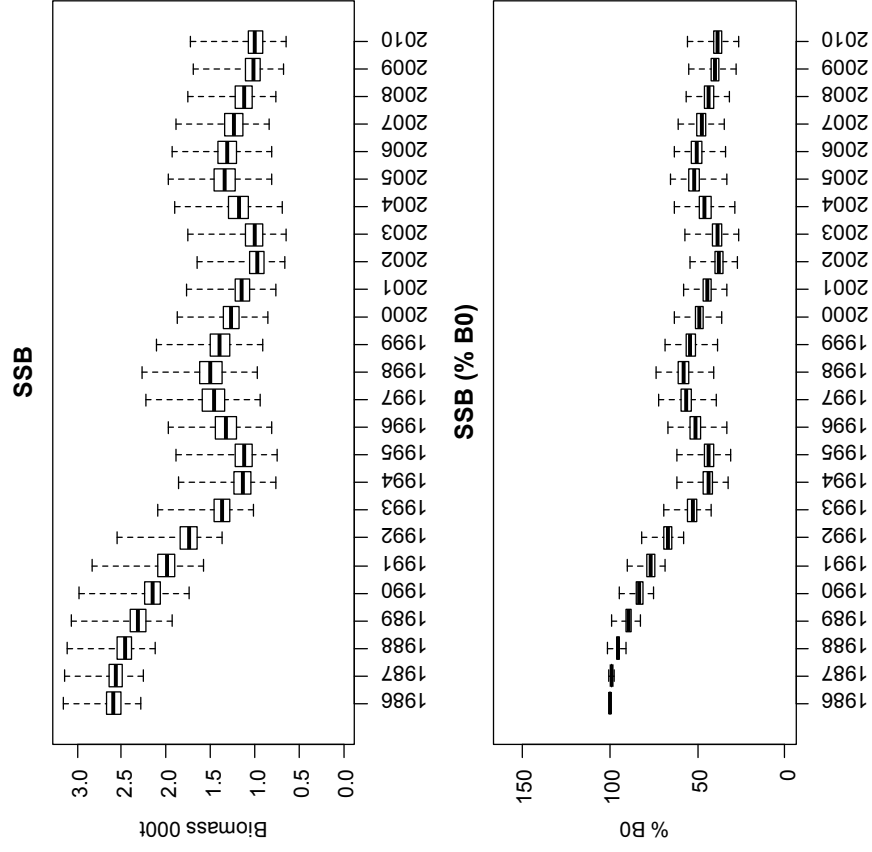
A5.2: Fits and q-q diagnostic plots to CPUE abundance indices for stratum 350, SCI 6A from model 8C.

11. **APPENDIX 5. SCI 6A model 8C plots.**
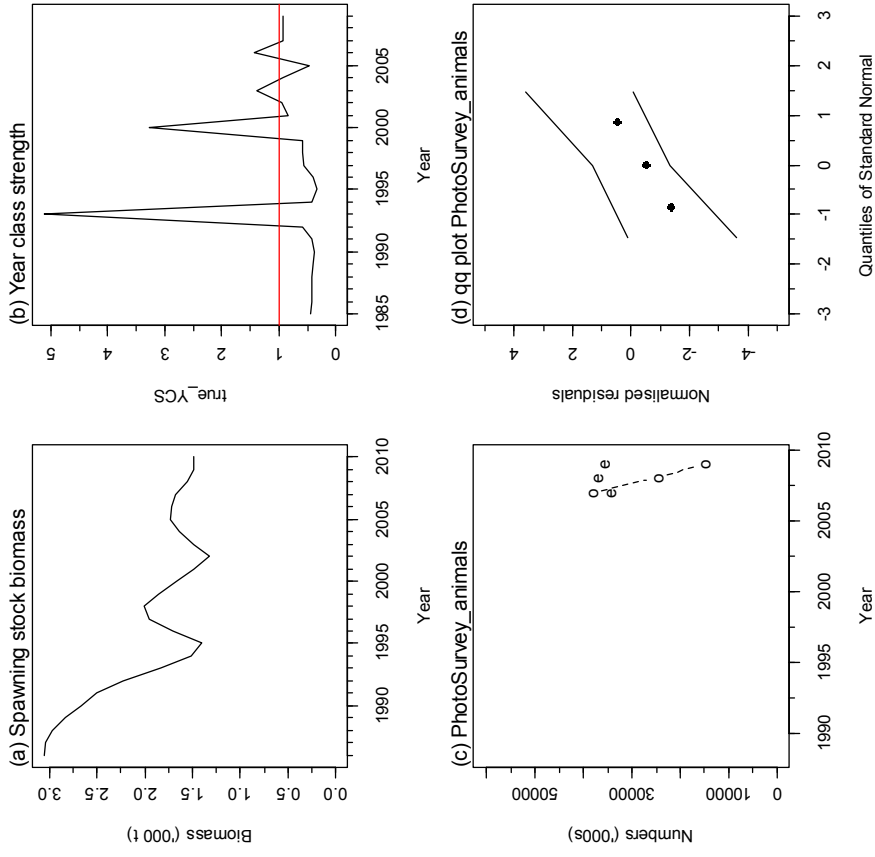
A5.1: Spawning stock biomass trajectory (a), year class strength (b) fits (c) and q-q diagnostic plots (d) to photo survey abundance index for SCI 6A from model 8C.

A5.4: Fits and q-q diagnostic plots to CPUE abundance indices for stratum 450, SCI 6A from model 8C.
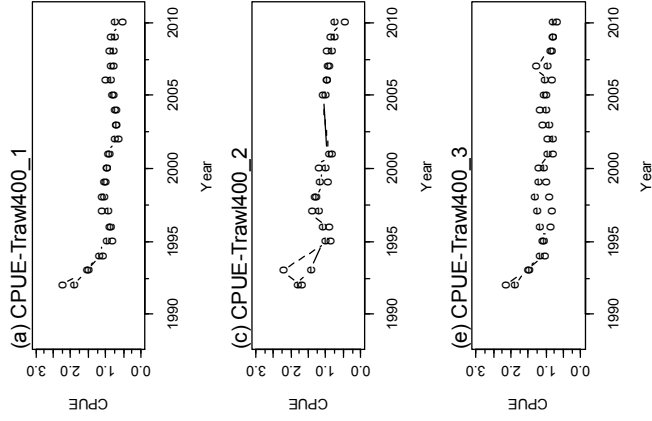
A5.3: Fits and q-q diagnostic plots to CPUE abundance indices for stratum 400, SCI 6A from model 8C.

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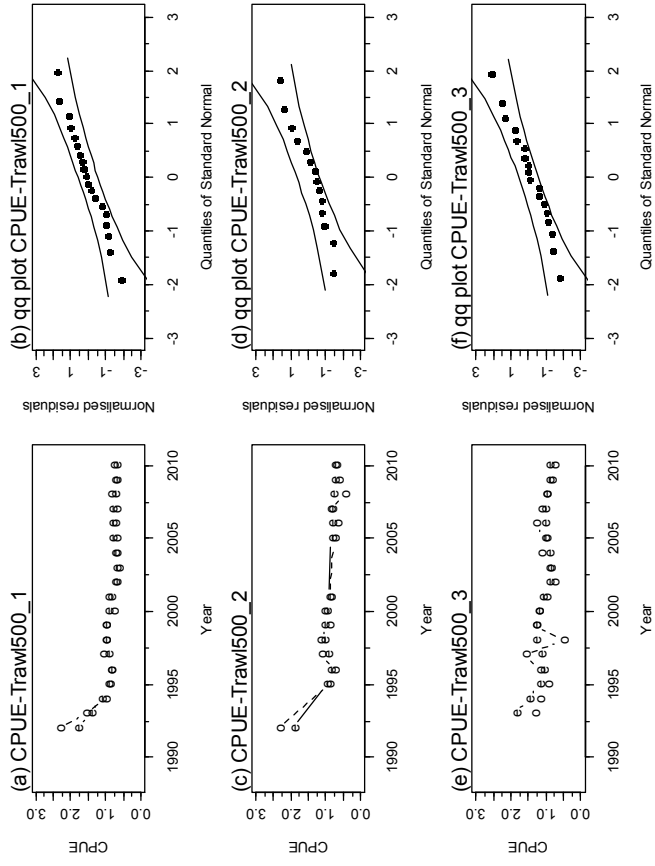
A5.5: Fits and q-q diagnostic plots to CPUE abundance indices for stratum 500, SCI 6A from model 8C.
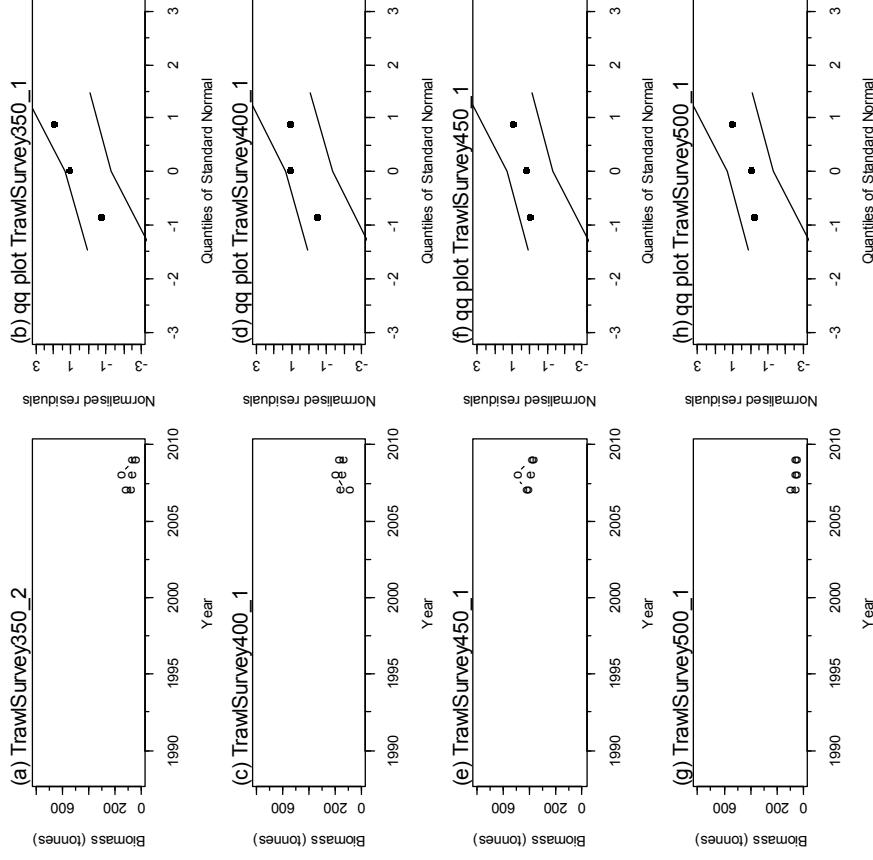
A5.6: Fits and q-q diagnostic plots to trawl survey abundance indices for SCI 6A from model 8C.

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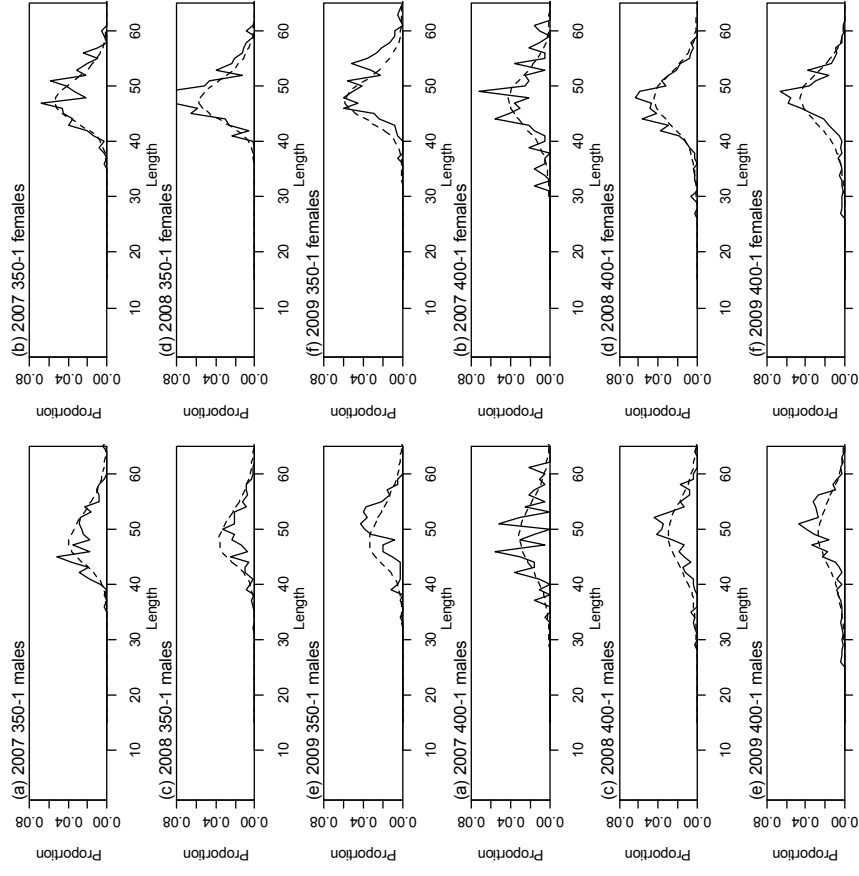
A5.7: Observed (solid lines) and fitted (dashed lines) length frequency distributions from strata 350 and 400 trawl surveys for SCI 6A from model 8C.
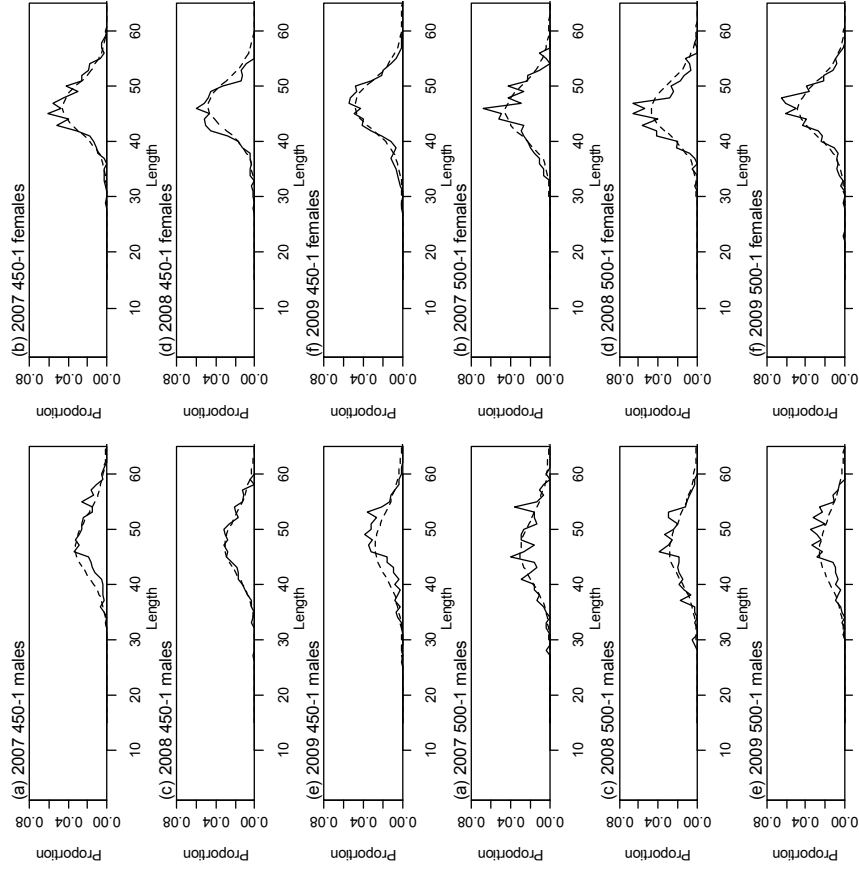
A5.8: Observed (solid lines) and fitted (dashed lines) length frequency distributions from strata 450 and 500 trawl surveys for SCI 6A from model 8C.
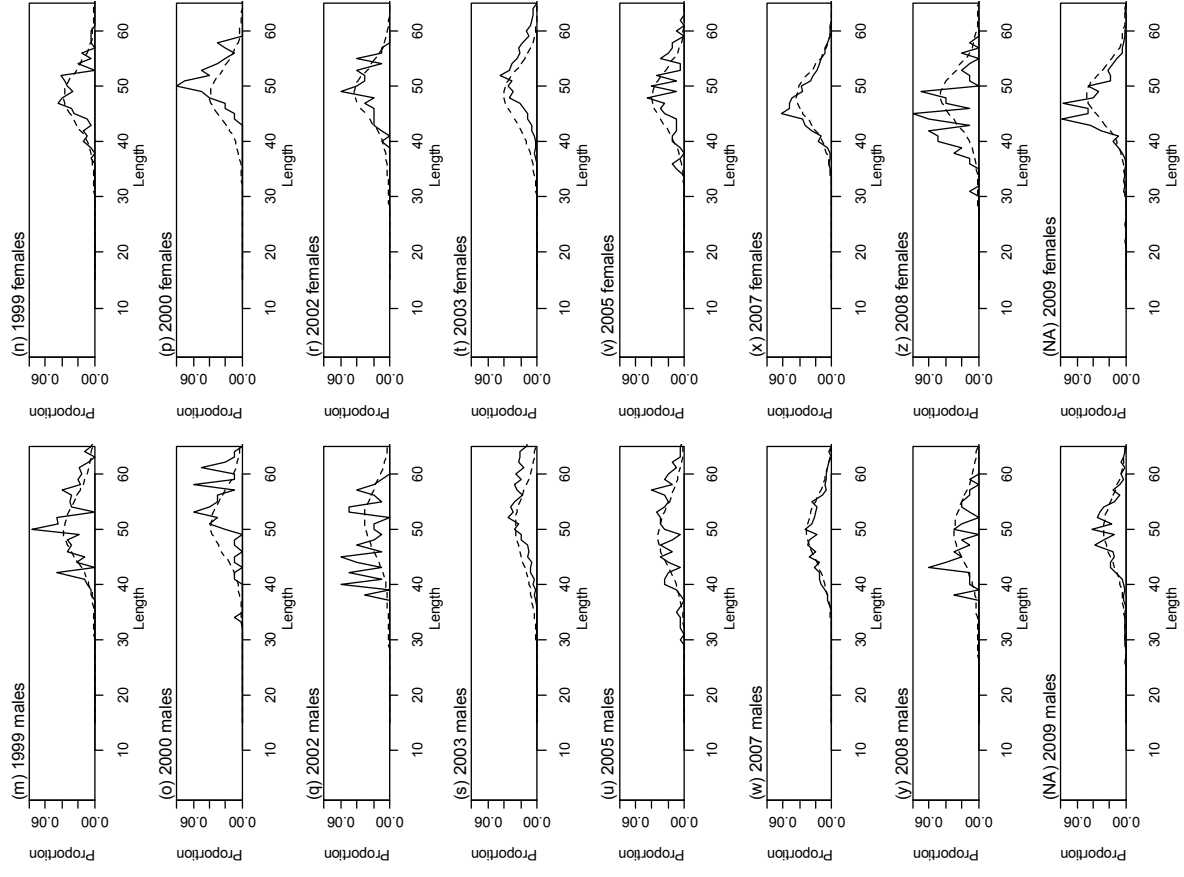
A5.9: Observed (solid lines) and fitted (dashed lines) length frequency distributions from stratum 350, time step 1 observer samples for SCI 6A from model 8C.
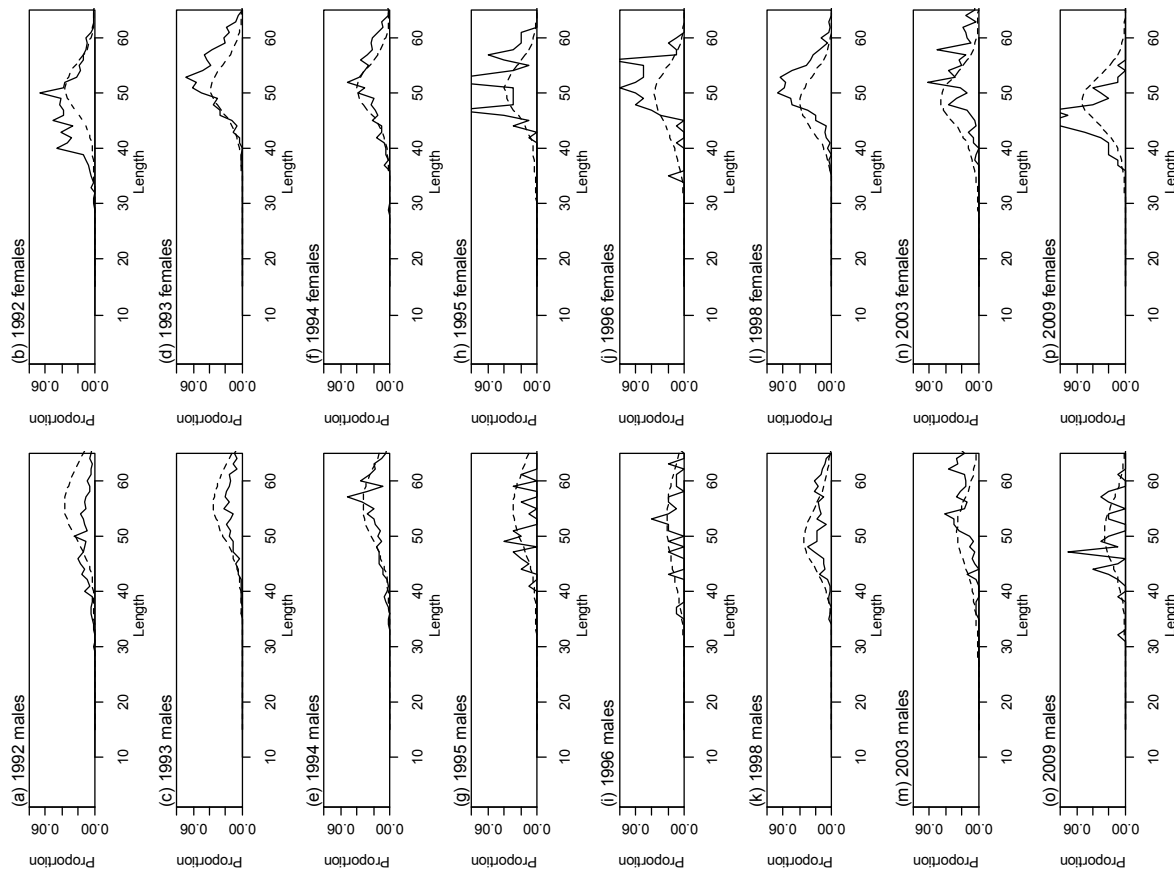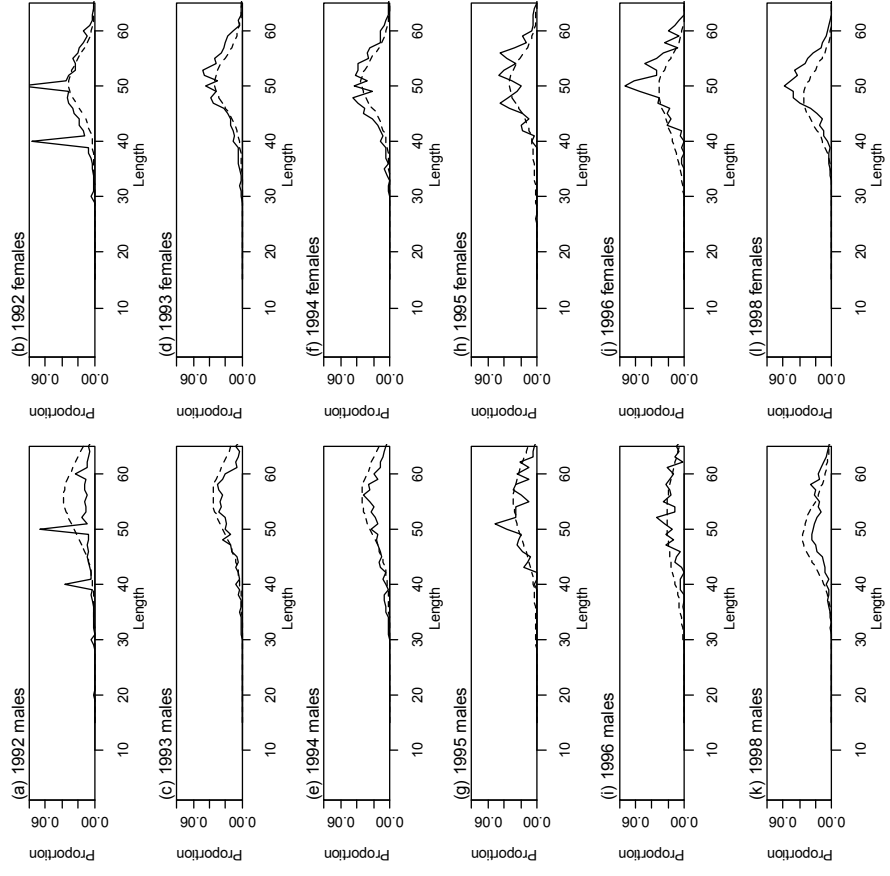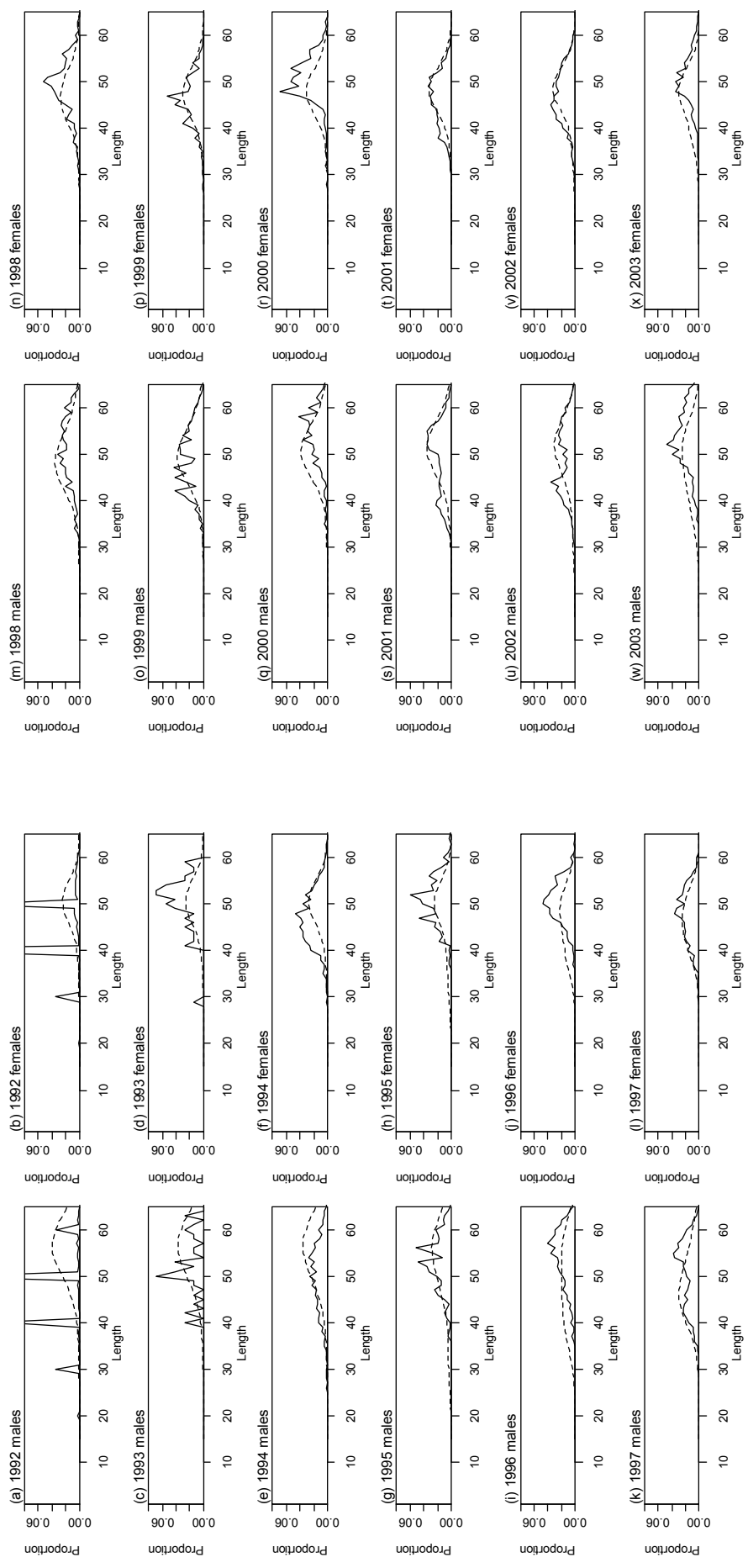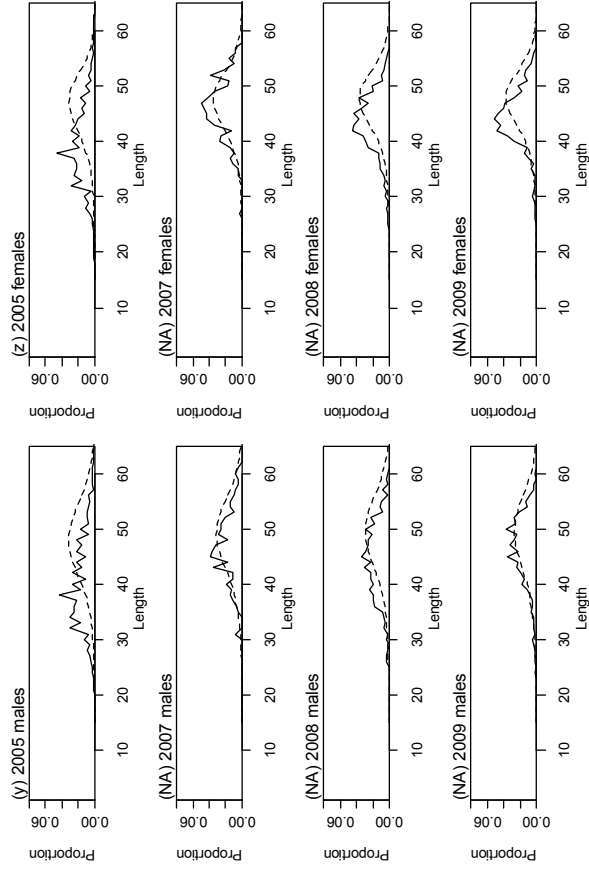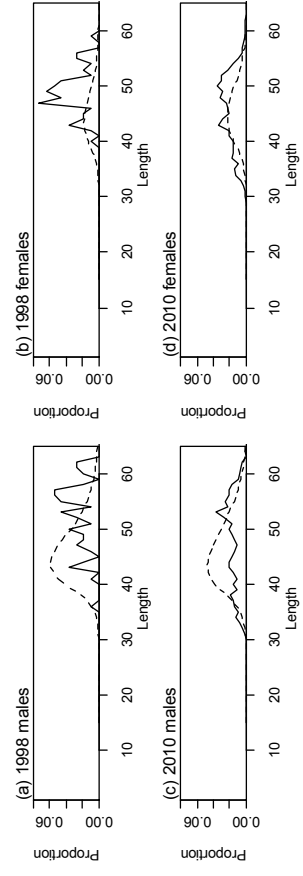
A5.10: Observed (solid lines) and fitted (dashed lines) length frequency distributions from stratum 400, time step 1 observer samples for SCI 6A from model 8C (all figures on this page).

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A5.13: Observed (solid lines) and fitted (dashed lines) length frequency distributions from stratum 450, time step 3 observer samples for SCI 6A from model 8C.
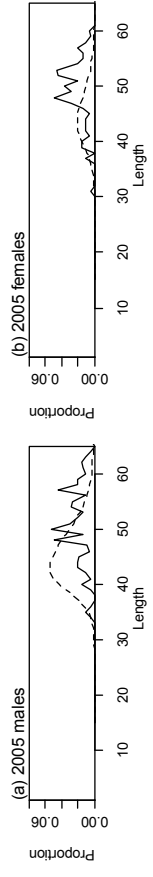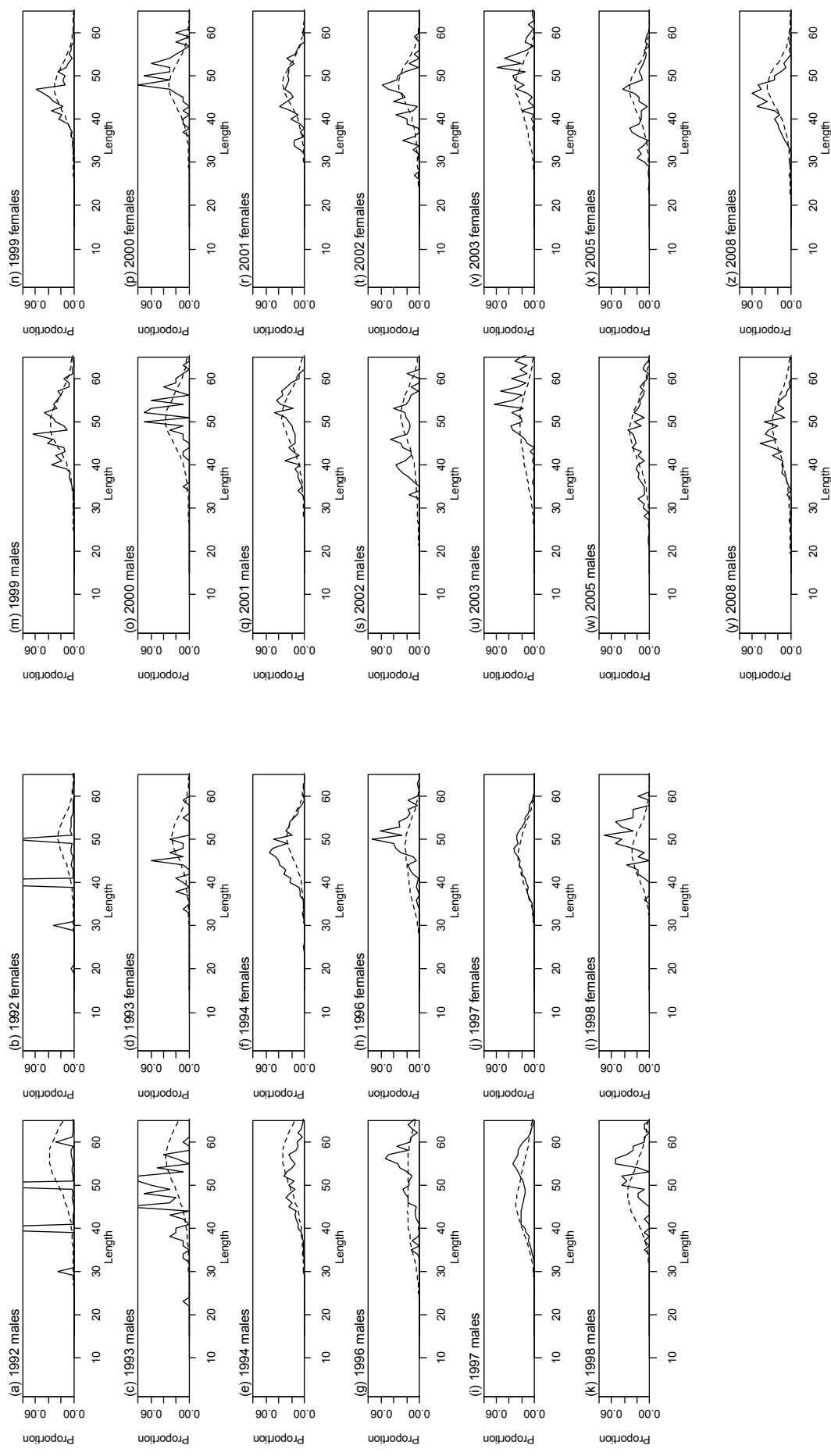

A5.11: Observed (solid lines) and fitted (dashed lines) length frequency distributions from stratum 450, time step 1 observer samples for SCI 6A from model 8C.

A5.12: Observed (solid lines) and fitted (dashed lines) length frequency distributions from stratum 450, time step 2 observer samples for SCI 6A from model 8C.
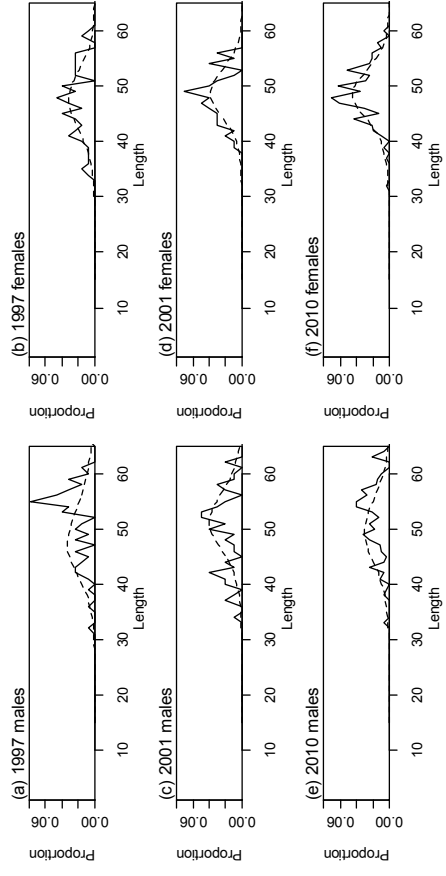
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A5.14: Observed (solid lines) and fitted (dashed lines) length frequency distributions from stratum 500, time step 1 observer samples for SCI 6A from model 8C.

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A5.15: Observed (solid lines) and fitted (dashed lines) length frequency distributions from stratum 500, time step 2 observer samples for SCI 6A from model 8C.
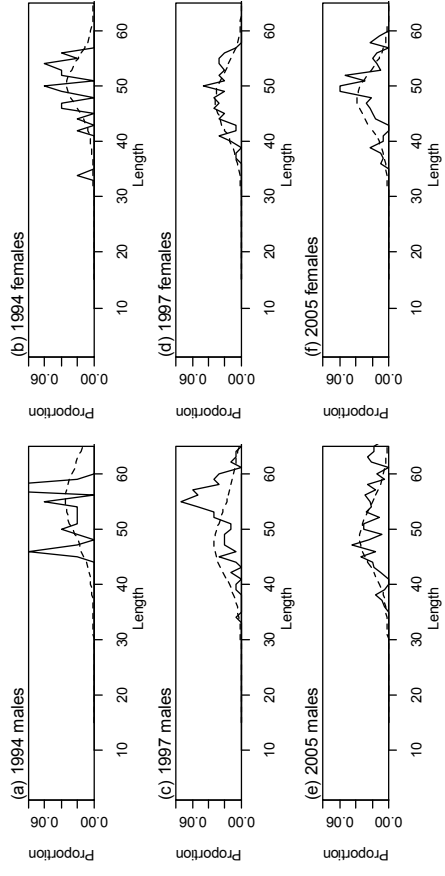

A5.16: Observed (solid lines) and fitted (dashed lines) length frequency distributions from stratum 500, time step 3 observer samples for SCI 6A from model 8C.
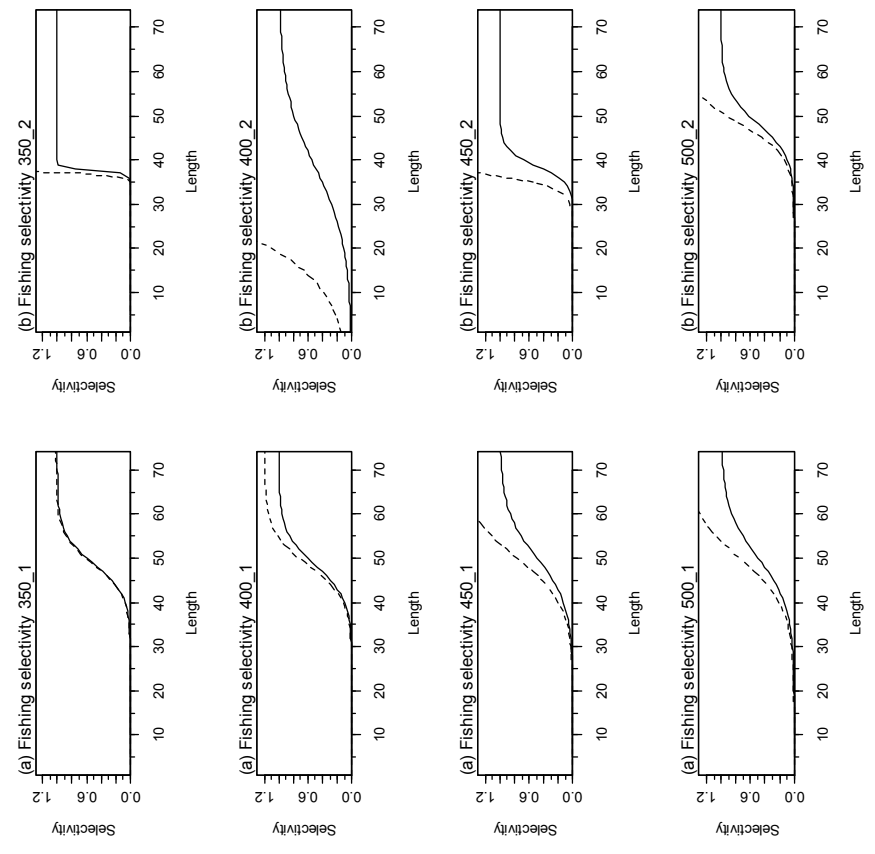

A5.17: Estimated ogives for selectivity at length for commercial trawling (a–h) for SCI 6A from model 8C. Solid line – females, dotted line – males.

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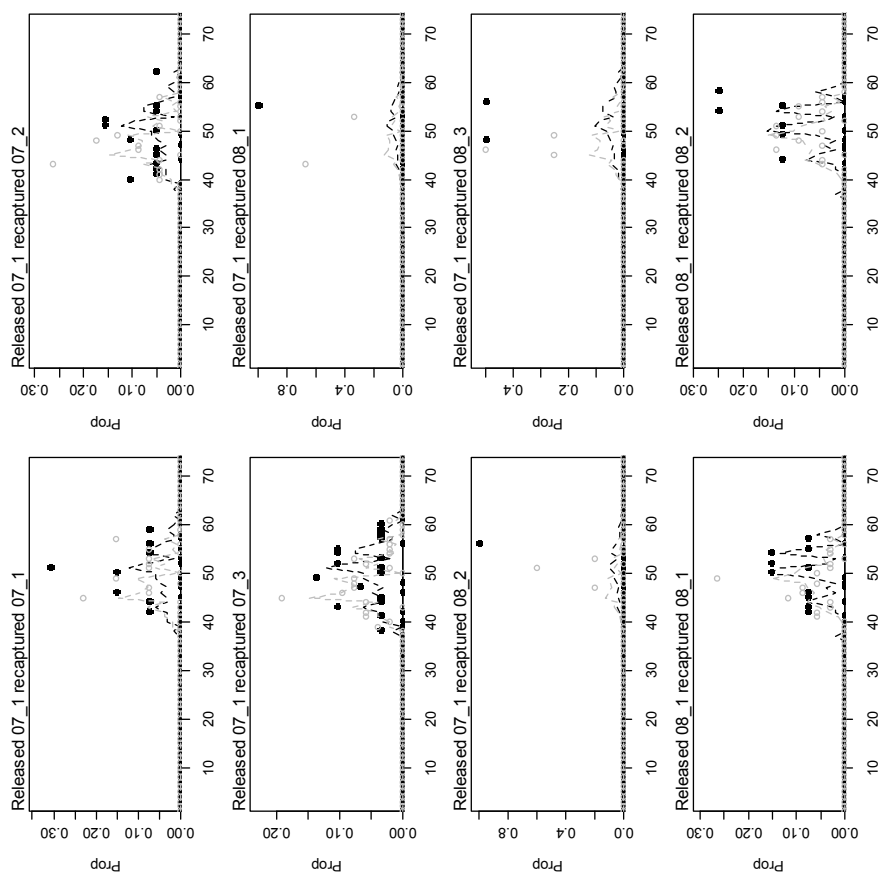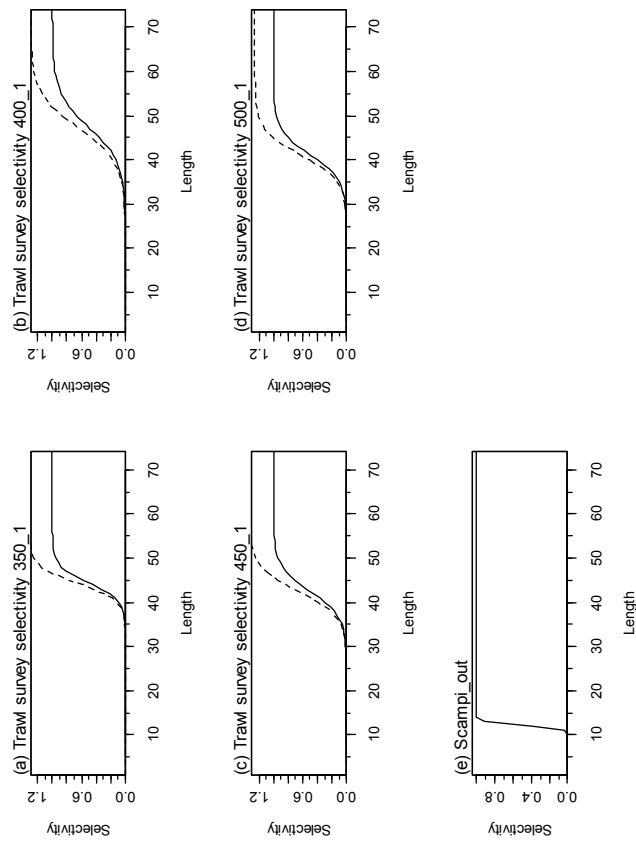
A5.18: Estimated ogives for selectivity at length for research trawling (a–d), and visible scampi (e) for SCI 6A from model 8C. Solid line – females, dotted line – males.

A5.20: Likelihood profiles for model 8C when B₀ is fixed in the model. Figures show profiles for main priors (top left, p–priors, r – recaptures, a – abundance indices, ● – proportions at length), abundance indices (top right, t – trawl survey time step 1, b – trawl survey time step 2, p – photo survey), proportion at length data (bottom left, a–trawl survey time step 1, b– trawl survey time step 2, 1 – observer time step 1, 2 – observer time step 2, 3 – observer time step 3) and priors (bottom right, b– B₀, YCS – r, p– *q-Photo*, t – *q-Trawl*).

A5.19: Estimated (dotted line) and observed (points) proportion at length of recaptures from tag releases for SCI 6A from model 8C. Black solid circles represent males, grey hollow circles represent females.

A5.22: Diagnostic plots for parameters in A5.21.
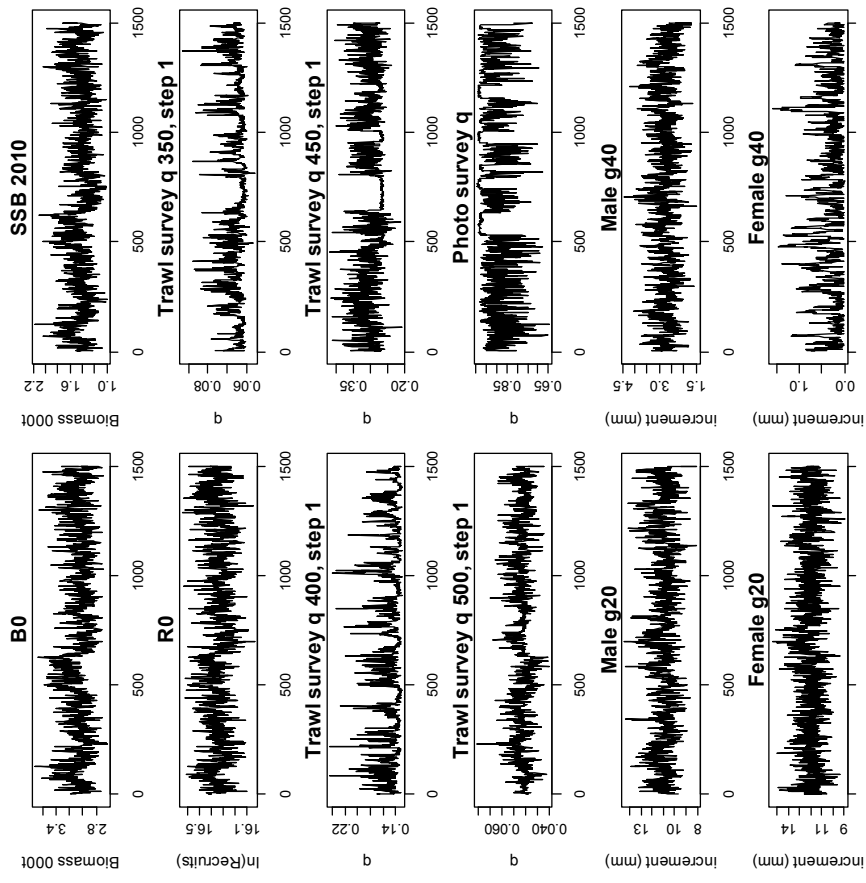
A5.21: MCMC traces for B_0, SSB_{2008}, R_0, SSB_{2008}, q-Trawl, q-Photo, and the four growth parameters indicated, for model 8C.
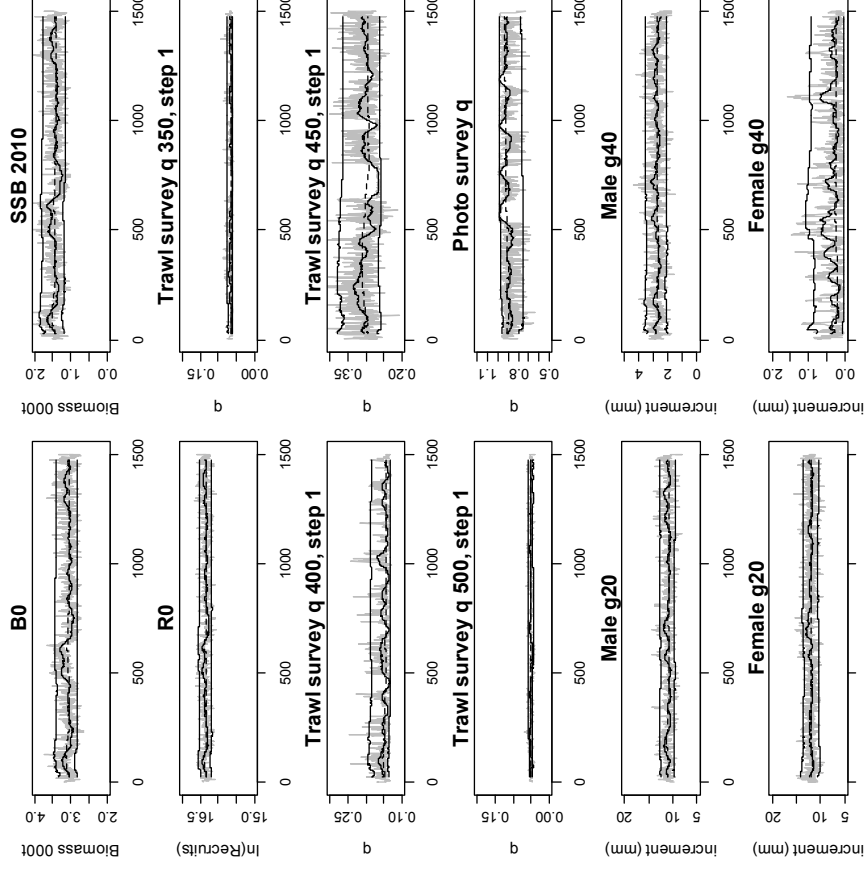
A5.24: Marginal posterior distribution of the parameters in A5.21.
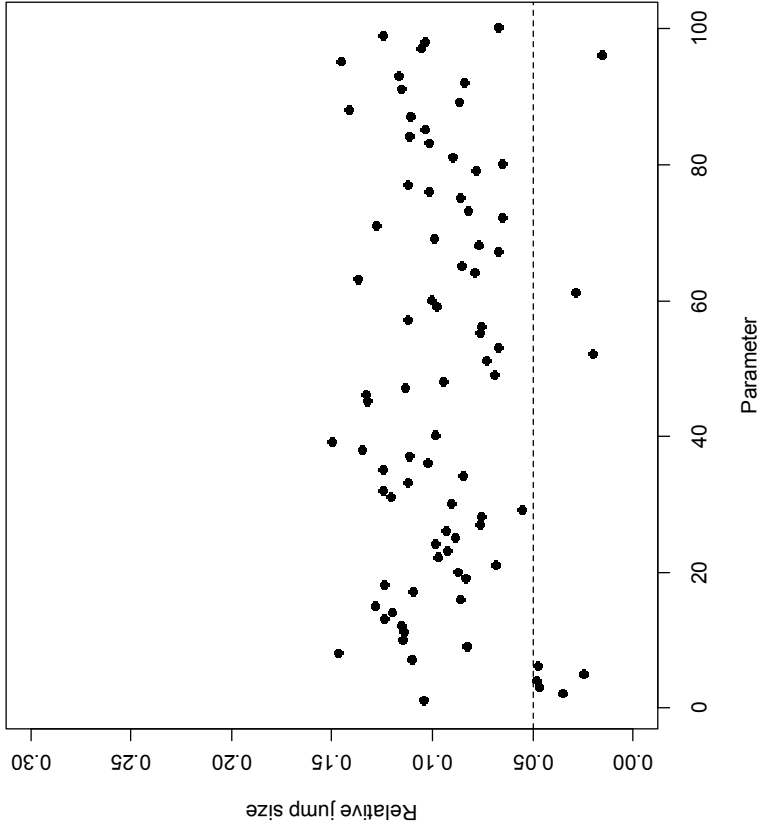
A5.23: MCMC diagnostic plot for model 8C, showing median relative jump size for all parameters (x axis, labelled 1–100). Parameter names are provided in Appendix 6.

A5.25: Posterior trajectory of SSB. Upper plot shows boxplots of SSB, while lower plot shows boxplots of SSB as a percentage of B_0.

12. APPENDIX 6. Model parameter details.

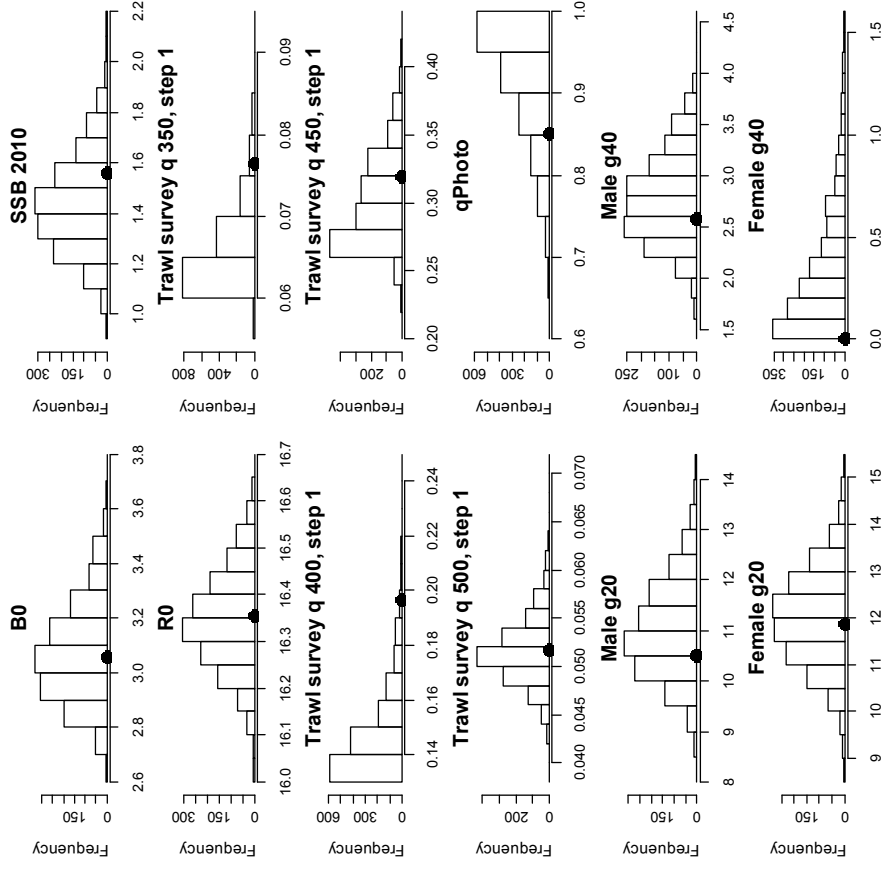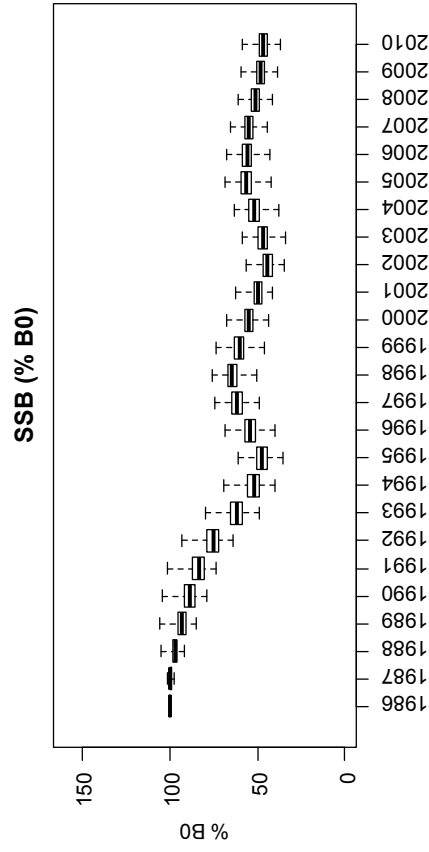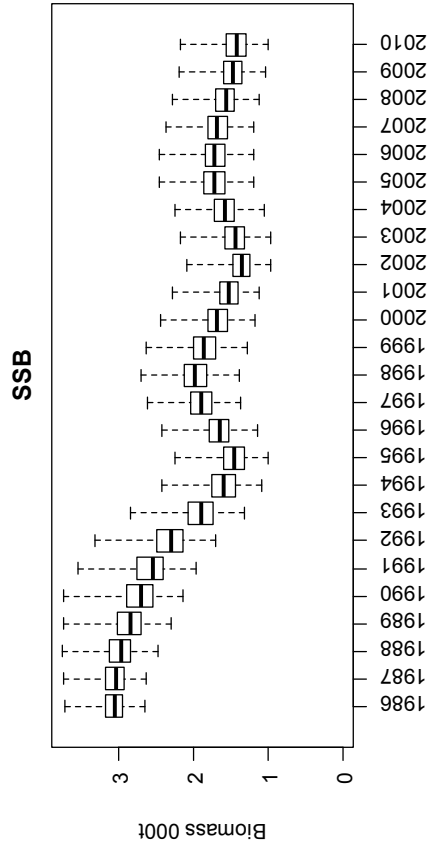|	SCI 1			SCI 1	
	Model 1C	Geweke		Model 2C	Geweke
1	initialization.B0	-0.37058	1	initialization.B0	0.546365
2	growth[1].minsigma_male	0.20207	2	growth[1].minsigma_male	-0.14101
3	recruitment.YCS.1	0.89614	3	recruitment.YCS.1	0.373233
4	recruitment.YCS.2	-0.51289	4	recruitment.YCS.2	-0.44352
5	recruitment.YCS.3	0.29393	5	recruitment.YCS.3	-0.03429
6	recruitment.YCS.4	0.00729	6	recruitment.YCS.4	-1.01214
7	recruitment.YCS.5	1.04043	7	recruitment.YCS.5	-1.15642
8	recruitment.YCS.6	-0.75202	8	recruitment.YCS.6	0.179005
9	recruitment.YCS.7	0.79823	9	recruitment.YCS.7	0.010877
10	recruitment.YCS.8	-0.04131	10	recruitment.YCS.8	-0.35288
11	recruitment.YCS.9	-0.2625	11	recruitment.YCS.9	0.247499
12	recruitment.YCS.10	0.95167	12	recruitment.YCS.10	1.009192
13	recruitment.YCS.11	1.11005	13	recruitment.YCS.11	1.247054
14	recruitment.YCS.12	-0.39202	14	recruitment.YCS.12	-0.63496
15	recruitment.YCS.13	1.52551	15	recruitment.YCS.13	-2.48684
16	recruitment.YCS.14	-0.35992	16	recruitment.YCS.14	1.153482
17	recruitment.YCS.15	0.66498	17	recruitment.YCS.15	-0.1997
18	recruitment.YCS.16	0.82538	18	recruitment.YCS.16	-0.28912
19	recruitment.YCS.17	0.04573	19	recruitment.YCS.17	0.917493
20	recruitment.YCS.18	2.13297	20	recruitment.YCS.18	-0.17066
21	recruitment.YCS.19	0.78544	21	recruitment.YCS.19	-1.80779
22	recruitment.YCS.20	1.22905	22	recruitment.YCS.20	0.574662
23	recruitment.YCS.21	-0.67884	23	recruitment.YCS.21	1.287683
24	recruitment.YCS.22	NaN	24	recruitment.YCS.22	NaN
25	recruitment.YCS.23	NaN	25	recruitment.YCS.23	NaN
26	recruitment.YCS.24	NaN	26	recruitment.YCS.24	NaN
27	recruitment.YCS.25	NaN	27	recruitment.YCS.25	NaN
28	maturity_props.all.1	-0.34132	28	maturity_props.all.1	1.464448
29	maturity_props.all.2	0.47966	29	maturity_props.all.2	-0.6307
30	selectivity[FishingSel202_1].female.1	-1.10732	30	selectivity[FishingSel202_1].female.1	-1.73091
31	selectivity[FishingSel202_1].female.2	-2.83791	31	selectivity[FishingSel202_1].female.2	0.32732
32	selectivity[FishingSel202_1].female.3	-1.78343	32	selectivity[FishingSel202_1].female.3	3.062066
33	selectivity[FishingSel202_1].female.4	NaN	33	selectivity[FishingSel202_1].female.4	NaN
34	selectivity[FishingSel202_2].female.1	1.04982	34	selectivity[FishingSel202_2].female.1	-0.10654
35	selectivity[FishingSel202_2].female.2	0.75073	35	selectivity[FishingSel202_2].female.2	1.771642
36	selectivity[FishingSel202_2].female.3	-2.34597	36	selectivity[FishingSel202_2].female.3	1.863102
37	selectivity[FishingSel202_2].female.4	NaN	37	selectivity[FishingSel202_2].female.4	NaN
38	selectivity[TrawlSurveySel202_1].female.1	0.1571	38	selectivity[FishingSel203_1].female.1	-1.91884
39	selectivity[TrawlSurveySel202_1].female.2	0.08274	39	selectivity[FishingSel203_1].female.2	0.843051
40	selectivity[TrawlSurveySel202_1].female.3	0.20457	40	selectivity[FishingSel203_1].female.3	1.506307
41	selectivity[TrawlSurveySel202_1].female.4	NaN	41	selectivity[FishingSel203_1].female.4	NaN
42	selectivity[TrawlSurveySel202_2].female.1	0.51034	42	selectivity[FishingSel203_2].female.1	-2.01991
43	selectivity[TrawlSurveySel202_2].female.2	1.0007	43	selectivity[FishingSel203_2].female.2	3.563292
44	selectivity[TrawlSurveySel202_2].female.3	-1.00236	44	selectivity[FishingSel203_2].female.3	1.190442
45	selectivity[TrawlSurveySel202_2].female.4	NaN	45	selectivity[FishingSel203_2].female.4	NaN
46	selectivity[PhotoSurveySel].male.1	0.86547	46	selectivity[TrawlSurveySel202_1].female.1	0.387755
47	selectivity[PhotoSurveySel].male.2	-0.47887	47	selectivity[TrawlSurveySel202_1].female.2	-1.01963
48	selectivity[PhotoSurveySel].male.3	NaN	48	selectivity[TrawlSurveySel202_1].female.3	0.89053
49	growth[1].g_male.1	0.03153	49	selectivity[TrawlSurveySel202_1].female.4	NaN
50	growth[1].g_male.2	-0.0901	50	selectivity[TrawlSurveySel203_1].female.1	0.460086
51	growth[1].g_female.1	0.34386	51	selectivity[TrawlSurveySel203_1].female.2	-2.01522
52	growth[1].g_female.2	0.46548	52	selectivity[TrawlSurveySel203_1].female.3	1.15178
			53	selectivity[TrawlSurveySel203_1].female.4	NaN
			54	selectivity[TrawlSurveySel202_2].female.1	0.445486
			55	selectivity[TrawlSurveySel202_2].female.2	-1.11075
			56	selectivity[TrawlSurveySel202_2].female.3	1.855759
			57	selectivity[TrawlSurveySel202_2].female.4	NaN
			58	selectivity[TrawlSurveySel203_2].female.1	2.543885
			59	selectivity[TrawlSurveySel203_2].female.2	-1.4133
			60	selectivity[TrawlSurveySel203_2].female.3	1.095293
			61	selectivity[TrawlSurveySel203_2].female.4	NaN
			62	selectivity[PhotoSurveySel].male.1	0.927061
			63	selectivity[PhotoSurveySel].male.2	0.538828
			64	selectivity[PhotoSurveySel].male.3	NaN
			65	growth[1].g_male.1	-0.05057
			66	growth[1].g_male.2	0.761517
			67	growth[1].g_female.1	-0.51149
			68	growth[1].g_female.2	-1.7498

	SCI 2	
	Model 4C	Geweke
1	initialization.B0	-0.5713
2	r_abund[PhotoSurvey].cv_process_error	NaN
3	r_abund[TrawlSurvey702_1].cv_process_error	NaN
4	r_abund[TrawlSurvey702_2].cv_process_error	NaN
5	r_abund[CPUE-Trawl702_1].cv_process_error	NaN
6	r_abund[CPUE-Trawl702_2].cv_process_error	NaN
7	r_abund [CPUE-Trawl702_3].cv_process_error	NaN
8	growth[1].minsigma_male	NaN
9	recruitment.YCS.1	1.0794
10	recruitment.YCS.2	0.4704
11	recruitment.YCS.3	0.6594
12	recruitment.YCS.4	-0.6265
13	recruitment.YCS.5	0.6194
14	recruitment.YCS.6	1.8805
15	recruitment.YCS.7	-1.5455
16	recruitment.YCS.8	1.6183
17	recruitment.YCS.9	-2.6941
18	recruitment.YCS.10	-0.152
19	recruitment.YCS.11	1.4281
20	recruitment.YCS.12	-0.1635
21	recruitment.YCS.13	0.3347
22	recruitment.YCS.14	0.2947
23	recruitment.YCS.15	1.0575
24	recruitment.YCS.16	1.0897
25	recruitment.YCS.17	0.44
26	recruitment.YCS.18	1.0247
27	recruitment.YCS.19	-1.4886
28	recruitment.YCS.20	0.9925
29	recruitment.YCS.21	0.4928
30	recruitment.YCS.22	NaN
31	recruitment.YCS.23	NaN
32	recruitment.YCS.24	NaN
33	recruitment.YCS.25	NaN
34	maturity_props.all.1	-0.4921
35	maturity_props.all.2	-1.2407
36	selectivity[FishingSel702_1].female.1	1.9201
37	selectivity[FishingSel702_1].female.2	1.3909
38	selectivity[FishingSel702_1].female.3	0.5317
39	selectivity[FishingSel702_1].female.4	NaN
40	selectivity[FishingSel702_2].female.1	-0.1212
41	selectivity[FishingSel702_2].female.2	-1.9768
42	selectivity[FishingSel702_2].female.3	-1.4194
43	selectivity[FishingSel702_2].female.4	NaN
44	selectivity[TrawlSurveySel702_1].female.1	1.6512
45	selectivity[TrawlSurveySel702_1].female.2	0.7741
46	selectivity[TrawlSurveySel702_1].female.3	-0.3771
47	selectivity[TrawlSurveySel702_1].female.4	NaN
48	selectivity[TrawlSurveySel702_2].female.1	3.2871
49	selectivity[TrawlSurveySel702_2].female.2	3.2075
50	selectivity[TrawlSurveySel702_2].female.3	-1.2457
51	selectivity[TrawlSurveySel702_2].female.4	NaN
52	selectivity[PhotoSurveySel].male.1	2.0416
53	selectivity[PhotoSurveySel].male.2	-0.8802
54	selectivity[PhotoSurveySel].male.3	NaN
55	growth[1].g_male.1	-0.8873
56	growth[1].g_male.2	-1.0733
57	growth[1].g_female.1	-0.229
58	growth[1].g_female.2	-1.4189

13. APPENDIX 7. Multinomial sample sizes.

Francis (2011) describes methods of correcting the multinomial sample sizes for at-age (or length) observations in a stock assessment model. Method TA1.8 is used here. The assessment model is run with initial sample sizes, and then the residuals from the model fit are analysed to calculate a correction factor for the sample size. The aim is to ensure that the size of the model residuals is consistent with the corrected sample sizes.

Let $p_{ay,\text{obs}}$ be the observed proportion at length a in year y in a set of length frequencies that is assumed to have a multinomial error structure, and let $N_{\text{init},y}$ denote the initial sample sizes. The aim is to calculate a correction factor f so that the size of the model residuals is consistent with the corrected sample sizes, $N_{\text{corr},y} = fN_{\text{init},y}$.

There two ways of calculating f, and these use different residuals. The first uses the residuals of the individual observations: $r_{ay} = p_{ay,\text{obs}} - p_{ay,\text{exp}}$, while the second method uses the residuals of mean age (or length): $r_y = (m_{y,\text{obs}} - m_{y,\text{exp}})$, where $m_{y,\text{obs}} = \Sigma_a(a\, p_{ay,\text{obs}})$, and $m_{y,\text{exp}}$ is defined similarly. The second method has been applied here.

The expected variance of the mean length, $m_{y,\text{obs}}$, and thus of the residual r_y, is $v_y/(fN_{\text{init},y})$ [i.e., $v_y/N_{\text{corr},y}$], where v_y is the variance of the length frequency in year y, given by $v_y = \Sigma_a(a^2\, p_{ay,\text{obs}}) - m_{y,\text{obs}}^2$. Therefore, the expected variance of $r_y(N_{\text{init},y}/v_y)^{0.5}$ is $1/f$, and we can estimate f as $1/\text{Var}(r_y(N_{\text{init},y}/v_y)^{0.5})$.