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Stock Assessment of arrow squid (SQU 1T and 6T)

New Zealand Fisheries Assessment Report 2016/28

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EXECUTIVE SUMMARY

McGregor, V.; Large, K. (2016). Stock Assessment of arrow squid (SQU 1T and 6T).

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Squid require a different approach to fisheries management than longer living species. They only live around one year, spawn and then die. The result of this is an entirely different stock each year, with little relationship in stock size between years.

It is possible to estimate the amount a squid stock has been depleted within a season using a depletion model. This approach is being used successfully elsewhere including the Falkland Islands. We have applied the model used for the *Loligo gahi* fishery in the Falkland Islands to the *Nototodarus sloanii* fisheries in the Snares and Auckland Islands in New Zealand for all years from 1990-2014. The depletion model requires CPUE, catches, natural mortality, and timings of population pulses as inputs. It estimates catchability, initial abundance in numbers, and abundance in numbers for all subsequent population pulses within the season. We fitted the CPUE in tonnes per hour towed. Mean weights were estimated from length data and length to weight conversion parameters from the fisheries observer data. These were used to convert the CPUE and catches into numbers. Timings of pulses in the population within each season were estimated from the CPUE. We considered using length frequency data to inform timings of recruitment pulses, but the signals from these are not clear for many seasons for both areas. These may be more useful with more information on the life cycle and perhaps growth rates of *N. sloanni* in New Zealand.

The depletion model failed to converge for several seasons for both the Snares and Auckland Islands. In the Falkland Islands, a pre-season survey is used to inform the prior on initial abundance. New Zealand does not have a pre-season survey and in the work here, an uninformative prior was used for initial abundance. It is likely for depletion modelling to be successful for the New Zealand squid fisheries, further information is required to inform the prior on initial abundance.

1. Introduction

Modelling population size in fish typically relies on a mathematical model that keeps track of the number of fish in each age class across years. As fish grow older in the model, they move from one age class to the next, subject to assumed or estimated patterns of growth and mortality. For a typical, relatively long-lived fish with low natural mortality, there will be many age classes in the water and the population size will tend to change relatively slowly, with incoming recruitment providing only a small increment to the stock size in most years.

Squid have a very different life-cycle that does not fit with standard fish population modelling approaches. Most squid live for around one year, spawn and then die. The result of this is an entirely new stock each year, the size of which tends to be driven by environmental factors. In numbers, the population is largest when it exists as eggs. The earliest estimation of population size can be made on recruits using either a recruit survey or back-calculating from the fishery driven depletion. It is this latter approach that we are investigating for the New Zealand Snares and Auckland Islands squid fisheries.

Assessing squid stocks in-season is possible and has been done for a small number of fisheries. Hurst et al. (2012) carried out a detailed characterisation of SQU 6T (Auckland Islands) and SQU 1T (Snares Islands) fisheries and a preliminary evaluation of potential in-season management approaches. McGregor & Tingley (2016) further developed these analyses and the depletion method as described in Roa-Ureta (2012), using the Auckland Islands 2008 data as a case study. This method is being further developed in the current project, and applied to each fishery (the Snares and Auckland Islands) and each fishing year (1990–2014).

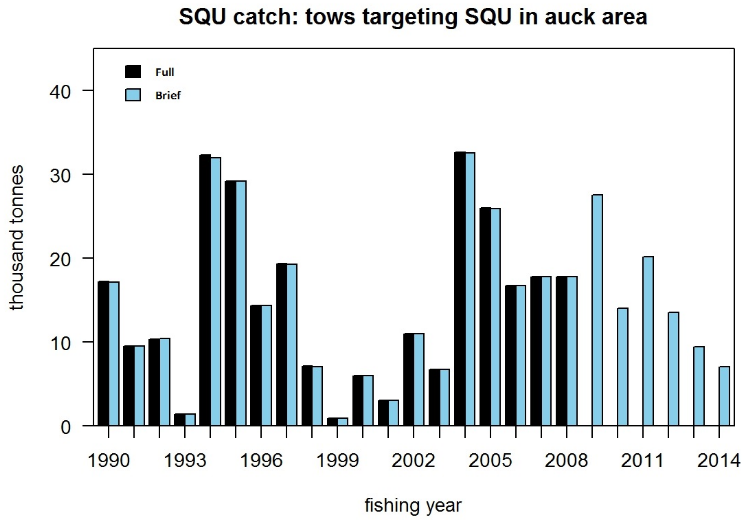
2. Methods

2.1. Grooming catch and effort data

Applying depletion modelling in-season will require grooming to be carried out on the catch and effort data as they arrive in real-time. There will be insufficient time to carry out a full grooming process where missing or outlier values are imputed, hence a minimal grooming process will be used. Also, early in the season there is unlikely to be sufficient data to adequately impute required values. To test the effects of minimal grooming compared with a full grooming process, we carried out 'brief' grooming on the data from each fishing year and area, then compared the resulting datasets with those that had been through the full grooming process, as described in Hurst et al. 2012. We applied the following process in our automated 'brief' grooming

- Formated the date fields
- Assigned fishing year and fishing date using the formatted start date field
- Assigned area based on start latitude and longitude, then kept only data in the area of interest (Snares or Auckland Islands)
- Removed non-TCEPR data
- Removed rows containing one or more outliers

The catch and effort (number of tows) from tows that targeted squid remained very similar for the Auckland Islands fishery, but dropped a small amount in the Snares fishery (Figures 1 and 2). We carried out a CPUE for the 'brief-groomed' datasets for fishing years 1990 and 2008 for the Snares and 2008 for the Auckland Islands. These were sufficiently similar to those fitted to the fully groomed datasets to support the use of the brief grooming process in the in-season modelling (Figures 3–5).



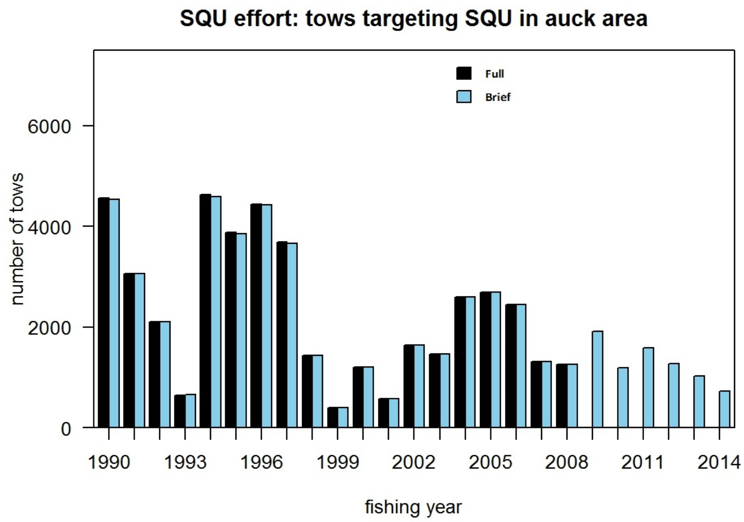


Figure 1: Auckland Islands catch in tonnes (top) and number of tows (bottom) that targeted squid for each fishing year 1990–2008 for the fully groomed dataset from Hurst et al. (2012) (black bars) and the dataset following 'brief' grooming as described above for fishing years 1990–2014 (blue bars).

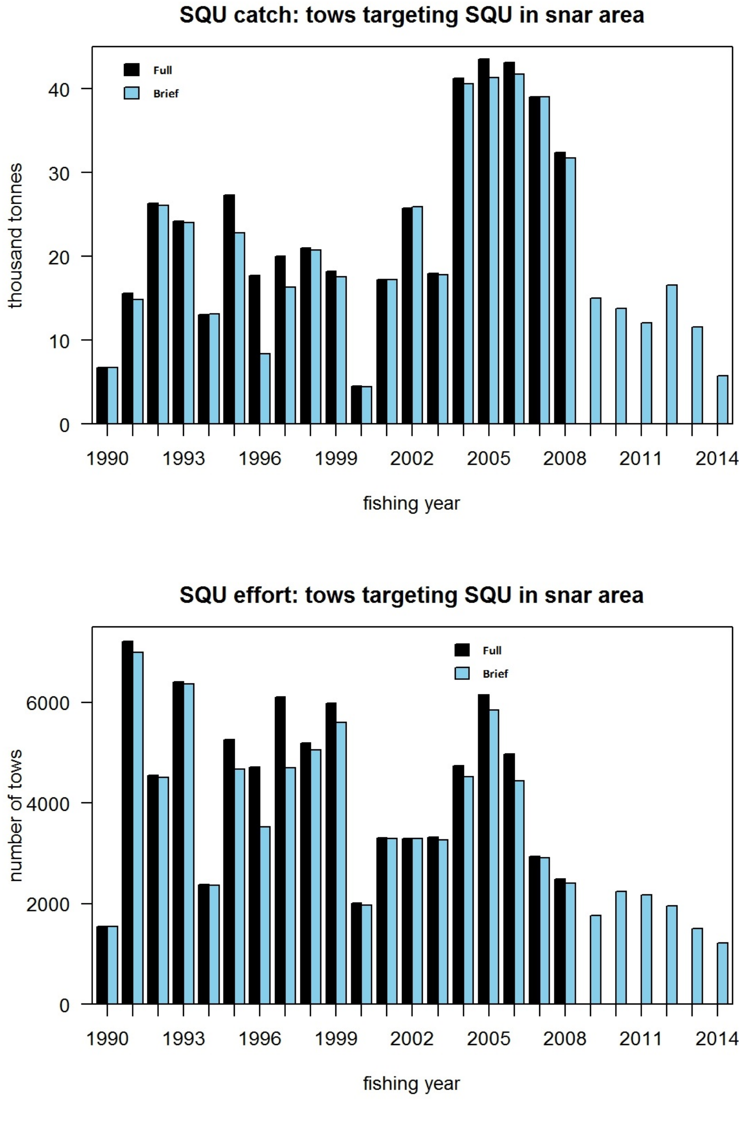


Figure 2: Snares catch in tonnes (top) and number of tows (bottom) that targeted squid for each fishing year 1990–2008 for the fully groomed dataset from Hurst et al. (2012) (black bars) and the dataset following 'brief' grooming as described above for fishing years 1990–2014 (blue bars).

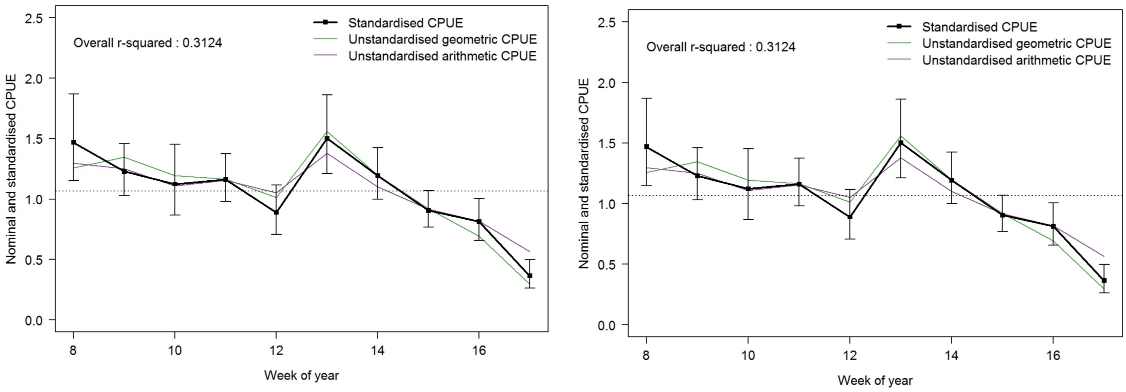


Figure 3: CPUE for the Auckland Islands, fishing year 2008 for the fully groomed dataset (left) and the 'brief' groomed dataset (right).

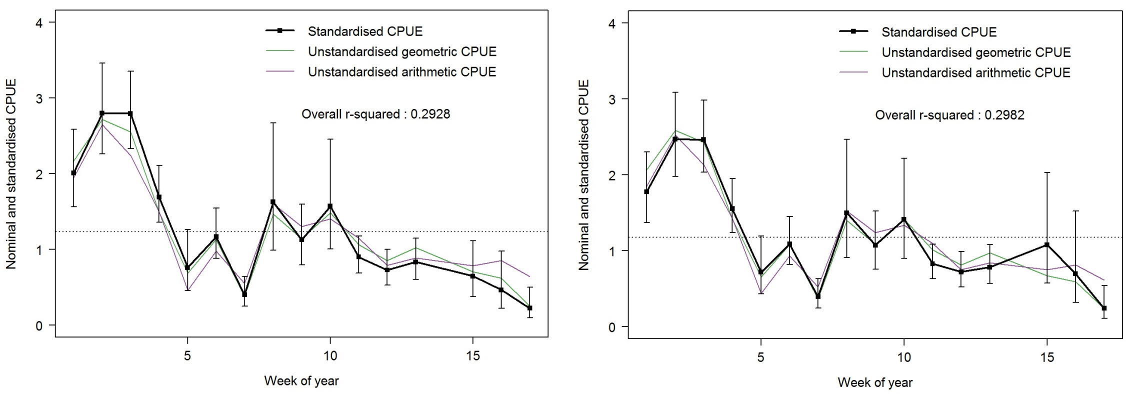


Figure 4: CPUE for the Snares, fishing year 1990 for the fully groomed dataset (left) and the 'brief' groomed dataset (right).

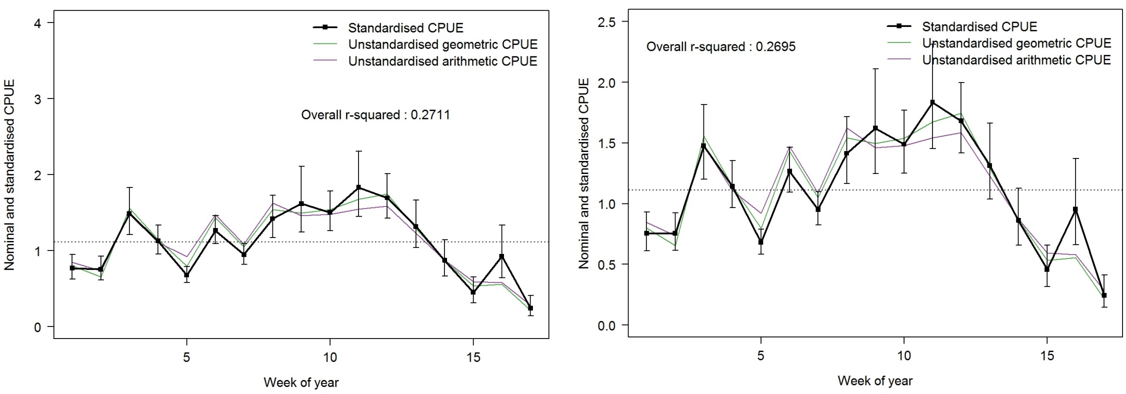


Figure 5: CPUE for the Snares, fishing year 2008 for the fully groomed dataset (left) and the 'brief' groomed dataset (right).

2.2. CPUE

2.2.1. Target species

Only tows that targeted squid were selected for fitting the CPUE. This kept most of the catch, and for the weeks where most of the catch was taken, it kept most of the effort (Figures 6 and 7).

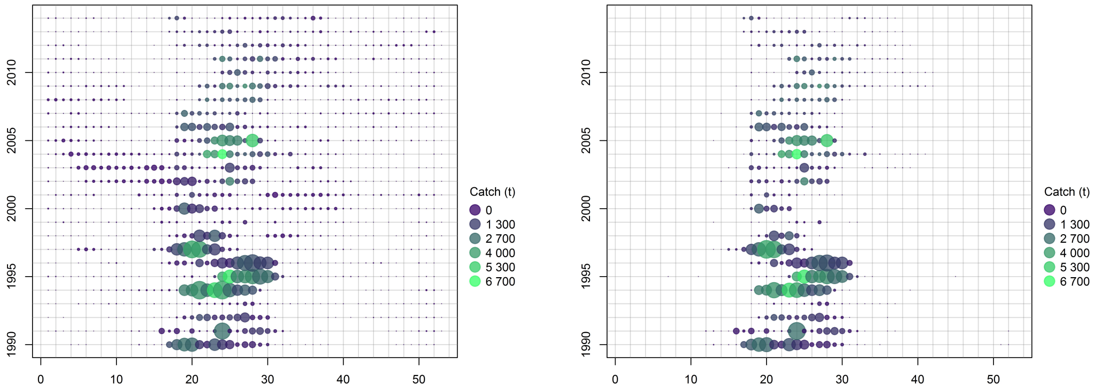


Figure 6: Auckland Islands catch (circle colour) and number of tows (circle area) for all tows (left) and only tows that targeted squid (right).

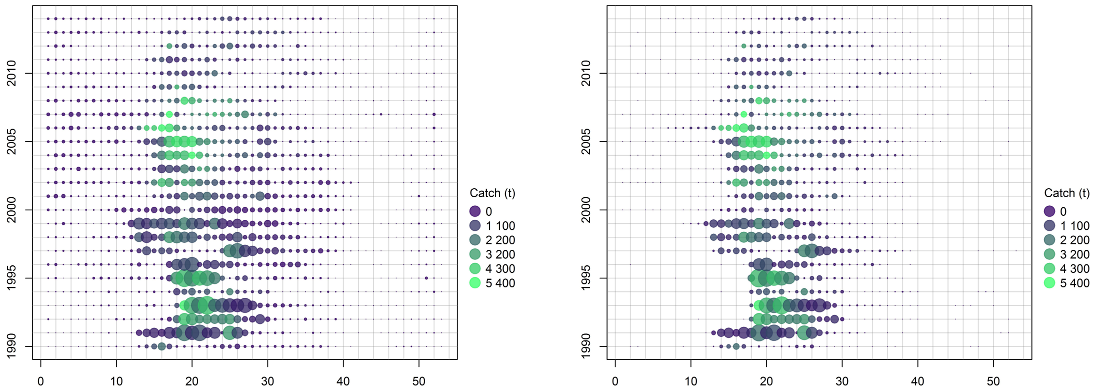


Figure 7: Snares catch (circle colour) and number of tows (circle area) for all tows (left) and only tows that targeted squid (right).

2.2.2. Core vessel selection

In the previous report (McGregor & Tingley, 2016), two core vessel selections were proposed. Selection criteria 1 required vessels to have records in at least four of the fishing weeks with at least four tows recorded in each of these weeks. Selection criteria 2 required vessels to have records in at least three weeks, with at least six tows recorded in each week (Table 1). We ran both selection criteria on each fishing year and area. There was little difference in the proportion of catch or number of tows retained (Tables 2 and 3). For the work that follows, core vessels were selected using selection criteria 1.

Table 1: Core vessel selection criteria for selection criteria 1 and selection criteria 2. Number of weeks is the minimum number of weeks a core vessel must be in the dataset with at least the stated number of records in each week.

	Number of weeks	Number of records
Selection 1	4	4
Selection 2	3	6

Table 2: Proportion of catch (weight) and effort (number of tows) retained from core vessel selection criterias 1 and 2 for the Snares for fishing years 1990–2014.

	Catch		Effort	
years	**Selection 1**	**Selection 2**	**Selection 1**	**Selection 2**
1990	0.76	0.71	0.69	0.63
1991	0.99	0.98	0.99	0.98
1992	0.94	0.95	0.94	0.94
1993	0.99	0.99	1.00	1.00
1994	0.82	0.85	0.85	0.87
1995	0.96	0.95	0.96	0.95
1996	0.93	0.98	0.89	0.97
1997	0.97	0.95	0.97	0.96
1998	1.00	1.00	0.99	0.99
1999	1.00	0.98	0.99	0.98
2000	0.95	0.96	0.94	0.97
2001	0.99	0.99	0.99	0.99
2002	0.99	0.99	0.97	0.97
2003	1.00	1.00	0.99	1.00
2004	1.00	0.99	0.99	0.99
2005	0.99	1.00	0.98	1.00
2006	1.00	0.98	0.99	0.97
2007	1.00	0.98	0.99	0.97
2008	0.97	1.00	0.95	1.00
2009	0.88	0.93	0.85	0.91
2010	0.99	0.99	0.99	0.99
2011	0.96	0.96	0.95	0.95
2012	0.98	0.98	0.98	0.98
2013	0.95	0.94	0.96	0.94
2014	0.91	0.9	0.89	0.88
Mean	0.96	0.96	0.95	0.95
Minimum	0.76	0.71	0.69	0.63
Maximum	1.00	1.00	1.00	1.00

Table 3: Proportion of catch (weight) and effort (number of tows) retained from core vessel selection criteria 1 and 2 for Auckland Islands for fishing years 1990–2014.

	Catch		Effort	
years	**Selection 1**	**Selection 2**	**Selection 1**	**Selection 2**
1990	0.98	0.94	0.97	0.92
1991	0.91	0.91	0.9	0.9
1992	0.8	0.75	0.81	0.73
1993	0.36	0.36	0.44	0.44
1994	1.00	0.98	1	0.97
1995	0.95	0.95	0.95	0.95
1996	0.95	0.93	0.97	0.96
1997	0.99	0.98	0.98	0.96
1998	0.72	0.71	0.77	0.78
1999	0.23	0.23	0.26	0.26
2000	0.77	0.67	0.77	0.68
2001	0.61	0.38	0.55	0.36
2002	0.93	0.89	0.92	0.9
2003	0.87	0.84	0.84	0.83
2004	0.95	0.95	0.94	0.94
2005	0.99	0.99	0.99	0.98
2006	0.98	0.94	0.97	0.93
2007	0.85	0.84	0.85	0.83
2008	0.99	0.93	0.98	0.94
2009	0.99	0.99	0.99	0.99
2010	0.91	0.9	0.85	0.84
2011	0.94	0.97	0.94	0.98
2012	0.98	0.98	0.97	0.97
2013	0.93	0.93	0.89	0.89
2014	0.89	0.78	0.85	0.75
Mean	0.86	0.83	0.85	0.83
Minimum	0.23	0.23	0.26	0.26
Maximum	1.00	0.99	1.00	0.99

2.2.3. Fitting CPUE

CPUE as catch in weight per tow duration (tonnes/hour) were fitted as if in real time to the groomed core dataset for each fishing year and area, providing this dataset held at least two unique vessels. The explanatory variables offered in each case were a subset of {vessel, method, depth, headline height, latitude, longitude, grid box and time} (see Table 4 for more details). Interaction terms offered were vessel.key:grid.box and vessel.key:fish.day. The categorical spatial explanatory variable, grid.box, was offered in the alt1 model only. These were the boxes that resulted from placing a 5-degree square grid over the model area (Figure 8). Variables that were factors were only offered where there were at least two unique values for them in the data. Variables that were polynomials of degree three required at least four unique values. Variable fish.day was forced into each model. Additional explanatory variables were then added based on the largest increase in r^2 and with the requirement that the increase in r^2 as a result of each additional variable was greater than 0.01. Figures 9 and 10 show the selected explanatory variables for each of the datasets for the base and alt1 models. Most of the explanatory power for both models and both areas came from the day effect (fish.day). The start time of the tow (time.start) was often selected for the base model for both areas, and for Auckland Islands using the alt1 model. For the alt1 model in the Snares, grid.box was usually selected. The r^2 values were generally higher for the base model (Figure 11). Diagnostic plots showed assumptions of variance and normality of errors were sufficiently met (Figure 12 as an example, and Appendix A for further diagnostic plots).

Table 4: Variables offered for CPUE models. fish.day was forced into every model. grid.box was only offered in the alt1 model.

Variable name	Variable description	Variable format
fish.day	day of the fishing year (day 1 corresponds to 1 October)	categorical (forced)
vessel.key	vessel unique key	categorical
primary.method	fishing method used	categorical
grid.box	box within 5 degree grid	categorical
effort.depth	depth of the net	polynomial, degree 3
effort.width	width of the trawl	polynomial, degree 3
effort.height	headline height	polynomial, degree 3
start.latitude	latitude for start position of tow	polynomial, degree 3
start.longitude	longitude for start position of tow	polynomial, degree 3
time.start	start time of fishing	polynomial, degree 3

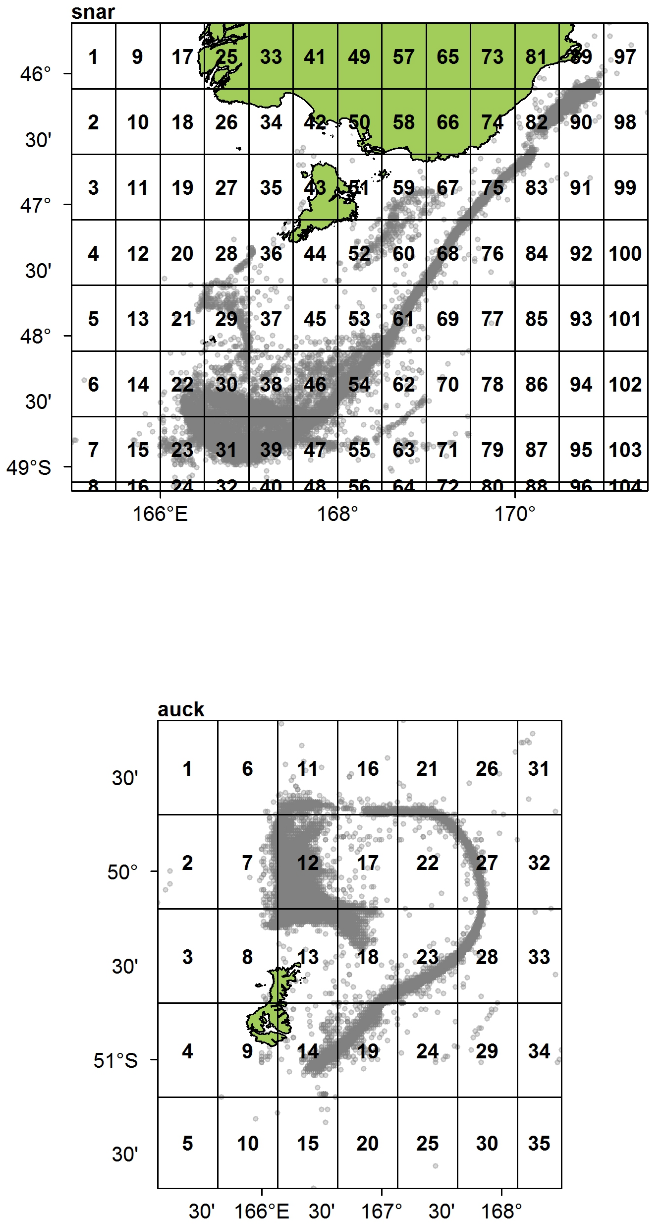


Figure 8: Grid box of 5 degree squares over the Snares (top) and Auckland Islands (bottom). Grey dots are the locations for the start of each tow where squid were targeted in years 1990–2014.

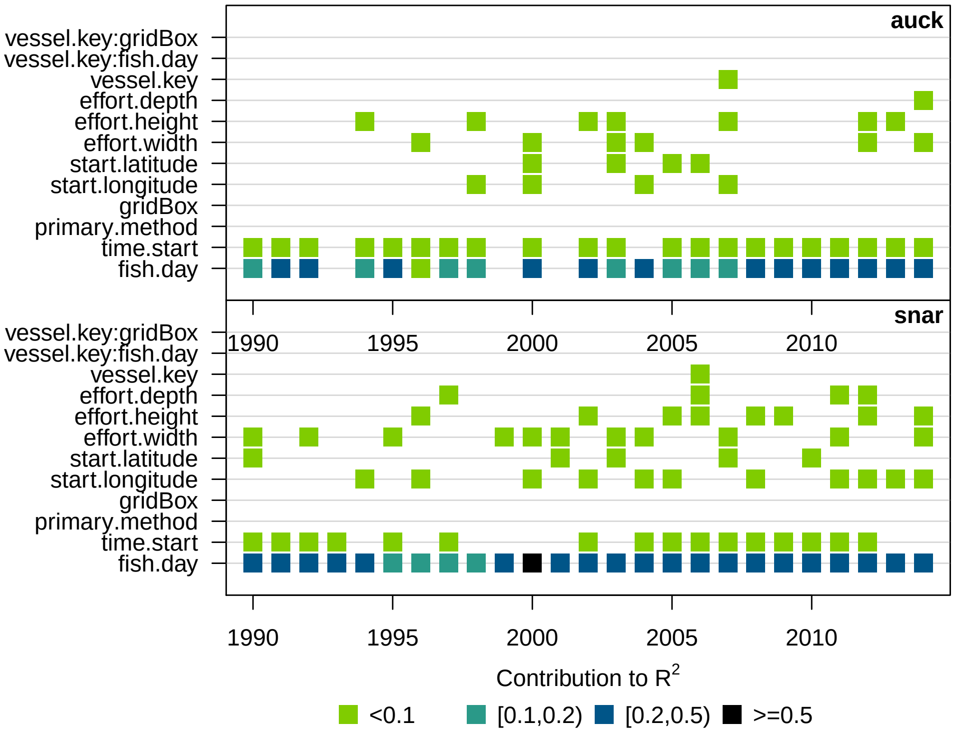


Figure 9: Variables selected for each dataset (area/year) for the base model, with the contribution to r^2 for each variable as indicated by the colour of each square.

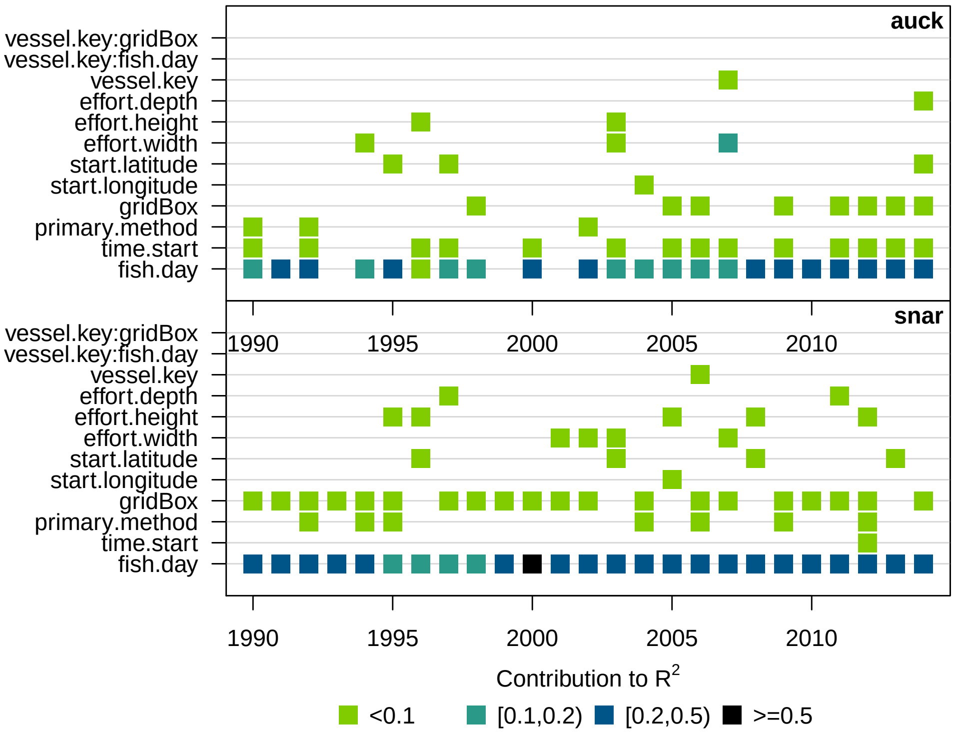


Figure 10: Variables selected for each dataset (area/year) for the alt1 model, with the contribution to r^2 for each variable as indicated by the colour of each square.

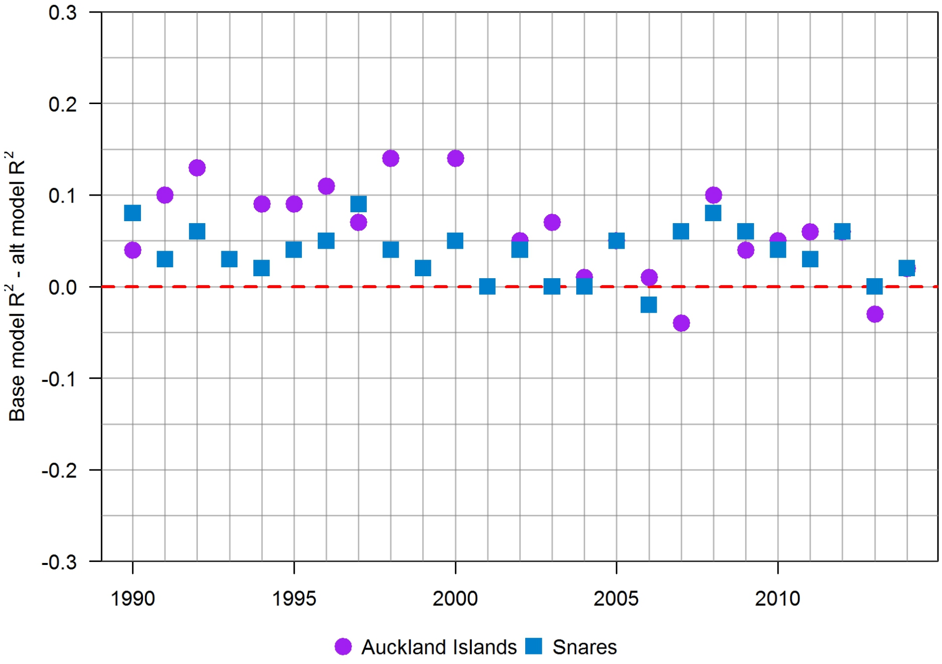


Figure 11: Base model r^2 – alt1 model r^2 for Auckland Islands (purple circles) and the Snares (blue squares). Points above zero (marked with red dashed line) show higher r^2 from the base model, points below zero show higher r^2 from the alt1 model.

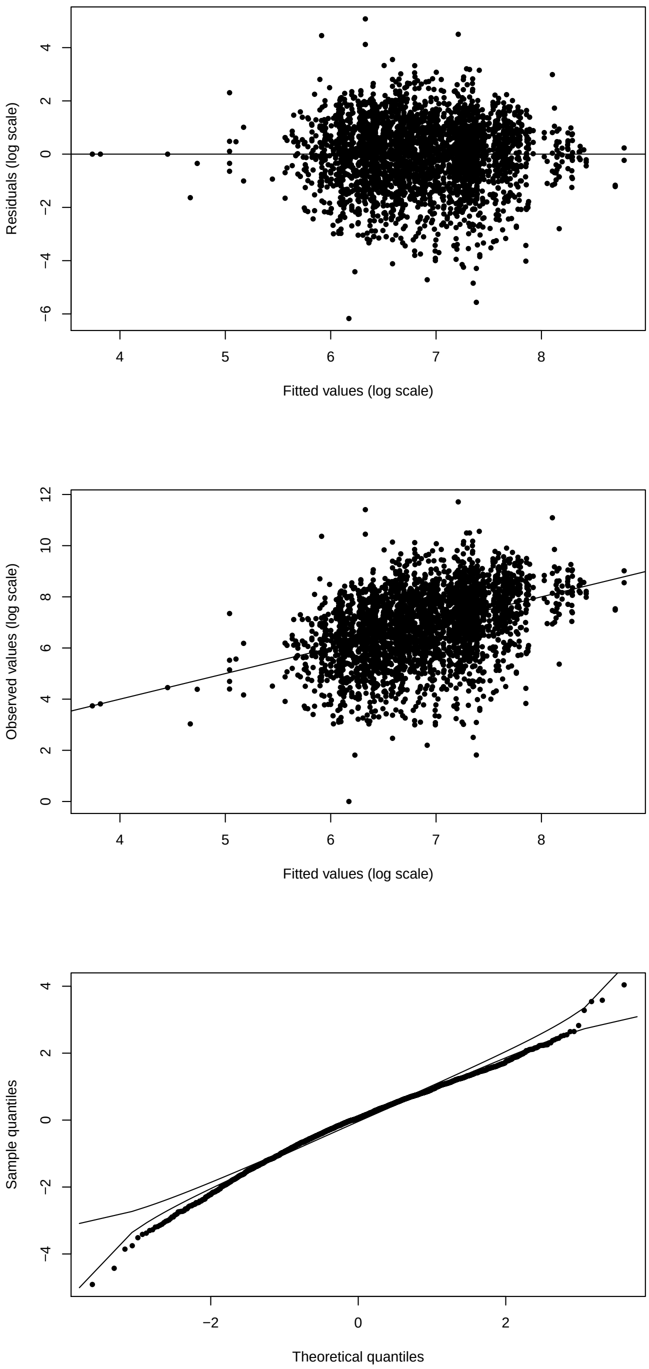


Figure 12: Diagnostic plots for Auckland Islands 1997 CPUE.

2.2.4. Mean weight by day

Mean weights by day (or some other appropriate time step) are required to convert catches and CPUEs from weights to numbers as it is numbers that are tracked through the depletion model. We estimated the mean weight using data from the Ministry for Primary Industries Observer Programme (OP). This data consists of squid length observations since 1986 (except from 2000–01 to 2006–07), and length and weight observations from 2007–08 to present from the Auckland Islands and Snares fisheries (Table 5). The sample sizes for weight are around one tenth those for length. The mean weights by day from the weight samples are highly variable (Figures 13 and 14), which is probably a result of small sample sizes.

For the work that follows in this report, the length samples were used with length to weight conversion parameters to obtain mean weight by day following the method used in McGregor and Tingley (2016). For years where there were no observed length data (2000–01–2006–07) we used the mean of the mean weights from the other years. Within years with length data, there were still days where there were catch and effort data but no length data. In these cases, the mean of the two values, one on either side of each missing value was used. Figure 15 shows the mean weights from the OP, with the completed mean weights for the Auckland Islands fishery 1991 data. The full set of figures are in Appendix B.

Table 5: Number of samples measured for length or weight from the Snares and Auckland Islands fisheries for fishing years 1990–2014.

Fishing year	Auckland length	Auckland weight	Snares length	Snares weight
1990	265		62	
1991	128		326	
1992	101		172	
1993	54		487	
1994	172		102	
1995	111		134	
1996	224		40	
1997	152		92	
1998	60		75	
1999	26		74	
2000	47		71	
2001				
2002				
2003				
2004				
2005				
2006				
2007				
2008	259	32	305	41
2009	489	54	282	28
2010	173	28	385	43
2011	378	31	404	40
2012	289	32	352	27
2013	560	48	753	45
2014	380	30	545	44

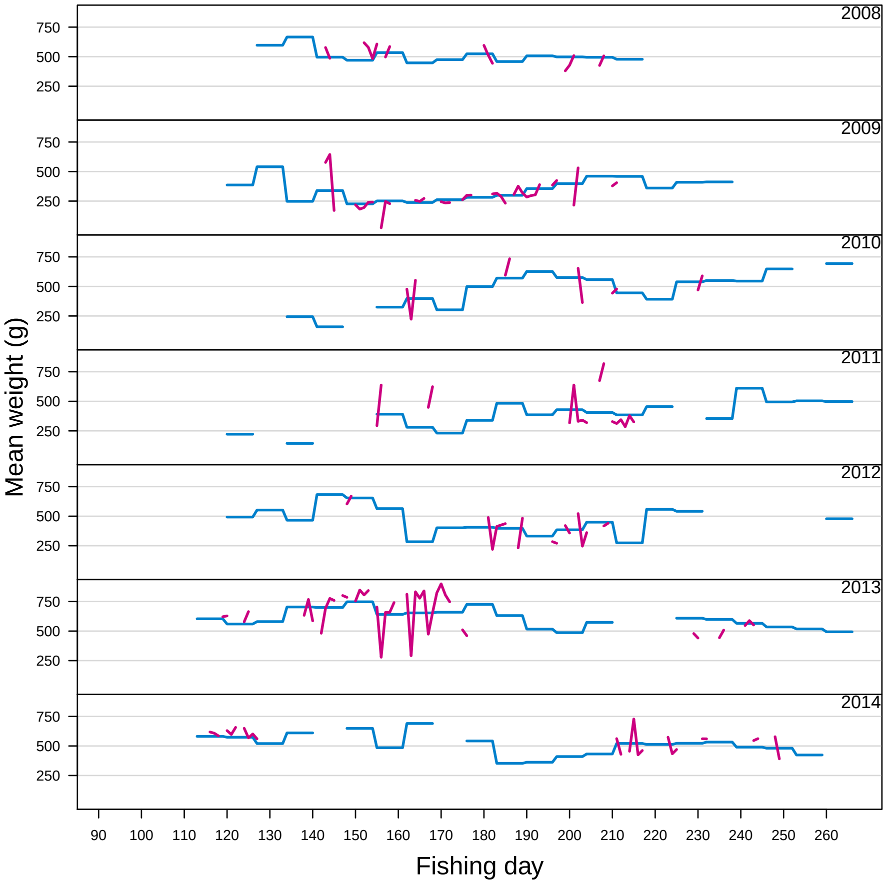


Figure 13: Mean weight by day from observed weights (red lines) and from observed lengths (blue line) for the Auckland Islands for fishing years 2008–2014.

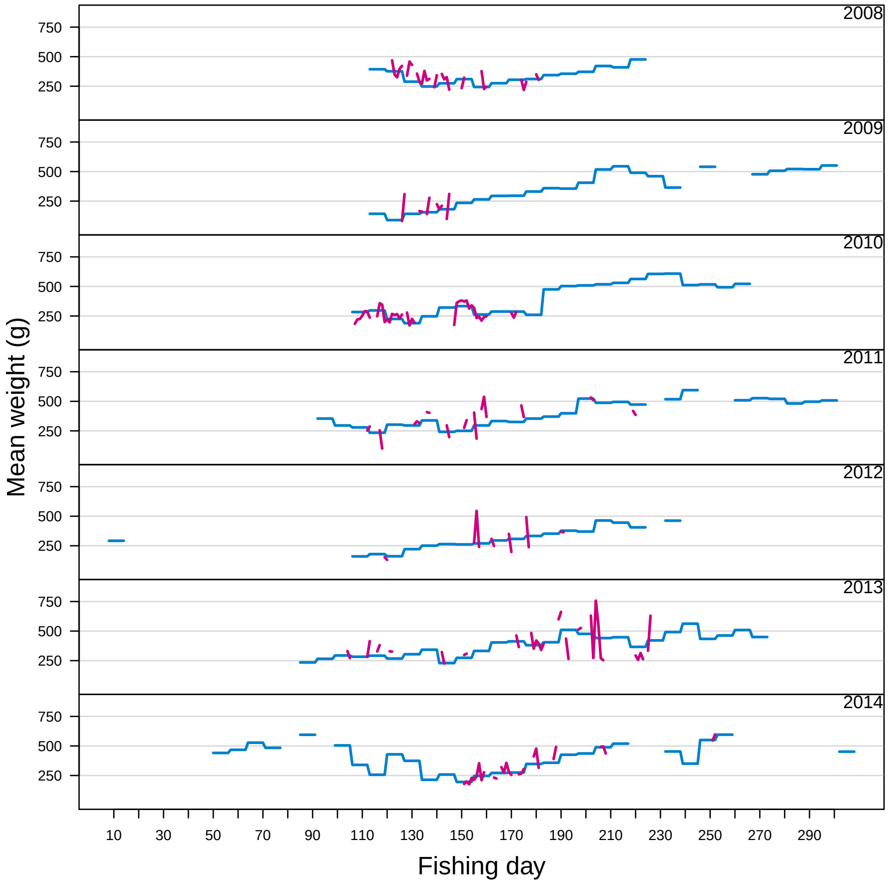


Figure 14: Mean weight by day from observed weights (red lines) and from observed lengths (blue line) for the Snares for fishing years 2008–2014.

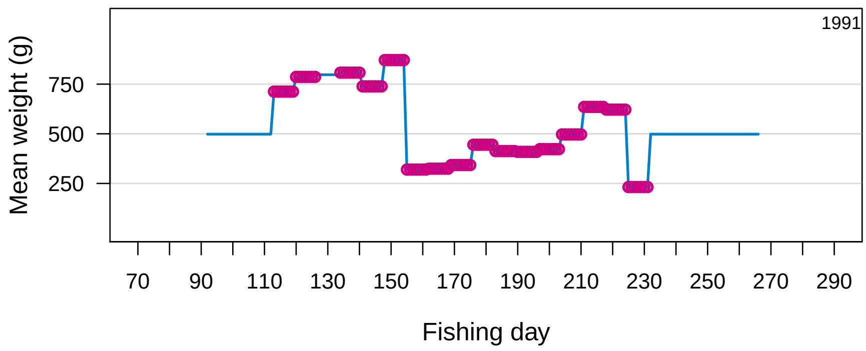


Figure 15: Auckland Islands 1991 mean weight by day (red circles), with missing data filled in using the method described above to get the full mean weight by day series (blue line).

2.2.5. Catch in numbers

Catches and standardised CPUEs were converted to numbers per hour by dividing by the mean weight by day (Equation 1). The CPUE in numbers by day plots are in Appendix C.

$$CPUE_{numbers/hour} = CPUE_{weight/hour} \times \frac{1}{\mu_{weight}} \tag{1}$$

2.3. Timing of population pulses

The depletion model requires timings of population pulses to be entered as an input. These include possible recruitment pulses and possible pulses of fish migrating into the fishery. These were estimated using the peaks and troughs in the CPUE. This was done by smoothing the CPUE using the R function *lowess()*, then attributing local maxima to pulses in the population if they were at least some minimum number of days apart and at least some minimum proportion of height increase from the previous local minima. The minimum days apart and minimum proportional increase were defined here as 5 and 0.33 respectively, however further research into the biological aspects of the species may suggest other values for these. Figure 16 shows an example of this process.

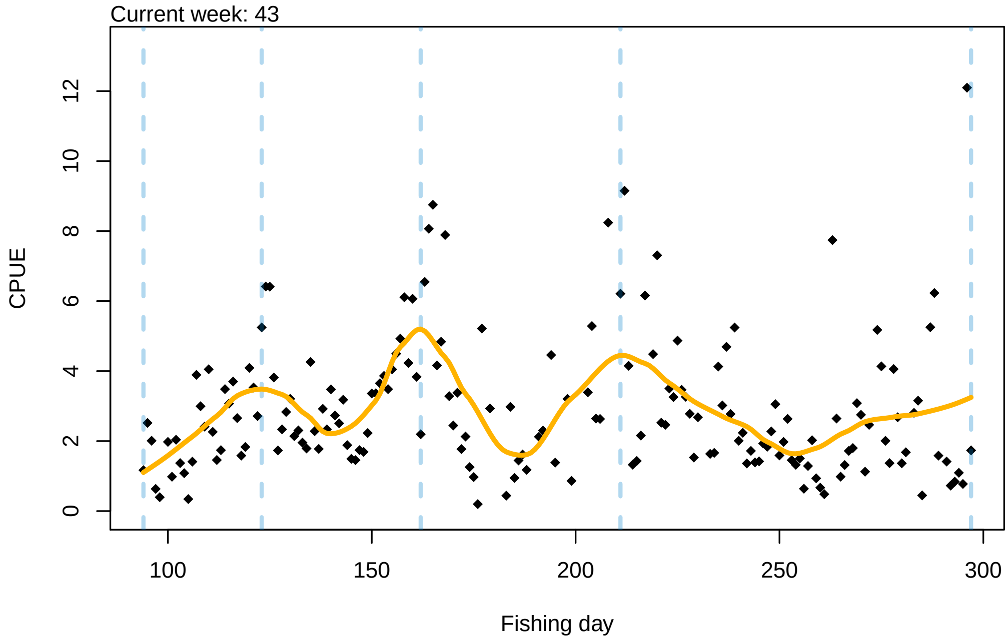


Figure 16: Population pulse timings (blue dashed lines) estimated from CPUE (black dots) by using the smoothed CPUE (orange line).

2.3.1. Recruitment pulses from length frequencies

Length frequency plots were investigated as these have the potential to be informative on timings of recruiment pulses to the fishery. The Auckland Islands seem to have either one or two recruitment pulses, although there does not seem to be a pattern to when they occur (Figures 17 and 18). The Snares show one, two, or three recruitment pulses within the fishery and no apparent pattern to these between seasons (Figures 19 and 20). Because there is little consistency in the recruitment pulses as apparent in the length frequency plots, the work that follows considers only the general population pulses, which are assumed to include recruitment pulses, as estimated from the CPUE.

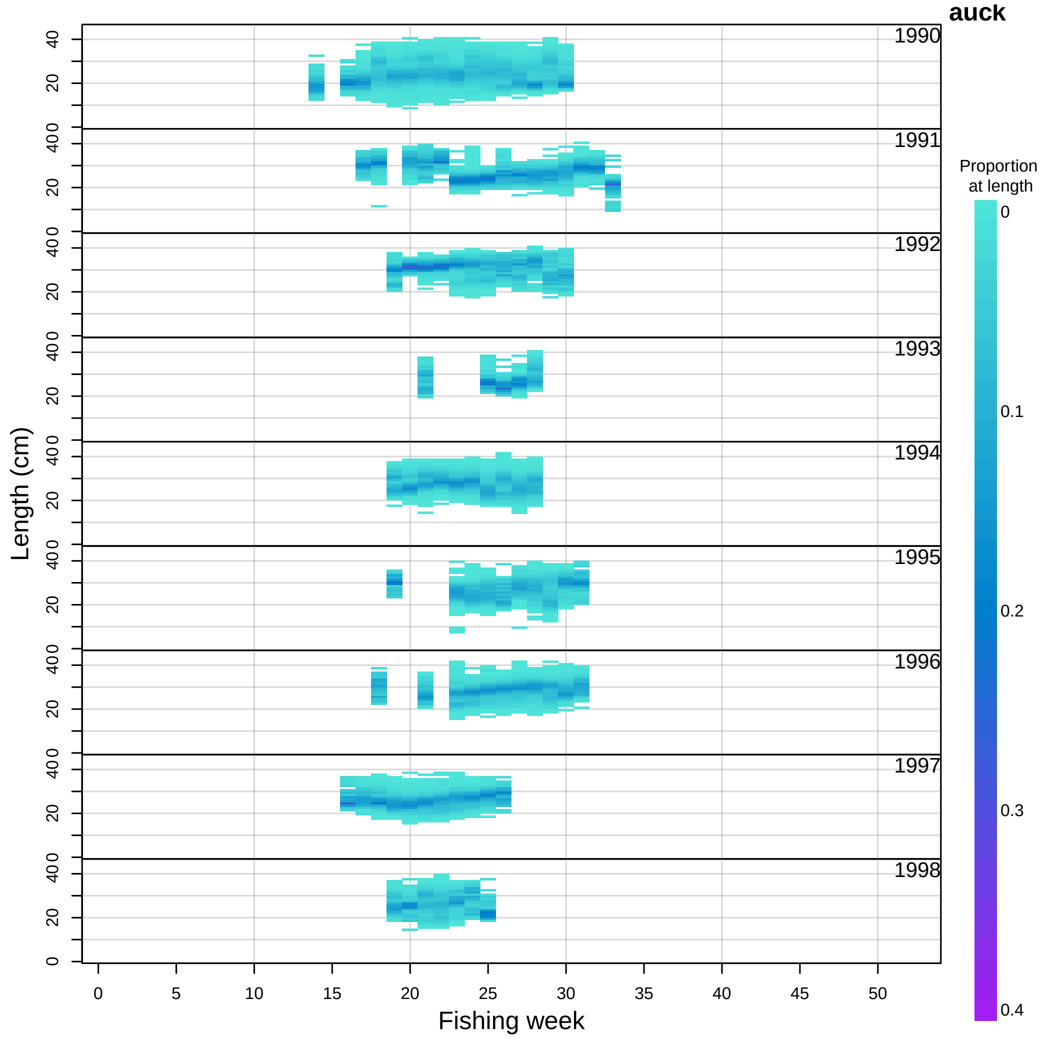


Figure 17: Length frequency plots for the Auckland Islands fisheries observer data for fishing years 1990–1998. Colour indicates the proportion at each length for each fishing week (zero starting at very light blue, through to purple for 0.4).

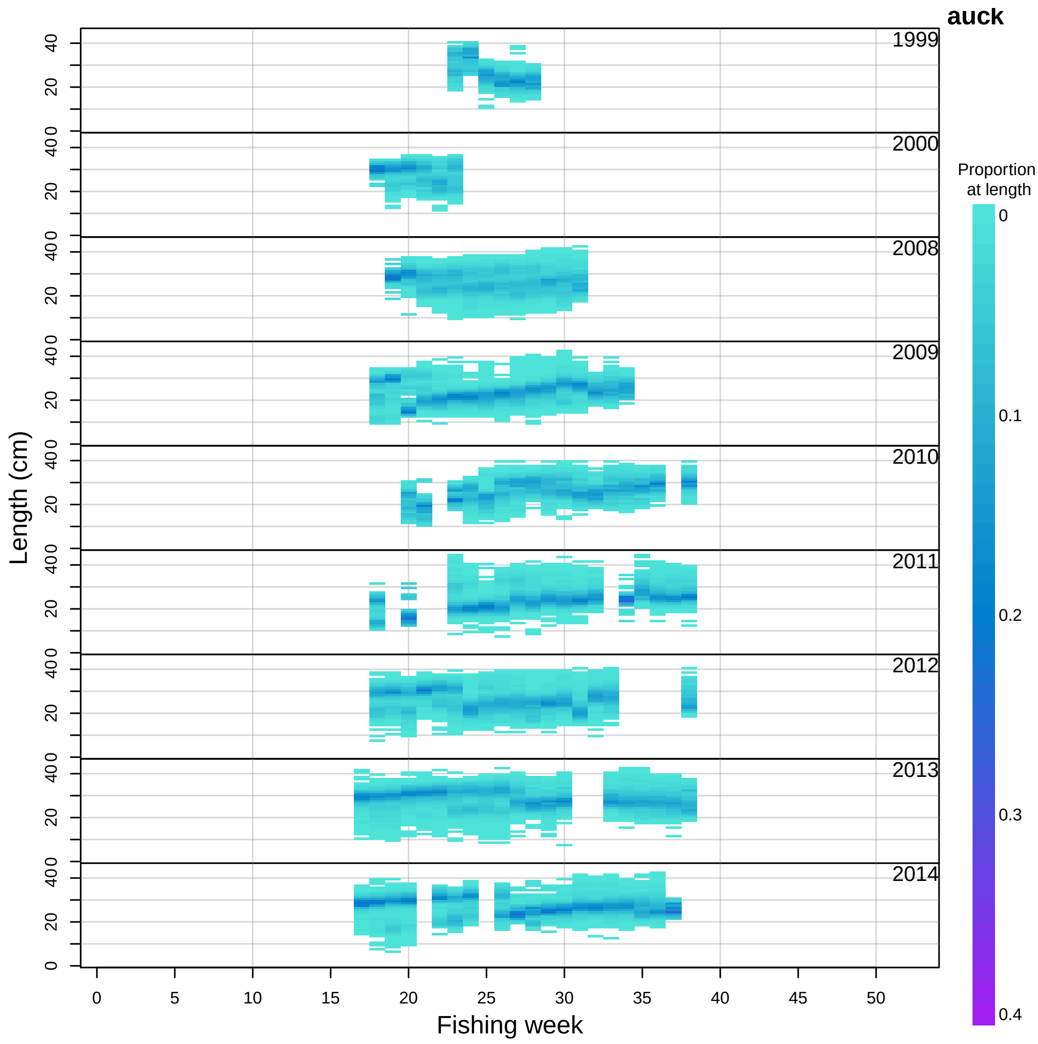


Figure 18: Length frequency plots for the Auckland Islands fisheries observer data for fishing years 1999–2014. Colour indicates the proportion at each length for each fishing week (zero starting at very light blue, through to purple for 0.4).

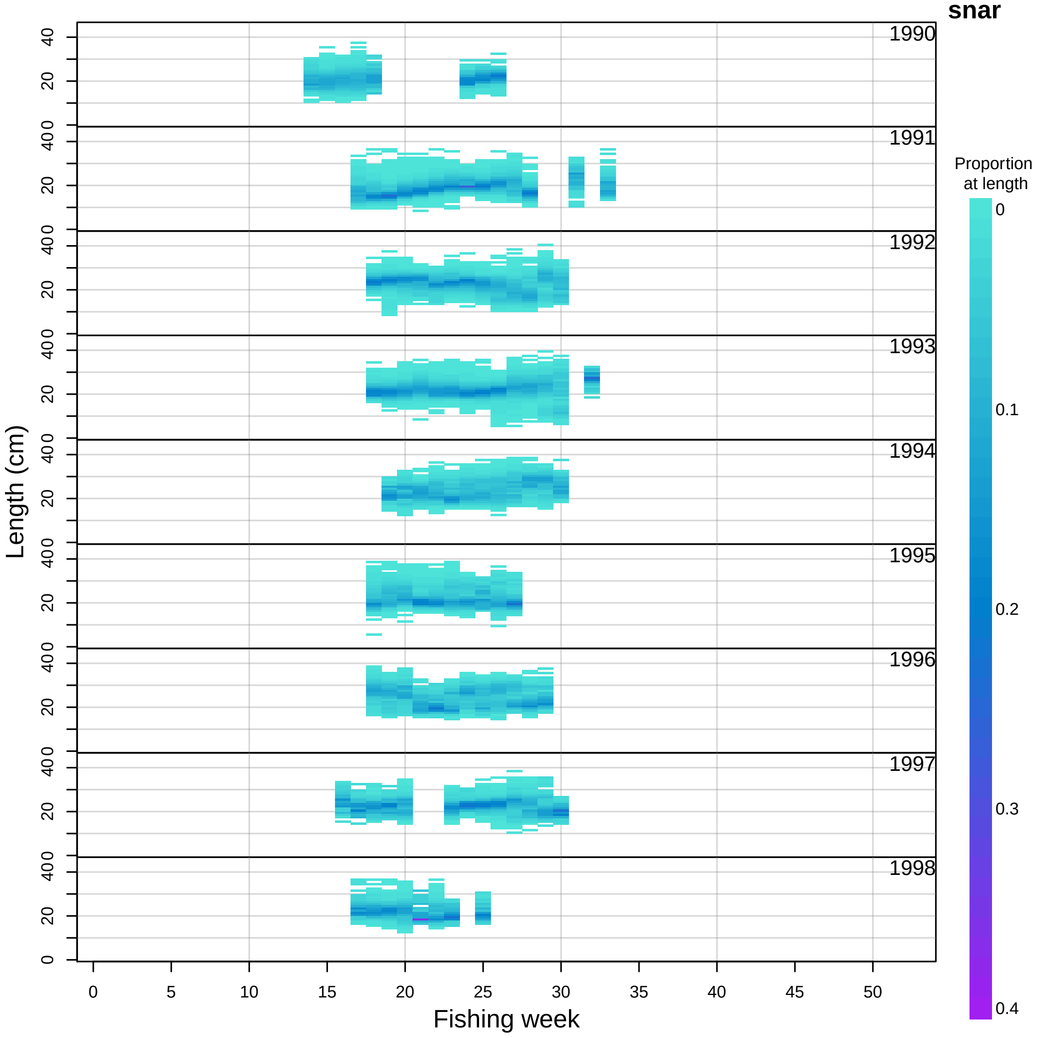


Figure 19: Length frequency plots for the Snares fisheries observer data for fishing years 1990–1998. Colour indicates the proportion at each length for each fishing week (zero starting at very light blue, through to purple for 0.4).

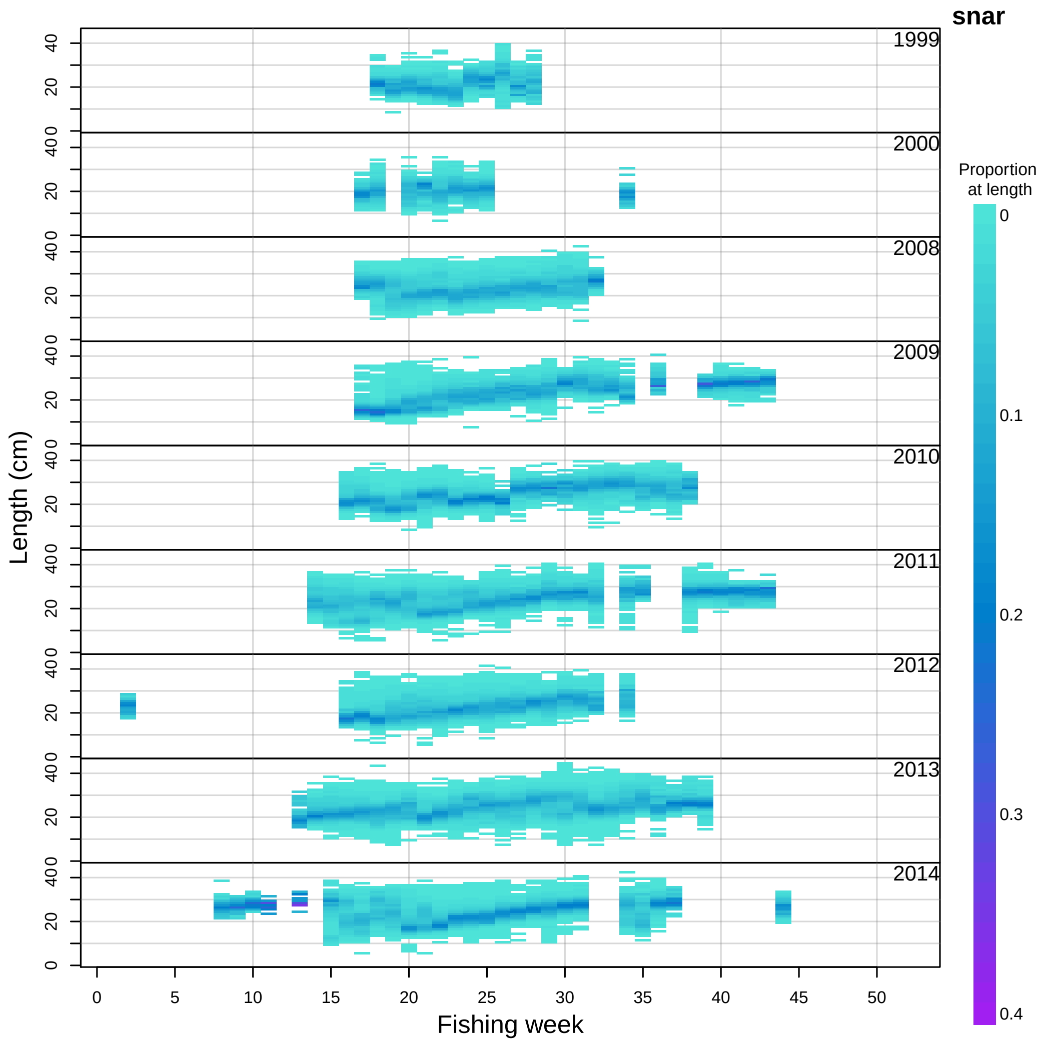


Figure 20: Length frequency plots for the Snares fisheries observer data for fishing years 1999–2014. Colour indicates the proportion at each length for each fishing week (zero starting at very light blue, through to purple for 0.4).

2.4. Depletion model

The depletion model is based on that used for the *L. gahi* fishery in the Falkland Islands (Roa-Ureta & Arkhipkin, 2007). It requires CPUE, catches, natural mortality, and timing of population pulses as inputs. It estimates abundance and catchability (Equation 2, Table 6). For each fishing year and area combination, we fitted the depletion model at the conclusion of each week to mimic modelling the fishery in real time.

$$CPUE_t = q\left(N_0 e^{-Mt} + \sum_j \left[P_j \mathbb{I}_{D_j<t} e^{-M(t-D_j)}\right] - e^{-M/2}\sum_{i=1}^{t-1}\left[C_i e^{-M(t-i-1)}\right]\right) e^{-M/2} \qquad (2)$$

$$\mathbb{I}_{D_j<t} = \begin{cases} 1, & D_j \leq t; \\ 0, & otherwise. \end{cases}$$

Table 6: Parameters in the depletion model.

Parameter	Description	Model Input	Model Estimate
$CPUE_t$	CPUE (numbers/hour) for the t^{th} time step	Yes	No
C_i	Catch (numbers) for the i^{th} time step	Yes	No
N_0	Initial numbers	No	Yes
P_j	Population pulse (in numbers) for the j^{th} population pulse	No	Yes
D_j	Timing (day) of the j^{th} population pulse	Yes	No
M	Natural mortality	Yes	No
q	Catchability	No	Yes

Depletion was calculated from the model estimates, following (Equation 3), where population was in numbers.

$$1 - \frac{Population|fishing}{Population|nofishing} \qquad (3)$$

3. Results

3.1. Population pulses

The timings of population pulses were generally estimated to be earlier in the season for the Snares than the Auckland Islands (Figure 21), which was expected given that the Snares fishery generally started earlier. The numbers estimated to enter the fishery were generally much greater for the Snares fishery than for the Auckland Islands fishery, which is most apparent in Figure 22. This figure also shows considerable inconsistencey between fishing years in the numbers estimated to enter the fishery —more so than the between year variation in landings would suggest (Figures 1 and 2). For example, the 2008 fishing year had fairly high catches from both areas, but the depletion model has estimated very low abundance into both fisheries compared to most other years. In contrast, the 2010 fishing year estimated very high abundance into the Snares fishery, but catches were much lower than those in 2008 for the Snares. If this were true it would suggest the catches had a much greater effect on the abundance (indicated by the CPUE) in 2008 than in 2010, but this does not appear to be the case (Figures 23, 24). It is possible that lack of consistency is due to a failure in the model to converge, even when a good fit to the data appears to have occurred.

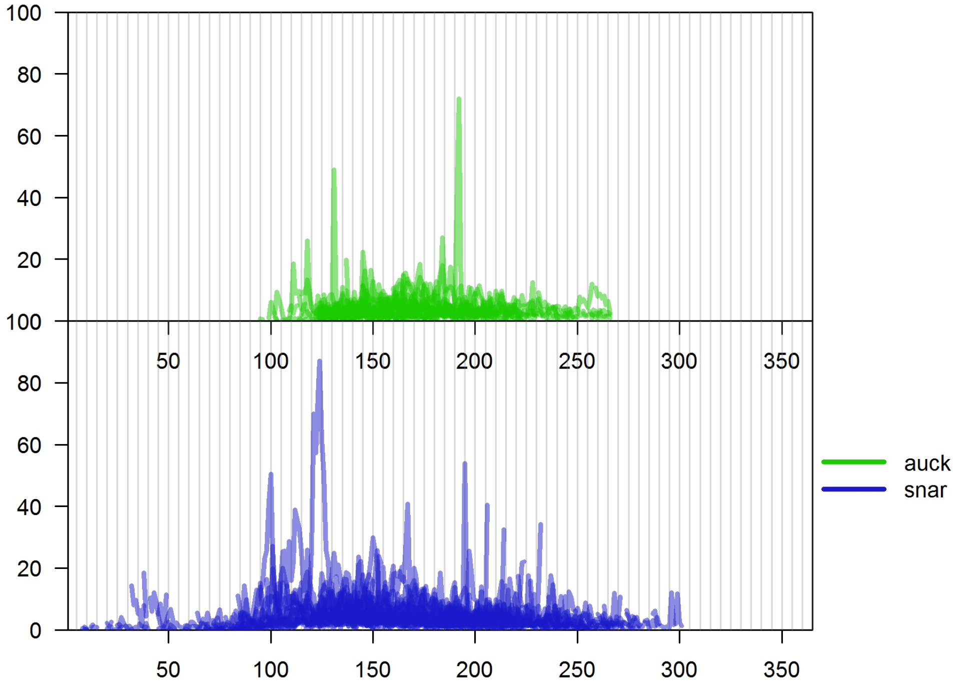


Figure 21: Population pulse abundance and timings for the Snares (blue) and the Auckland Islands (green) for fishing years 1990–2014.

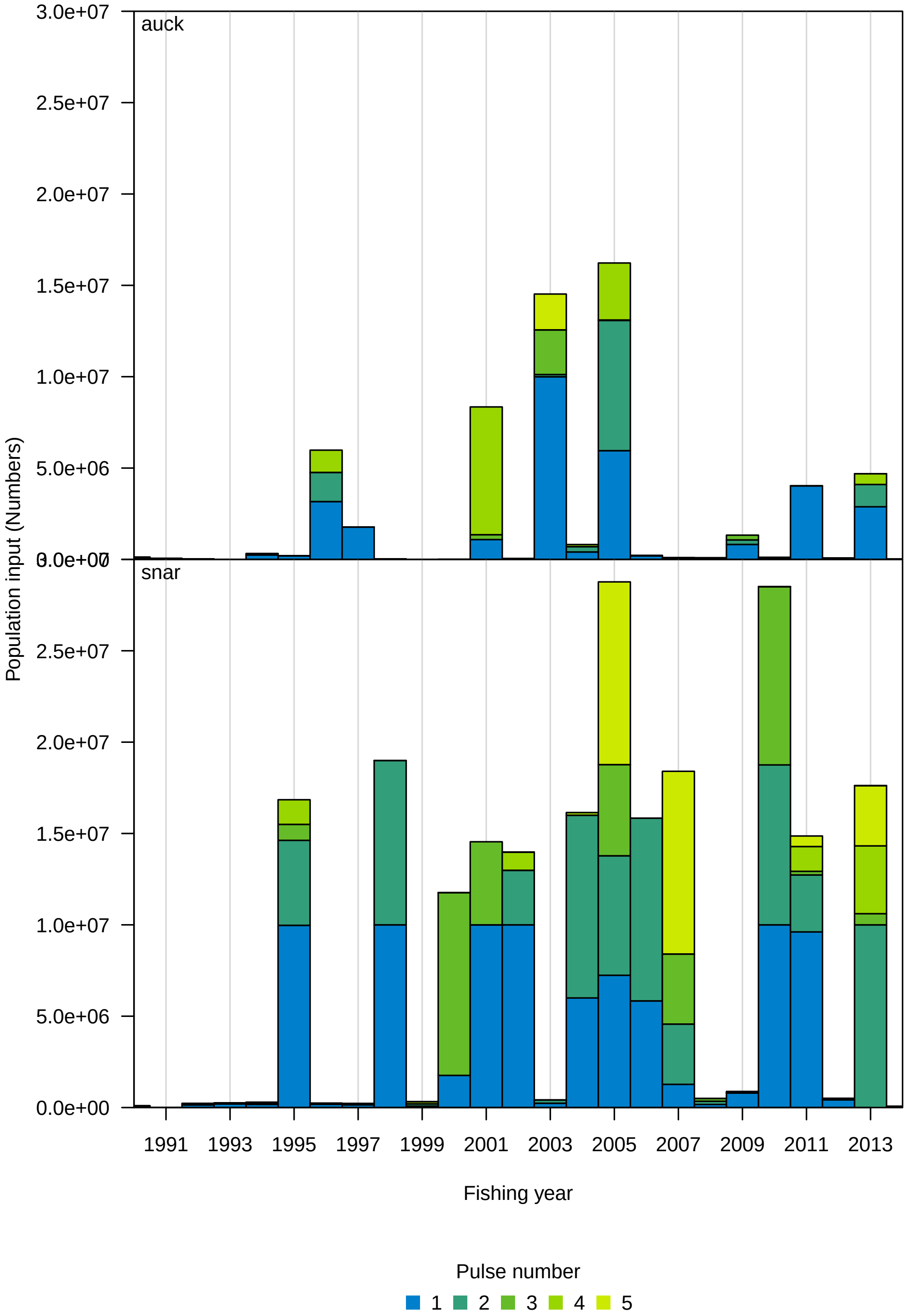


Figure 22: Abundance (numbers) estimated for population pulses by the depletion model for the Auckland Islands (top) and the Snares (bottom) for fishing years 1990–2014.

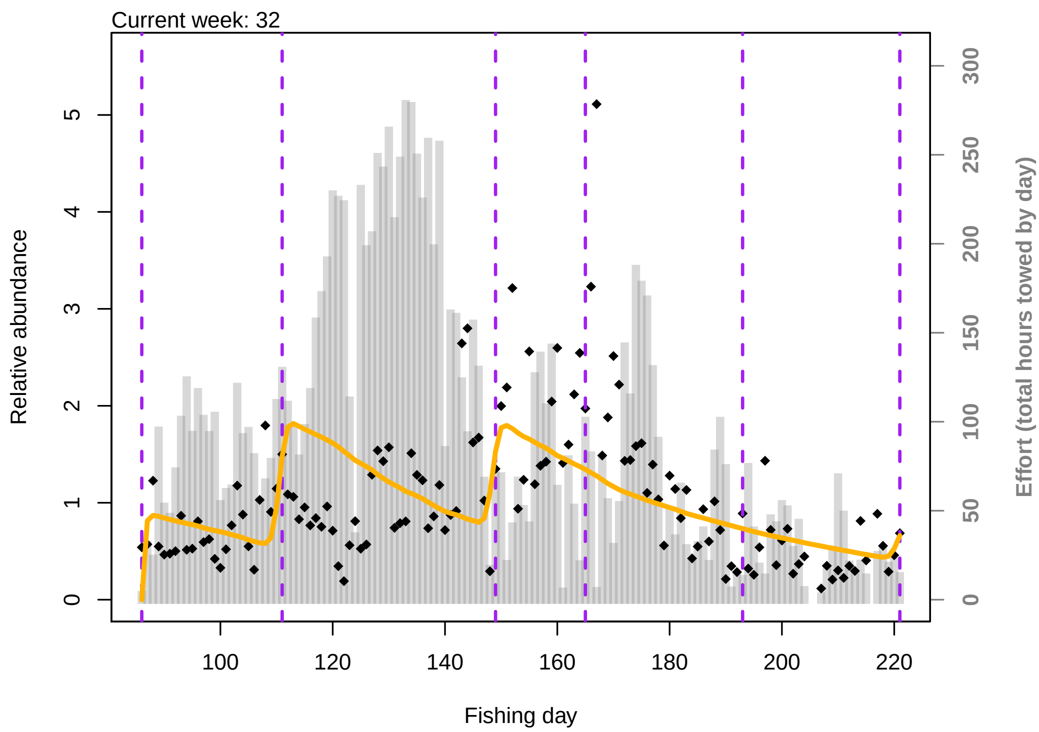


Figure 23: Relative CPUE (black dots), expected relative abundance from the depletion model (orange line), timings of population pulses (purple dashed lines), observed effort (grey bars) for the Snares 2008 fishery.

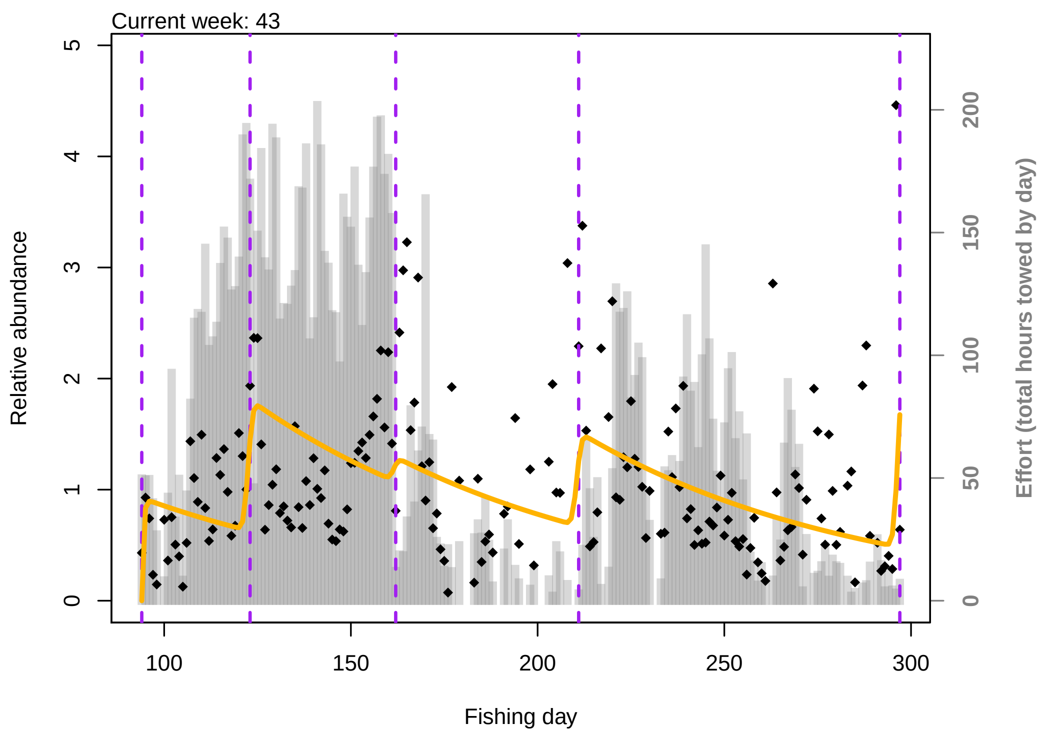


Figure 24: Relative CPUE (black dots), expected relative abundance from the depletion model (orange line), timings of population pulses (purple dashed lines), observed effort (grey bars) for the Snares 2010 fishery.

3.2. Model ability to fit the data

The model failed to fit to the data for many of the year/area/week datasets (Figure 25), where week is the last week included in the dataset, mimicking fitting the model in real-time. There were cases where convergence occurred when some weeks were included in the data, and failed when an additional week was added, such as the Auckland Islands, 2009. In such cases, including an additional week may have confused the signal from the data, resulting in failure of the model to converge.

When the model did fit to the data, the estimated catches matched the observed catches well (Figure 26 is an example, further examples are in Appendix D).

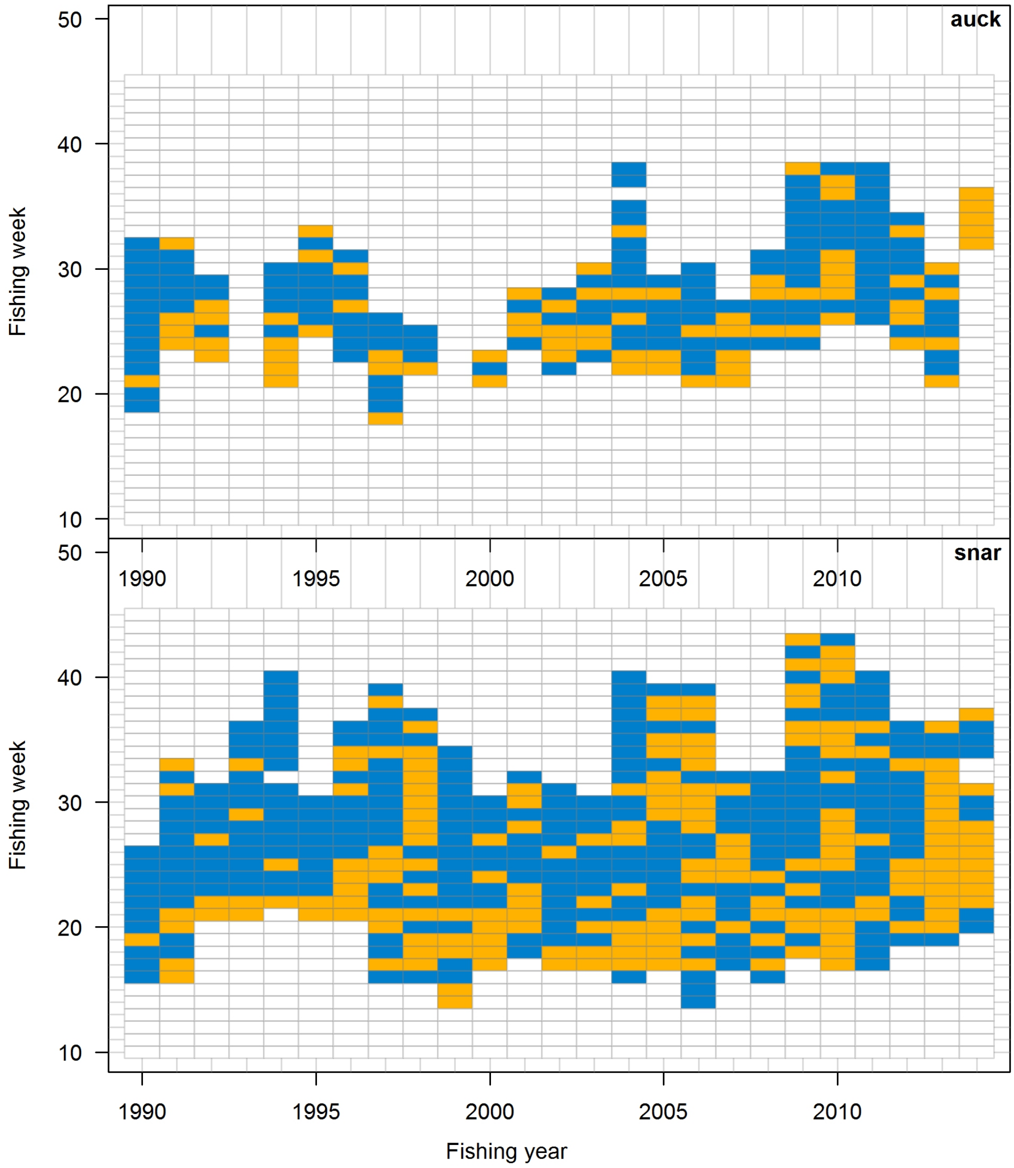


Figure 25: Summary of model convergence for the Auckland Islands (top) and the Snares (bottom) for all years. Models that converged are shown in blue, models that did not converge are shown in orange, and models that were not attempted due to insufficient catch and effort data are white. The fishing year and fishing week axes line up with the centre points of the polygons to which they relate.

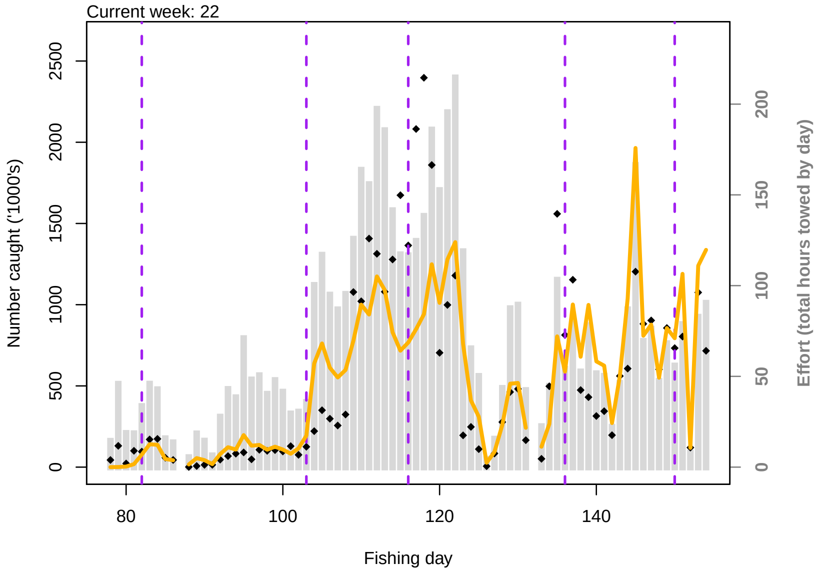


Figure 26: Estimated catch (orange line), actual catch (black dots) and effort (grey bars) for the Snares 2007, up to and including fishing week 22. Fishing week 1 corresponds to the first week in October and fishing day 1 to the 1st of October.

3.3. Depletion

The depletions as fitted in mimicked real time generally converged well throughout the season (example in Figure 27, the full set in Appendix E).

The estimated depletions varied greatly across the years and between areas. For many of the years and both areas the model estimated the depletion to have exceeded 40% and some even exceeded 60% and 80% (Figure 28). In some cases, depletion remains close to zero for the entire season. Where this has occurred it is likely that the CPUE is fairly flat, suggesting that removing the catches from the population had little effect on the population, hence the population must have been fairly high. This can also happen when there is a lot of noise in the CPUE or a time-series that is not long enough to detect any decreases in the CPUE.

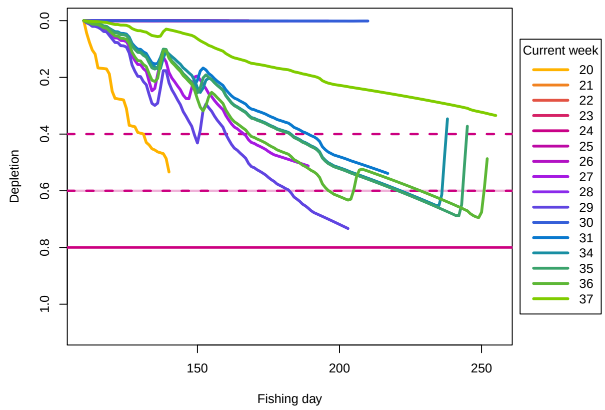


Figure 27: Estimated depletion from the model as it moved through the fishing season mimicking real time, for the Snares 2014. Red horizontal lines mark 80%, 60% and 40% depletion.

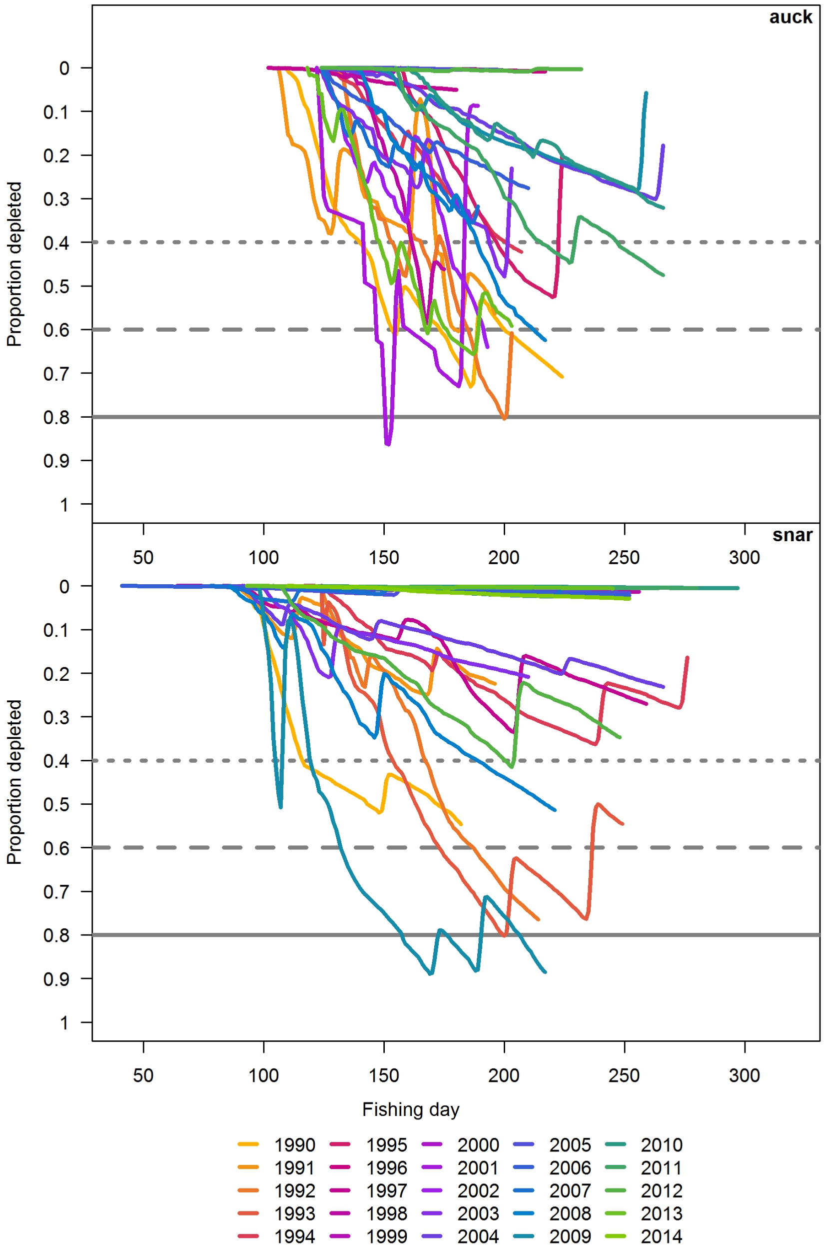


Figure 28: Summary of depletion estimated for the Auckland Islands (top) and the Snares (bottom) for all years. Grey horizontal lines mark 80%, 60% and 40% depletion.

4. Discussion

The model applied here struggled to fit to the data for many of the datasets. A typical season is quite short, so there is not a very long time-series of data for the model to get enough signal to converge correctly, estimating the parameters that provide the best fit to the data. It is possible that there are multiple solutions that give very similar results. Further, even when the model converged, inconsistencies in abundance estimates between seasons suggest that true global maxima may not have been reached in all cases. This model has been adapted from that used in the Falkland Islands, where it is successfully used to manage squid stocks in-season. The Falkland Islands have a pre-season survey which is used to inform the prior on initial abundance, which we do not have for the Auckland Islands or the Snares. It is likely that an informative prior on initial abundance greatly improves the ability of the model to optimise correctly. In the absence of a pre-season survey, it seems necessary to help inform the model in some other way.

A possible connection between pre-season chlorophyll records and catches of squid from the Auckland Islands has been found (Jim Roberts (NIWA), *pers. comm.*). Further investigation into this relationship may provide sufficient information for a prior on initial abundance in the Auckland Islands. The Auckland Islands generally has a shorter fishing season than the Snares, and hence is most problematic for model optimisation. It may be there is also a link between chlorophyll or some other environmental indicator and abundance in the Snares.

Length frequency distributions from fisheries observers may be useful for informing the timing of recruitment pulses within a season. However, while signals from length frenquency distributions were sometimes quite clear, they lack any pattern or consistency between seasons and areas. It is possible that this data may be more informative with more information on the biology and ecology of *N. sloanii* in New Zealand, in particular when and where they spawn, growth rates, and migration. The use of a constant mean weight for years without length data (2000–01 to 2006–07) limits the value of analyses for those years.

5. Acknowledgments

We thank John Barton (Director of Natural Resources) and Andreas Winter (Falkland Islands Fisheries Department) for generously providing us with the program code for the current Falkland Islands *Loligo gahi* depletion model, the Ministry for Primary Industries for funding the project under Project code DEE2014-03 and Andy McKenzie for reviewing the report.

6. References

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McGregor, V.; Tingley, G. (2016). A preliminary evaluation of depletion modelling to assess New Zealand squid stocks. *New Zealand Fisheries Assessment Report 2016/25*.

Roa-Ureta, R.H. (2012). Modelling in-season pulses of recruitment and hyperstability-hyperdepletion in the *Loligo gahi* fishery around the Falkland Islands with generalized depletion models.*ICES Journal of Marine Science 69:*. 1403–1415.

Roa-Ureta, R.H.; Arkhipkin, A. (2007). Short-term stock assessment of *Loligo gahi* at the Falkland Islands: sequential use of stochastic biomass projection and stock depletion models. *ICES Journal of Marine Science 64:*3–17

Appendix

.1. Appendix A CPUE Diagnostic Plots

.1.1. Auckland Islands

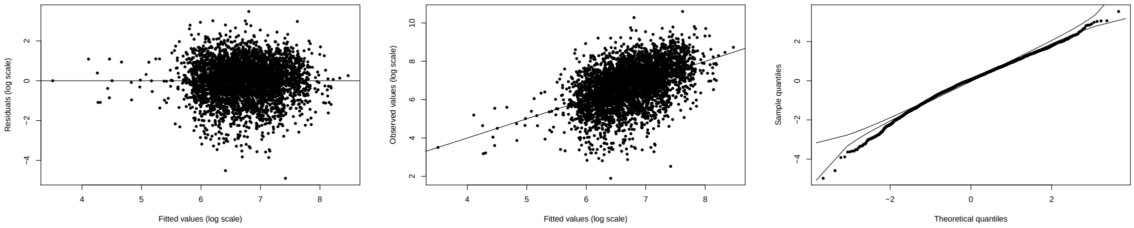

Figure A1: Diagnostic plots for CPUE model for Auckland Islands 1990, up to and including fishing week 35. Fishing week 1 corresponds to the first week in October.

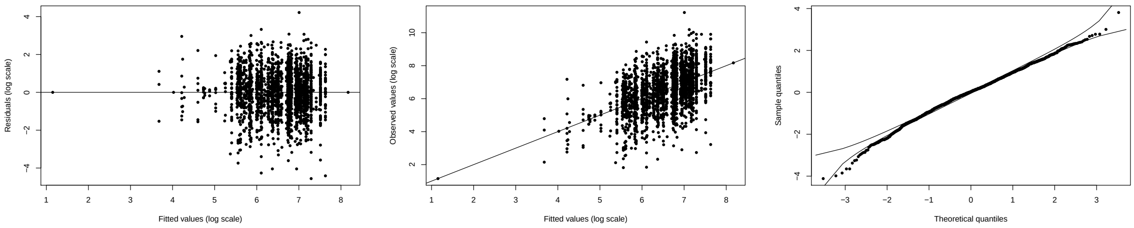

Figure A2: Diagnostic plots for CPUE model for Auckland Islands 1991, up to and including fishing week 37. Fishing week 1 corresponds to the first week in October.

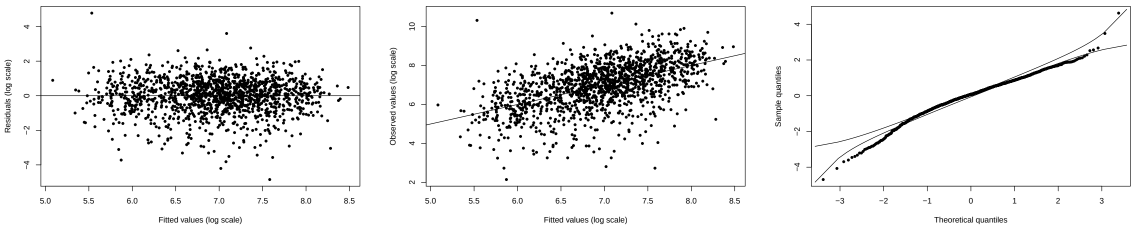

Figure A3: Diagnostic plots for CPUE model for Auckland Islands 1992, up to and including fishing week 31. Fishing week 1 corresponds to the first week in October.

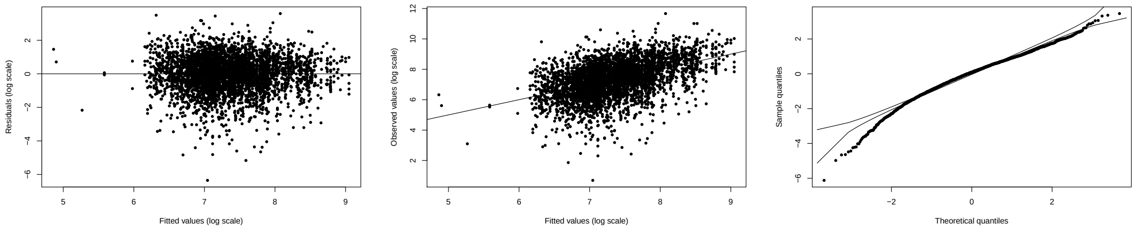

Figure A4: Diagnostic plots for CPUE model for Auckland Islands 1994, up to and including fishing week 34. Fishing week 1 corresponds to the first week in October.

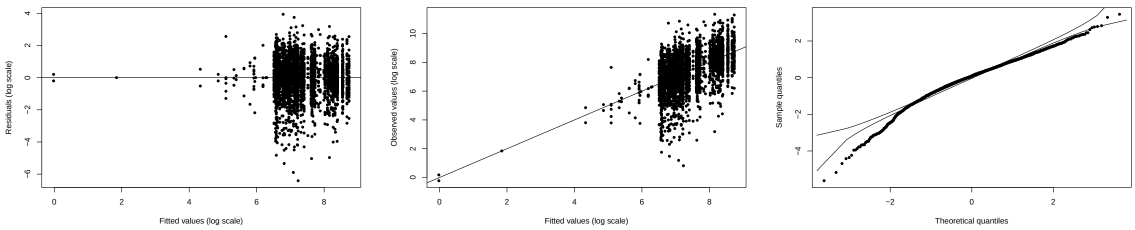

Figure A5: Diagnostic plots for CPUE model for Auckland Islands 1995, up to and including fishing week 34. Fishing week 1 corresponds to the first week in October.

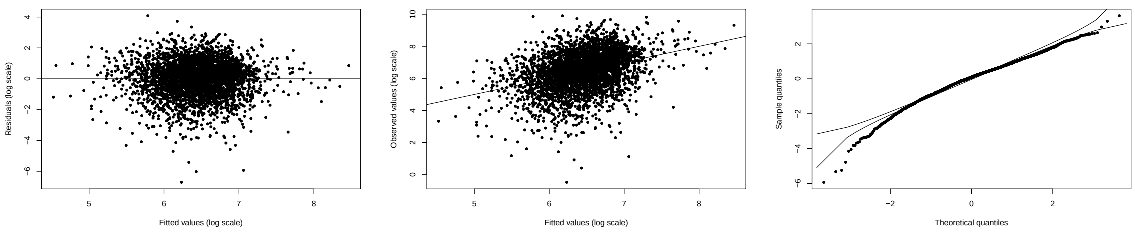

Figure A6: Diagnostic plots for CPUE model for Auckland Islands 1996, up to and including fishing week 31. Fishing week 1 corresponds to the first week in October.

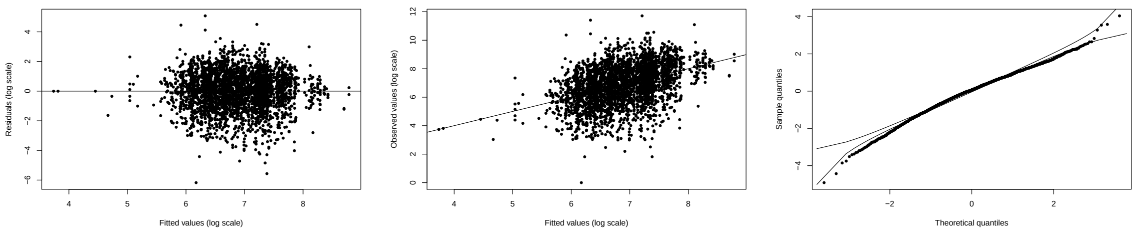

Figure A7: Diagnostic plots for CPUE model for Auckland Islands 1997, up to and including fishing week 26. Fishing week 1 corresponds to the first week in October.

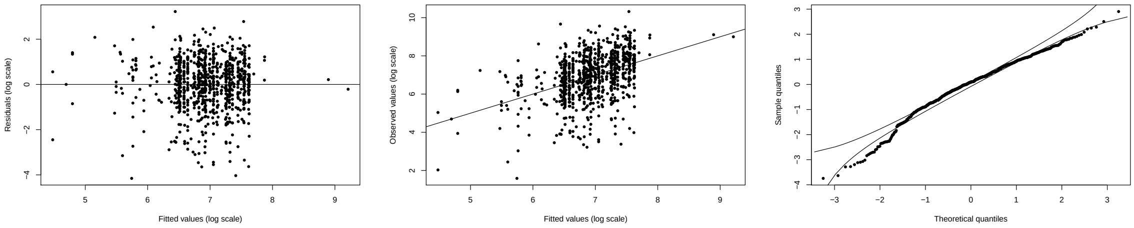

Figure A8: Diagnostic plots for CPUE model for Auckland Islands 1998, up to and including fishing week 27. Fishing week 1 corresponds to the first week in October.

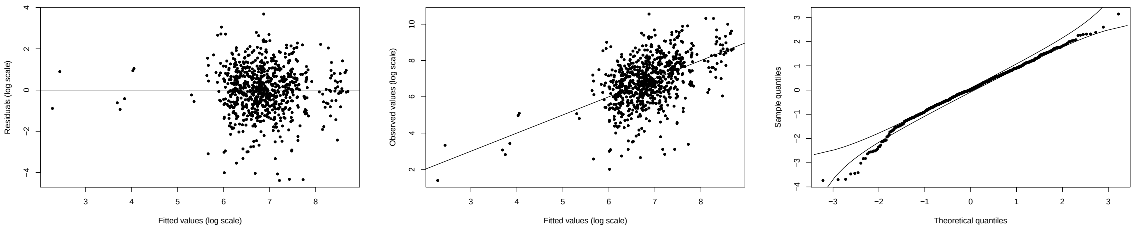

Figure A9: Diagnostic plots for CPUE model for Auckland Islands 2000, up to and including fishing week 23. Fishing week 1 corresponds to the first week in October.

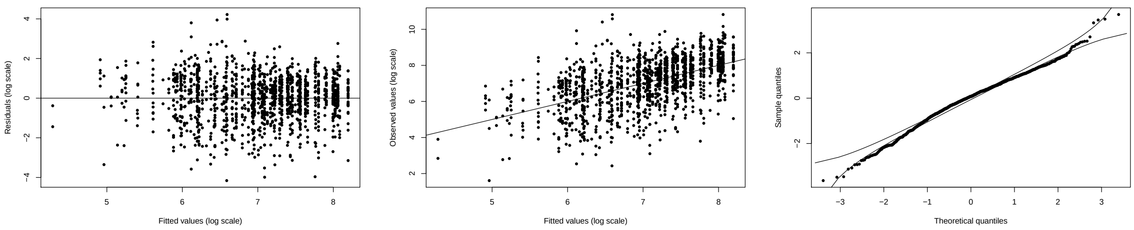

Figure A10: Diagnostic plots for CPUE model for Auckland Islands 2002, up to and including fishing week 28. Fishing week 1 corresponds to the first week in October.

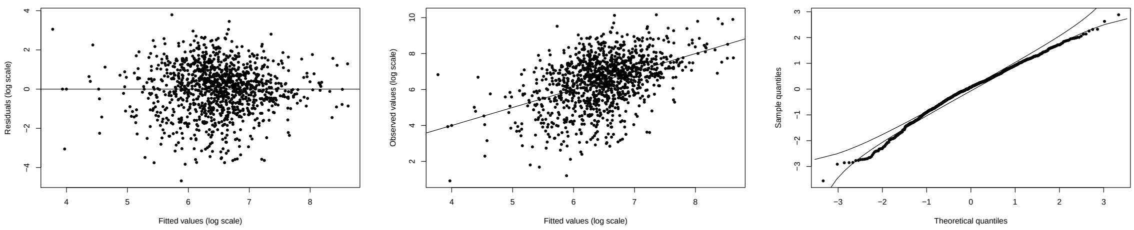

Figure A11: Diagnostic plots for CPUE model for Auckland Islands 2003, up to and including fishing week 39. Fishing week 1 corresponds to the first week in October.

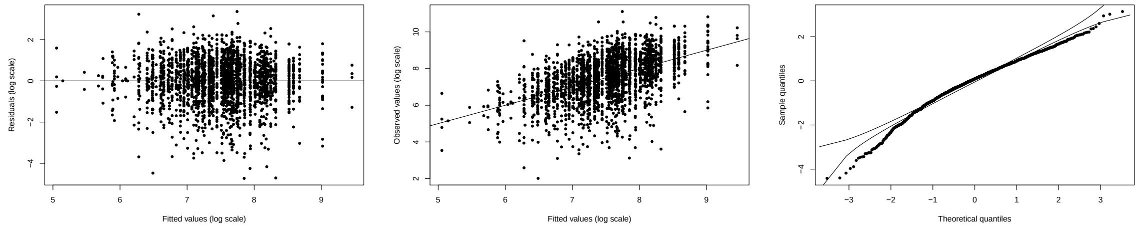

Figure A12: Diagnostic plots for CPUE model for Auckland Islands 2004, up to and including fishing week 41. Fishing week 1 corresponds to the first week in October.

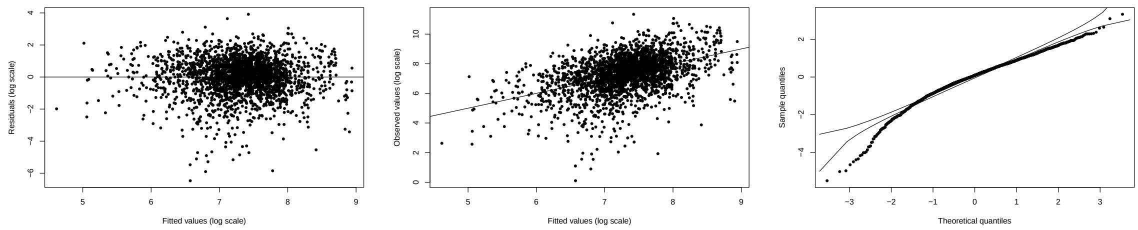

Figure A13: Diagnostic plots for CPUE model for Auckland Islands 2005, up to and including fishing week 29. Fishing week 1 corresponds to the first week in October.

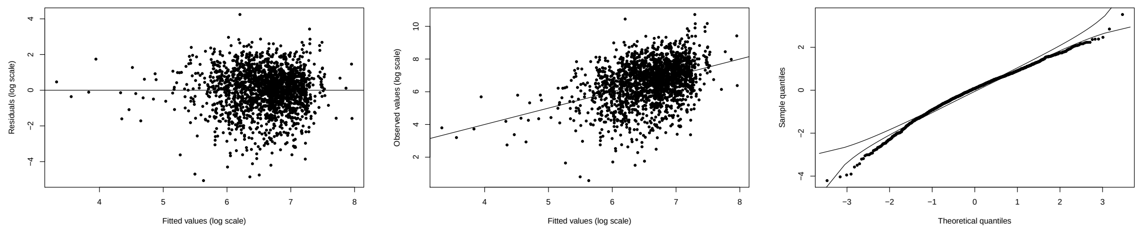

Figure A14: Diagnostic plots for CPUE model for Auckland Islands 2006, up to and including fishing week 30. Fishing week 1 corresponds to the first week in October.

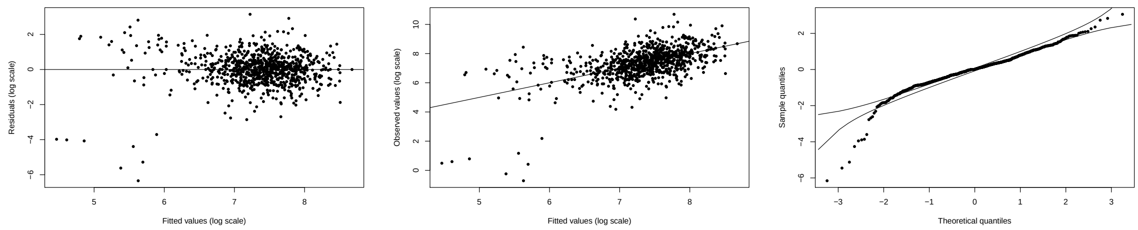

Figure A15: Diagnostic plots for CPUE model for Auckland Islands 2007, up to and including fishing week 30. Fishing week 1 corresponds to the first week in October.

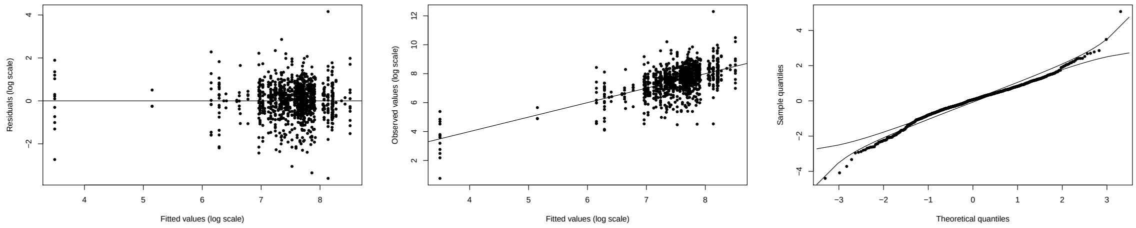

Figure A16: Diagnostic plots for CPUE model for Auckland Islands 2008, up to and including fishing week 31. Fishing week 1 corresponds to the first week in October.

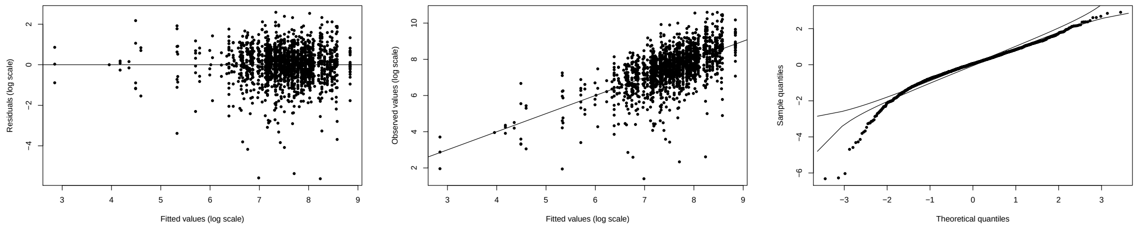

Figure A17: Diagnostic plots for CPUE model for Auckland Islands 2009, up to and including fishing week 42. Fishing week 1 corresponds to the first week in October.

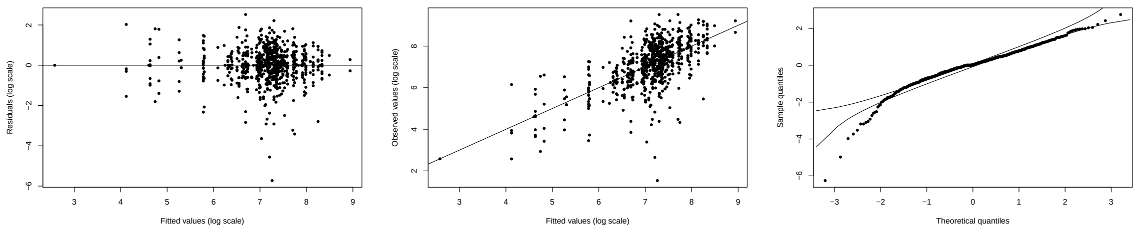

Figure A18: Diagnostic plots for CPUE model for Auckland Islands 2010, up to and including fishing week 42. Fishing week 1 corresponds to the first week in October.

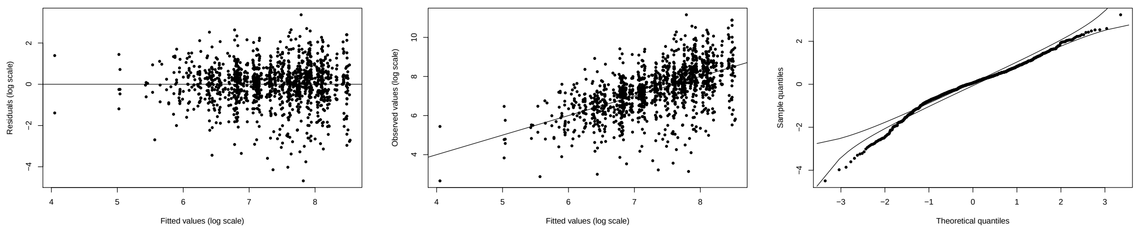

Figure A19: Diagnostic plots for CPUE model for Auckland Islands 2011, up to and including fishing week 38. Fishing week 1 corresponds to the first week in October.

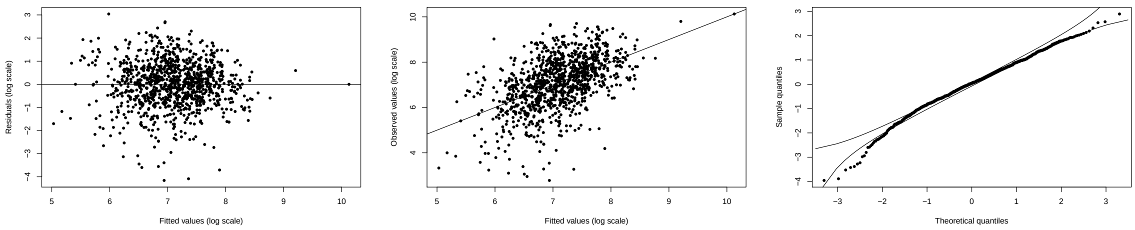

Figure A20: Diagnostic plots for CPUE model for Auckland Islands 2012, up to and including fishing week 39. Fishing week 1 corresponds to the first week in October.

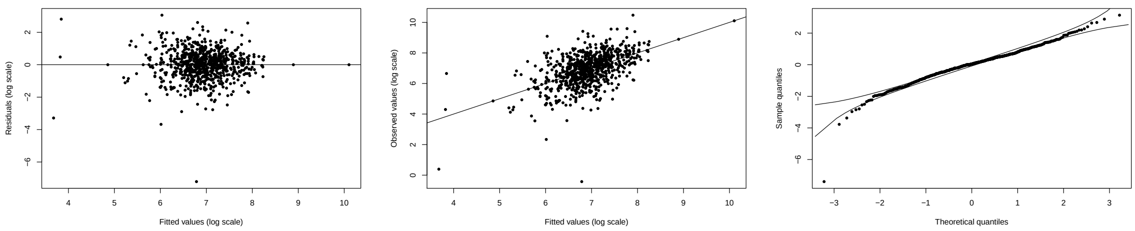

Figure A21: Diagnostic plots for CPUE model for Auckland Islands 2013, up to and including fishing week 38. Fishing week 1 corresponds to the first week in October.

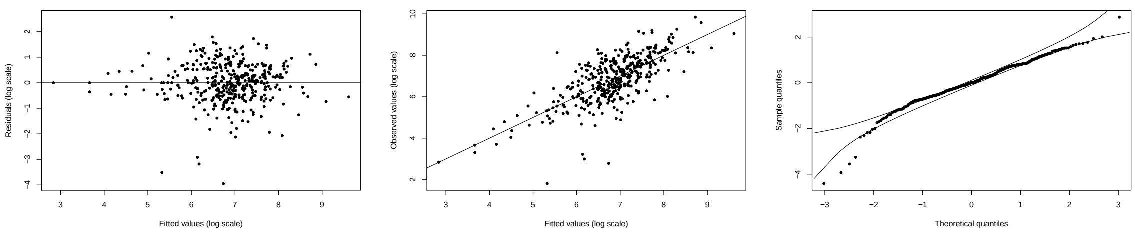

Figure A22: Diagnostic plots for CPUE model for Auckland Islands 2014, up to and including fishing week 37. Fishing week 1 corresponds to the first week in October.

.1.2. The Snares

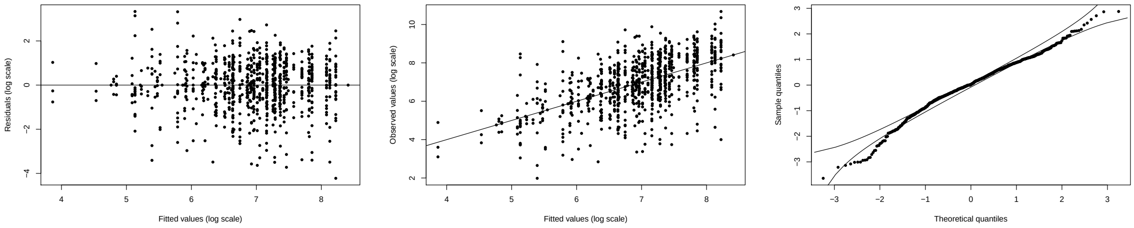

Figure A23: Diagnostic plots for CPUE model for the Snares 1990, up to and including fishing week 30. Fishing week 1 corresponds to the first week in October.

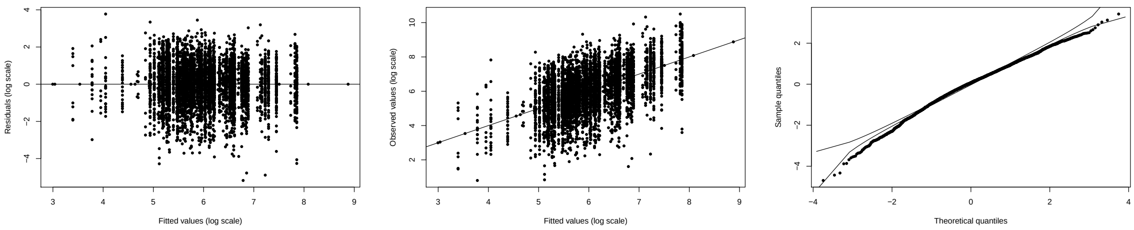

Figure A24: Diagnostic plots for CPUE model for the Snares 1991, up to and including fishing week 38. Fishing week 1 corresponds to the first week in October.

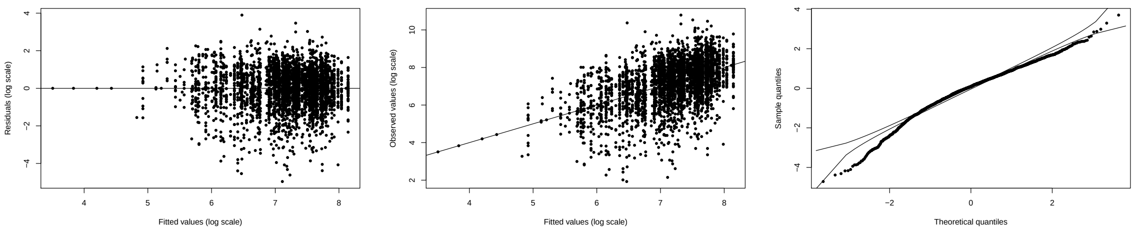

Figure A25: Diagnostic plots for CPUE model for the Snares 1992, up to and including fishing week 40. Fishing week 1 corresponds to the first week in October.

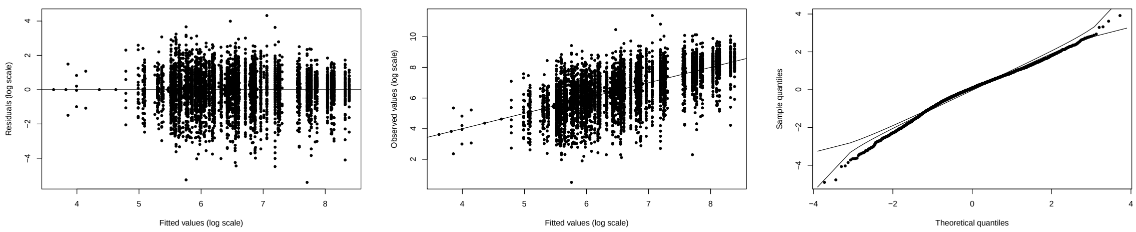

Figure A26: Diagnostic plots for CPUE model for the Snares 1993, up to and including fishing week 40. Fishing week 1 corresponds to the first week in October.

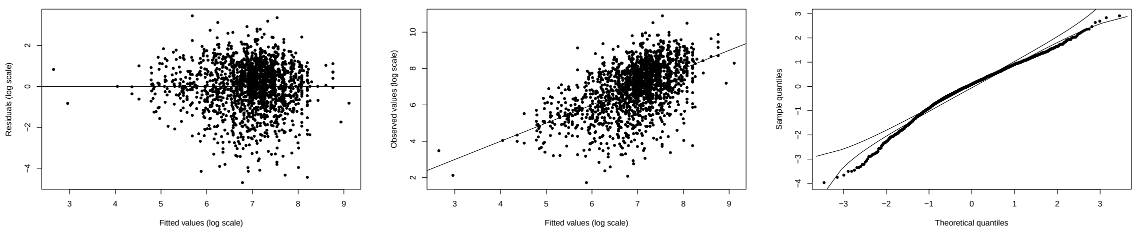

Figure A27: Diagnostic plots for CPUE model for the Snares 1994, up to and including fishing week 40. Fishing week 1 corresponds to the first week in October.

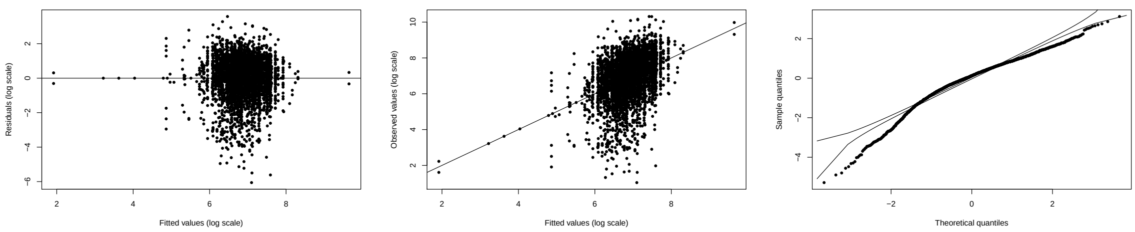

Figure A28: Diagnostic plots for CPUE model for the Snares 1995, up to and including fishing week 38. Fishing week 1 corresponds to the first week in October.

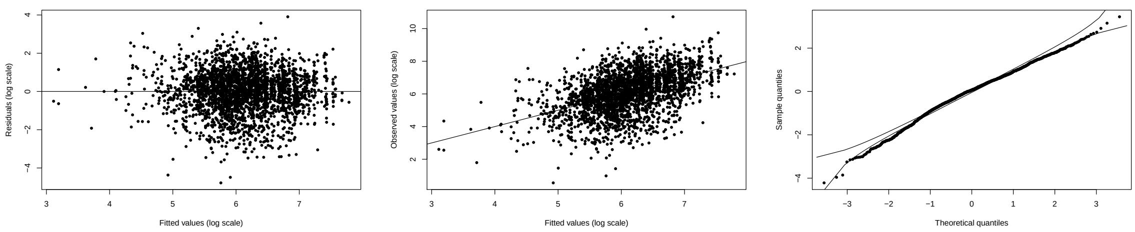

Figure A29: Diagnostic plots for CPUE model for the Snares 1996, up to and including fishing week 39. Fishing week 1 corresponds to the first week in October.

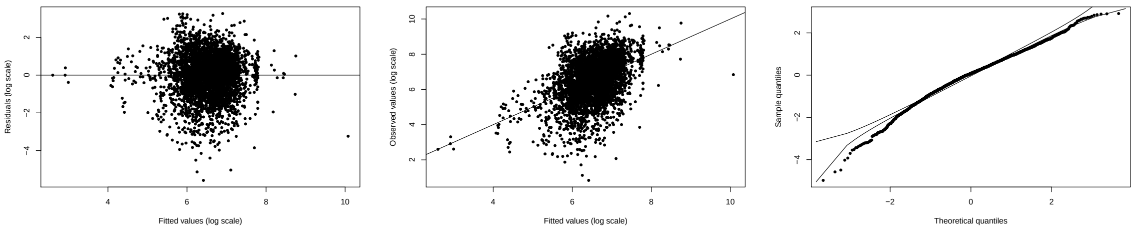

Figure A30: Diagnostic plots for CPUE model for the Snares 1997, up to and including fishing week 39. Fishing week 1 corresponds to the first week in October.

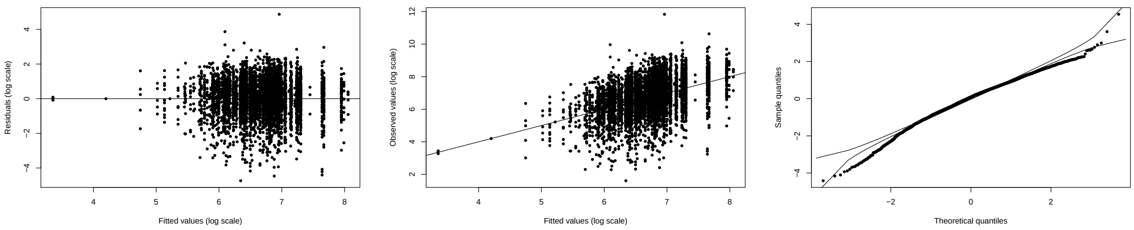

Figure A31: Diagnostic plots for CPUE model for the Snares 1998, up to and including fishing week 37. Fishing week 1 corresponds to the first week in October.

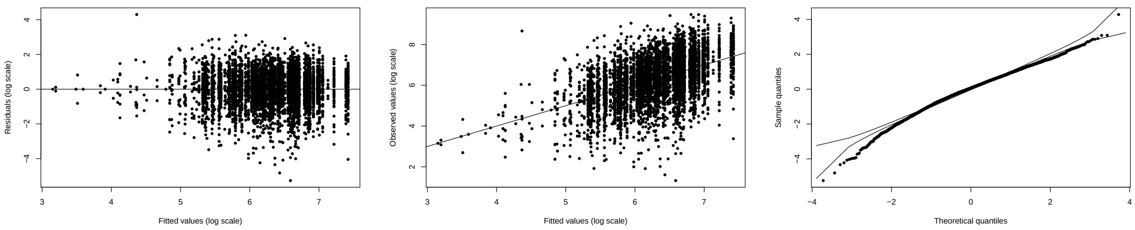

Figure A32: Diagnostic plots for CPUE model for the Snares 1999, up to and including fishing week 40. Fishing week 1 corresponds to the first week in October.

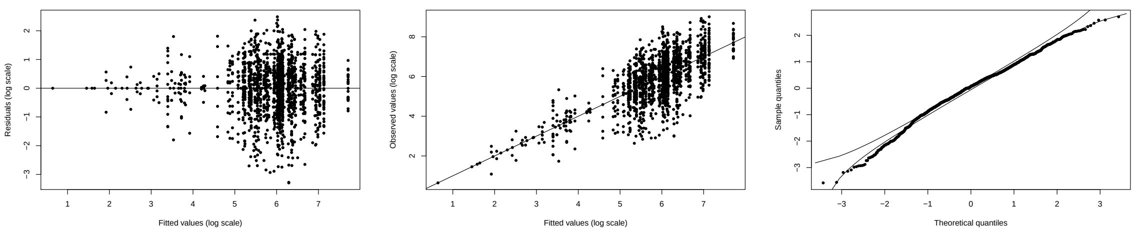

Figure A33: Diagnostic plots for CPUE model for the Snares 2000, up to and including fishing week 34. Fishing week 1 corresponds to the first week in October.

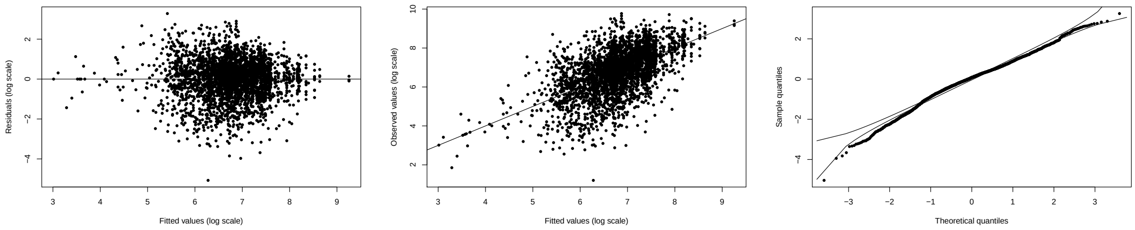

Figure A34: Diagnostic plots for CPUE model for the Snares 2001, up to and including fishing week 39. Fishing week 1 corresponds to the first week in October.

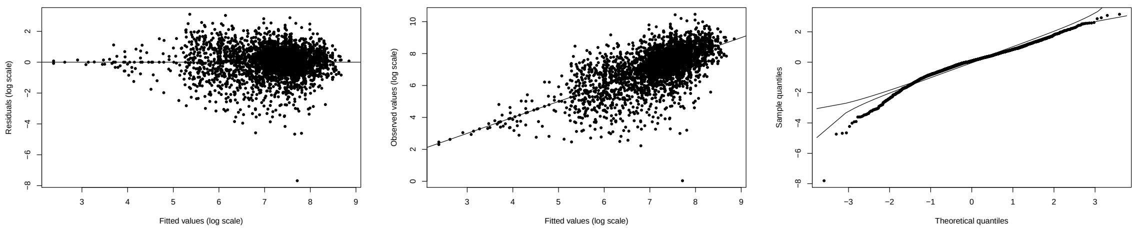

Figure A35: Diagnostic plots for CPUE model for the Snares 2002, up to and including fishing week 38. Fishing week 1 corresponds to the first week in October.

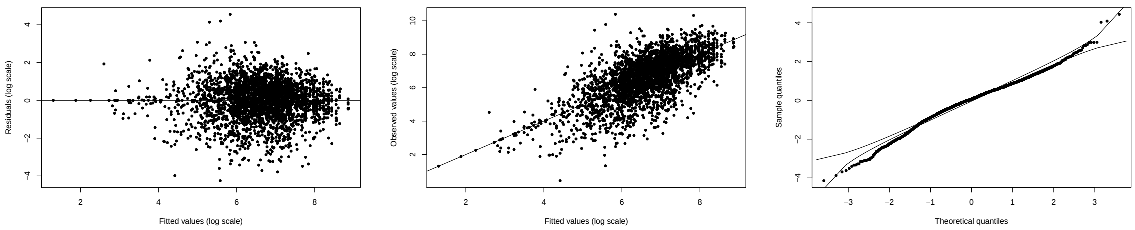

Figure A36: Diagnostic plots for CPUE model for the Snares 2003, up to and including fishing week 39. Fishing week 1 corresponds to the first week in October.

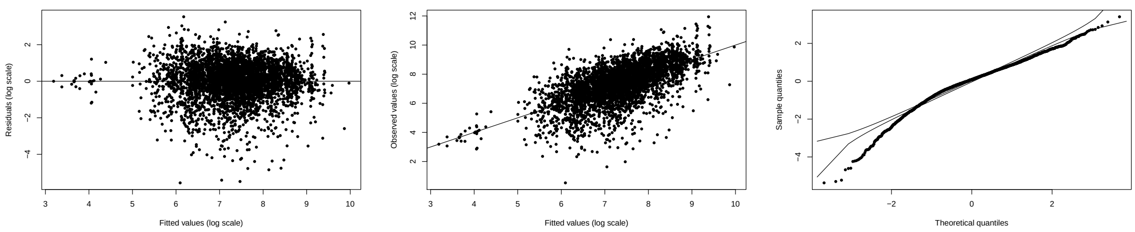

Figure A37: Diagnostic plots for CPUE model for the Snares 2004, up to and including fishing week 40. Fishing week 1 corresponds to the first week in October.

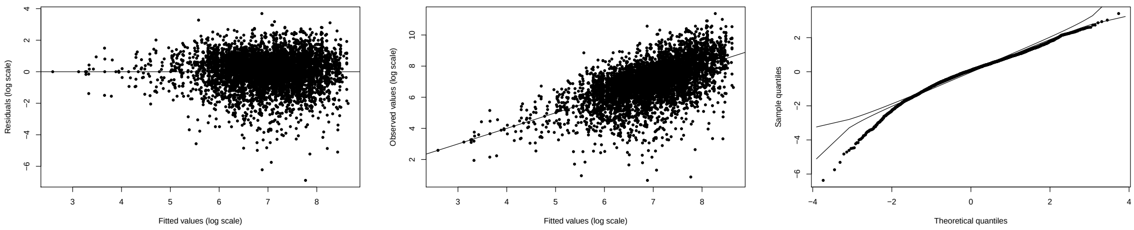

Figure A38: Diagnostic plots for CPUE model for the Snares 2005, up to and including fishing week 43. Fishing week 1 corresponds to the first week in October.

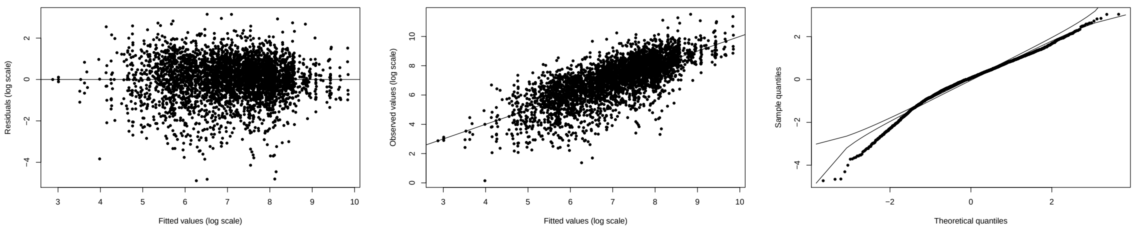

Figure A39: Diagnostic plots for CPUE model for the Snares 2006, up to and including fishing week 39. Fishing week 1 corresponds to the first week in October.

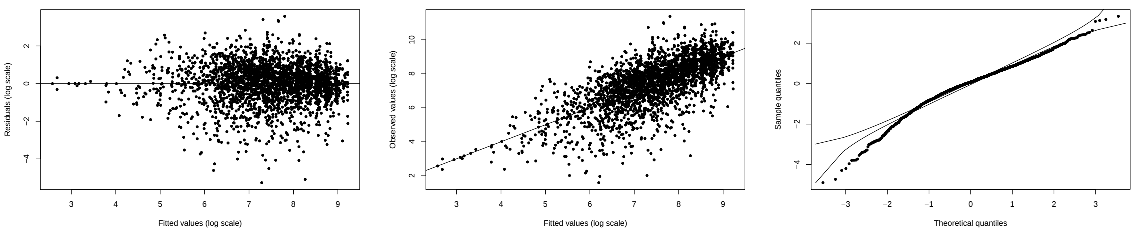

Figure A40: Diagnostic plots for CPUE model for the Snares 2007, up to and including fishing week 35. Fishing week 1 corresponds to the first week in October.

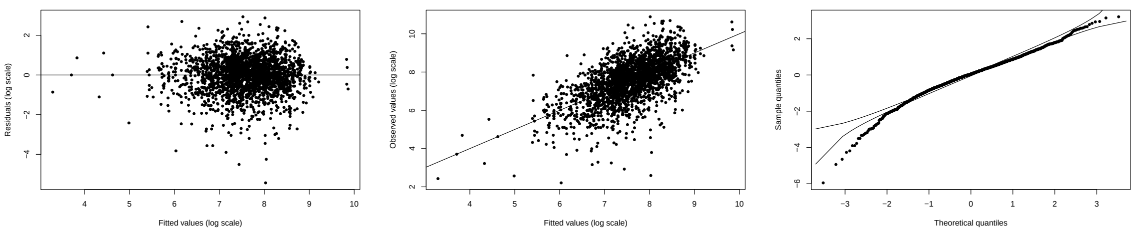

Figure A41: Diagnostic plots for CPUE model for the Snares 2008, up to and including fishing week 32. Fishing week 1 corresponds to the first week in October.

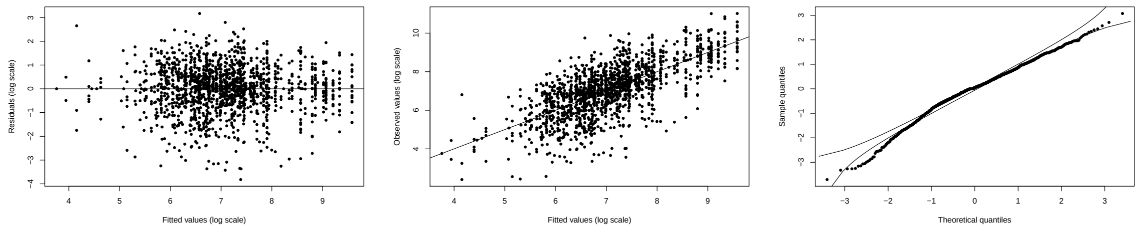

Figure A42: Diagnostic plots for CPUE model for the Snares 2009, up to and including fishing week 43. Fishing week 1 corresponds to the first week in October.

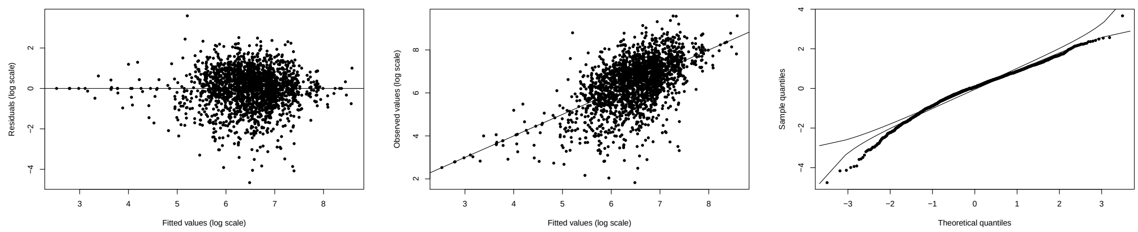

Figure A43: Diagnostic plots for CPUE model for the Snares 2010, up to and including fishing week 43. Fishing week 1 corresponds to the first week in October.

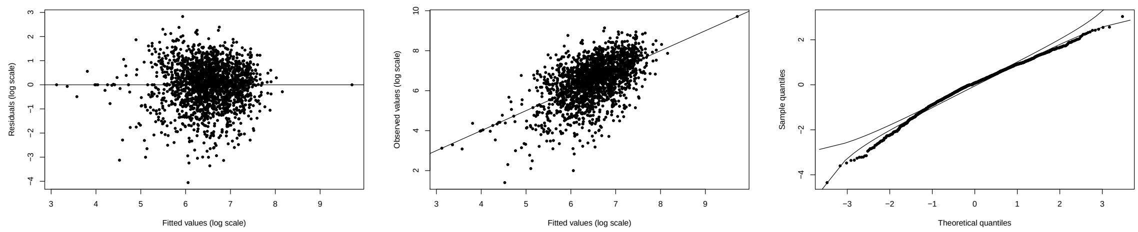

Figure A44: Diagnostic plots for CPUE model for the Snares 2011, up to and including fishing week 43. Fishing week 1 corresponds to the first week in October.

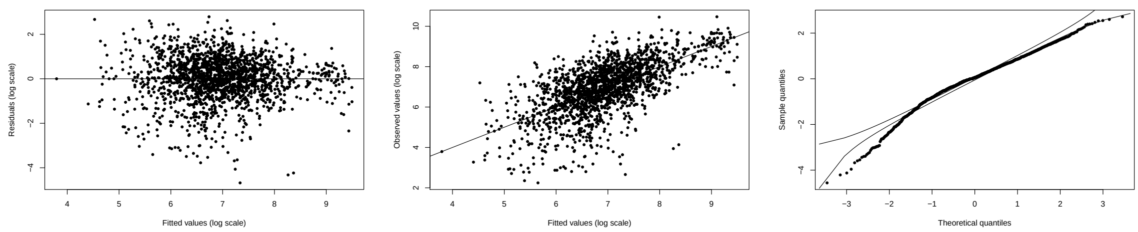

Figure A45: Diagnostic plots for CPUE model for the Snares 2012, up to and including fishing week 43. Fishing week 1 corresponds to the first week in October.

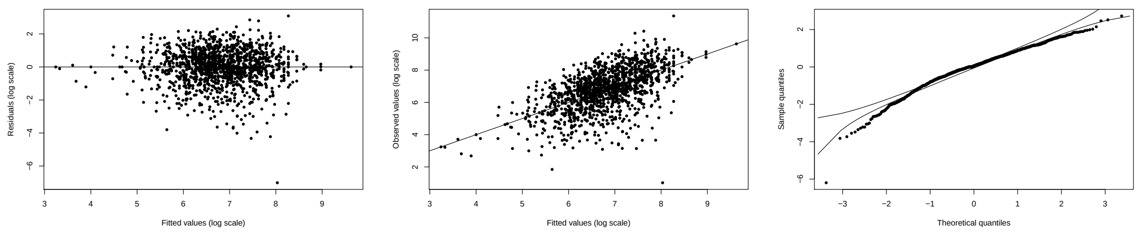

Figure A46: Diagnostic plots for CPUE model for the Snares 2013, up to and including fishing week 39. Fishing week 1 corresponds to the first week in October.

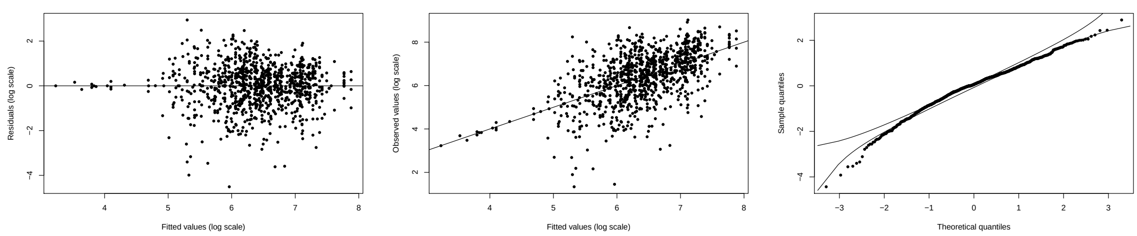

Figure A47: Diagnostic plots for CPUE model for the Snares 2014, up to and including fishing week 37. Fishing week 1 corresponds to the first week in October.

.2. Appendix B Mean weights

.2.1. Auckland Islands

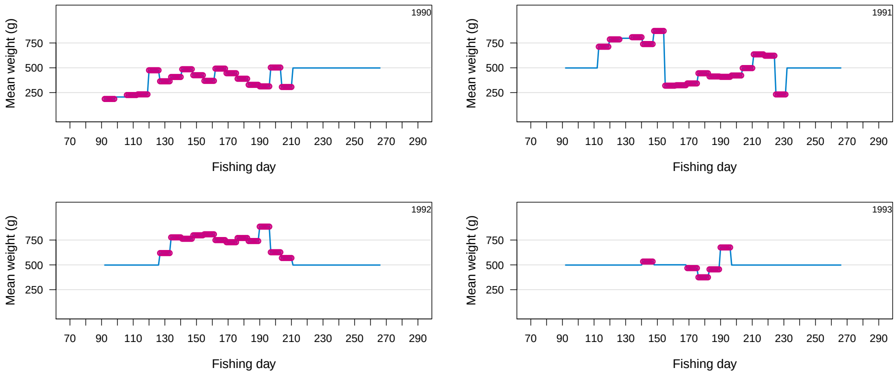

Figure B1: Filled in mean weights for Auckland Islands, years 1990–1993.

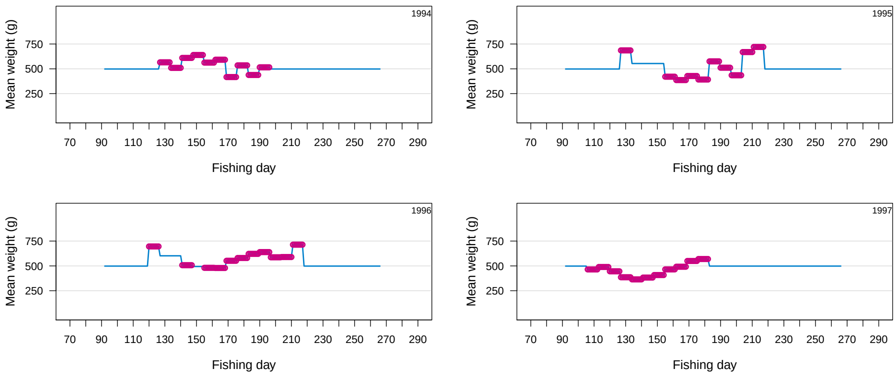

Figure B2: Filled in mean weights for Auckland Islands, years 1994–1997.

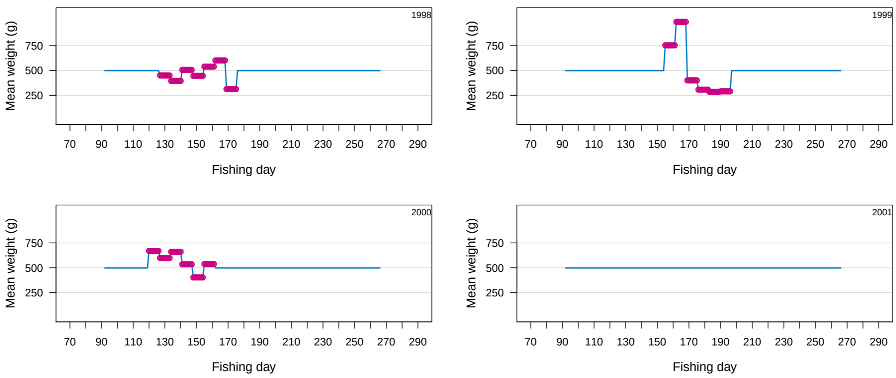

Figure B3: Filled in mean weights for Auckland Islands, years 1998–2001.

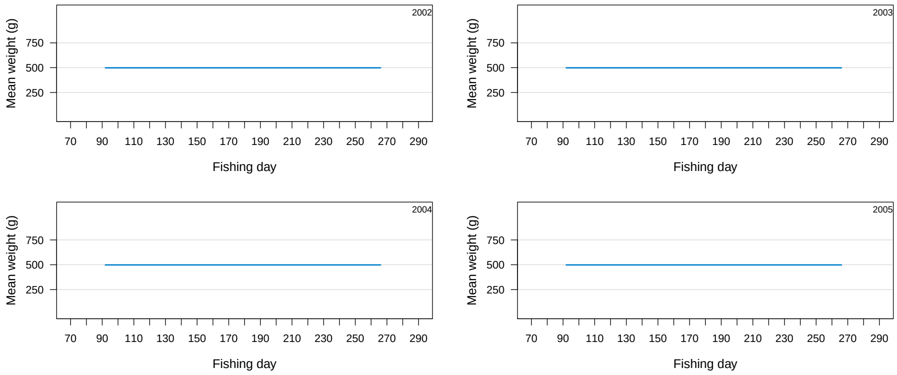

Figure B4: Filled in mean weights for Auckland Islands, years 2002–2005.

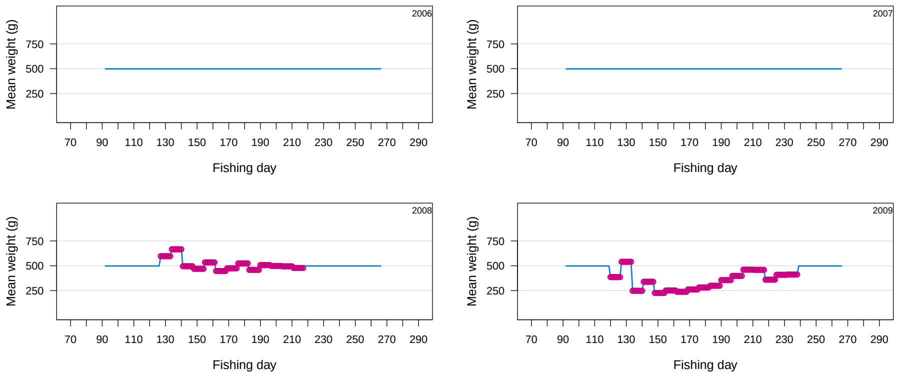

Figure B5: Filled in mean weights for Auckland Islands, years 2006–2009.

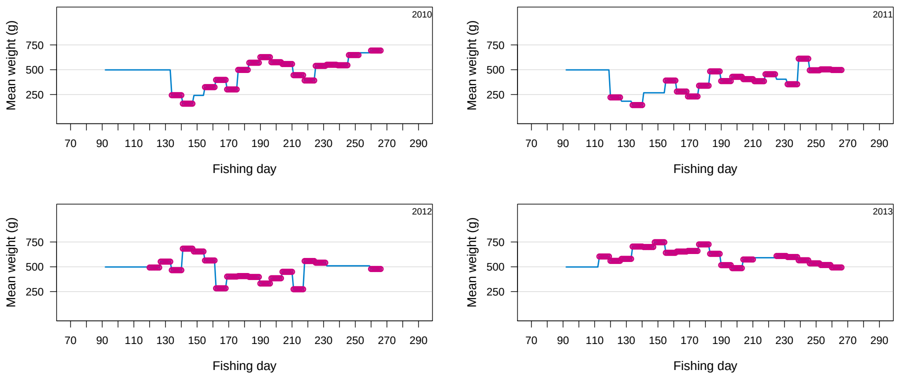

Figure B6: Filled in mean weights for Auckland Islands, years 2010–2013.

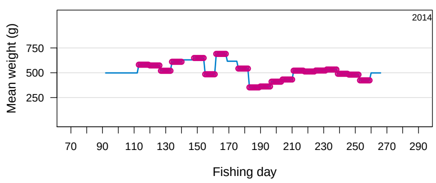

Figure B7: Filled in mean weights for Auckland Islands for 2014.

.2.2. Snares

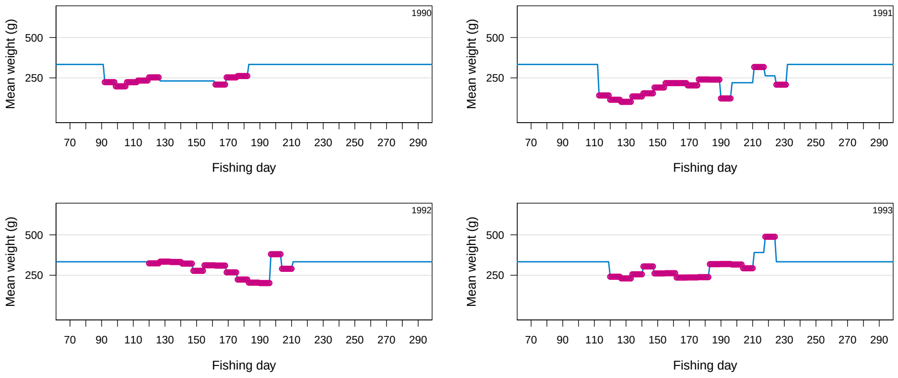

Figure B8: Filled in mean weights for the Snares, years 1990–1993.

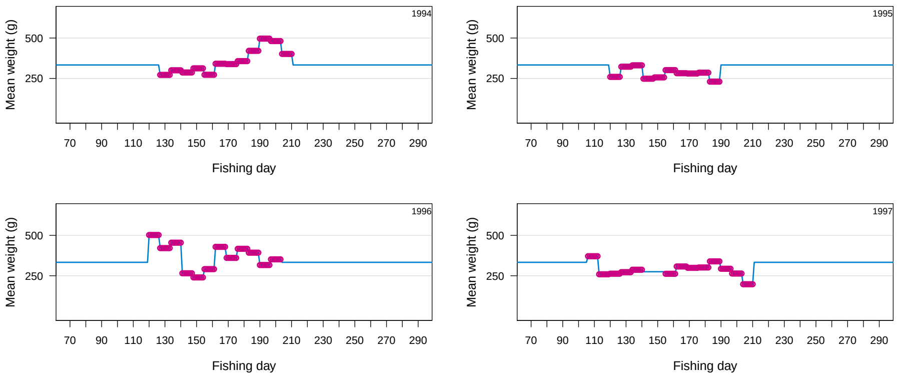

Figure B9: Filled in mean weights for the Snares, years 1994–1997.

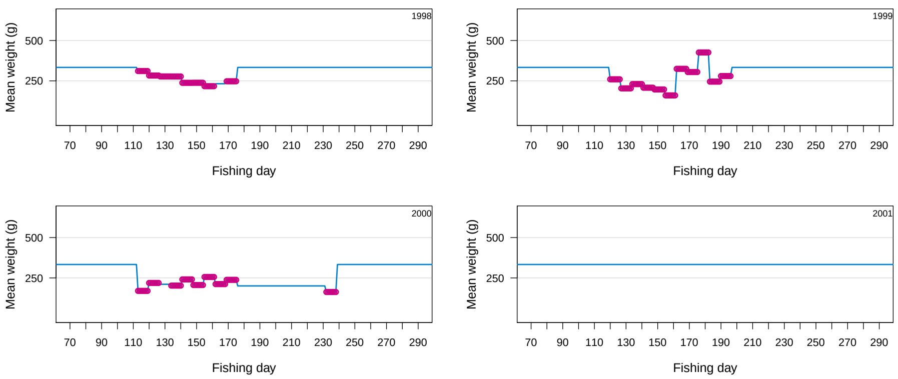

Figure B10: Filled in mean weights for the Snares, years 1998–2001.

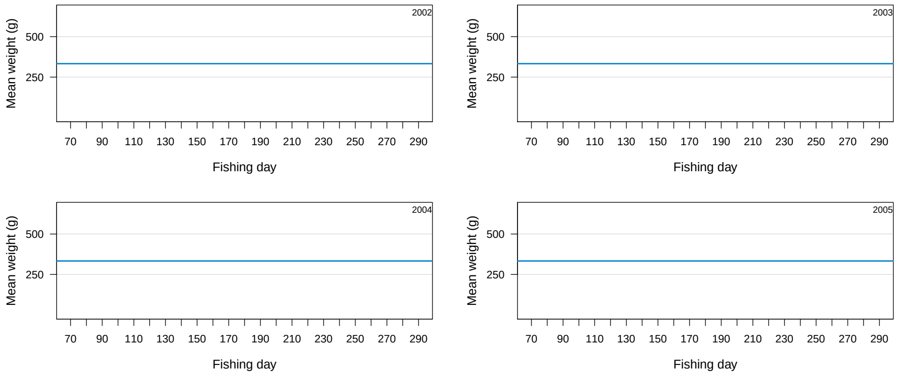

Figure B11: Filled in mean weights for the Snares, years 2002–2005.

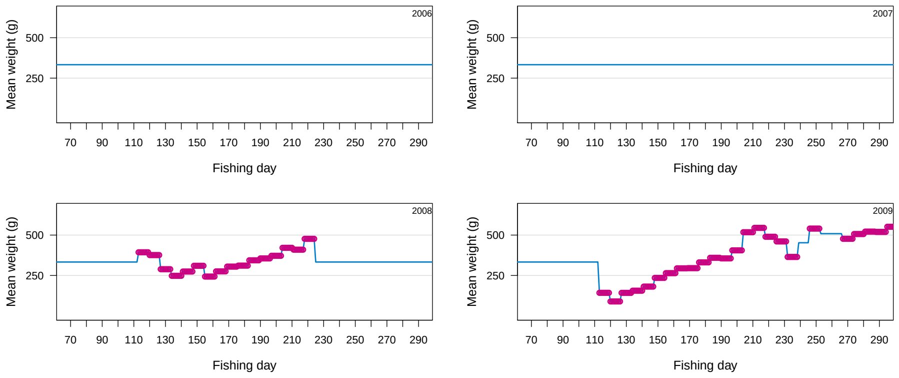

Figure B12: Filled in mean weights for the Snares, years 2006–2009.

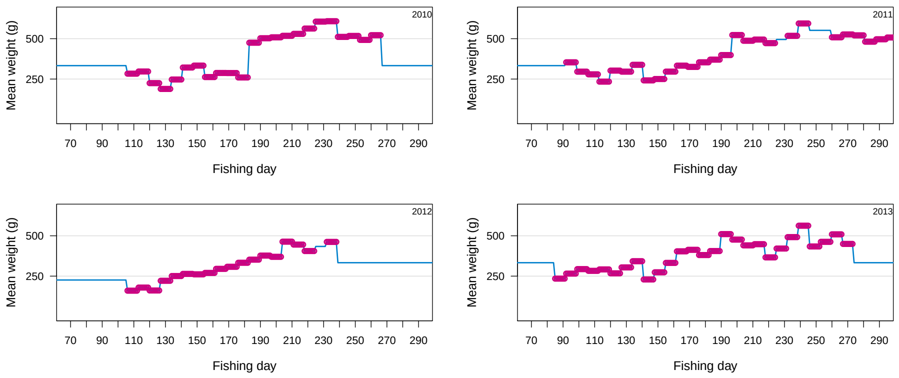

Figure B13: Filled in mean weights for the Snares, years 2010–2013.

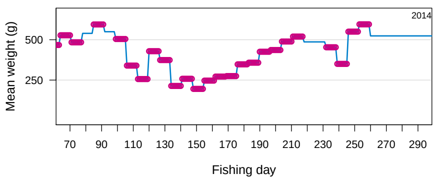

Figure B14: Filled in mean weights for the Snares for 2014.

.3. Appendix C CPUE

.3.1. Auckland Islands

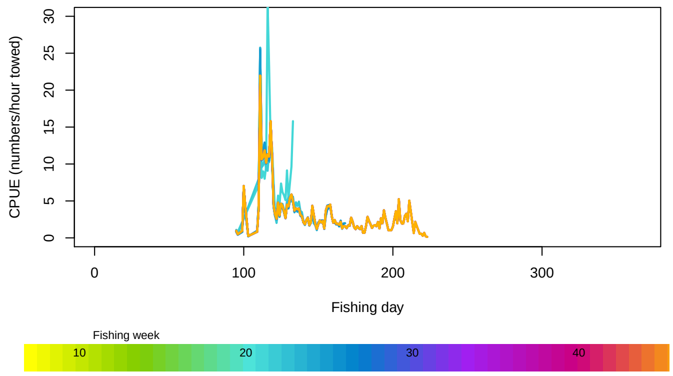

Figure C1: CPUE in numbers per hour towed for Auckland Islands 1990.

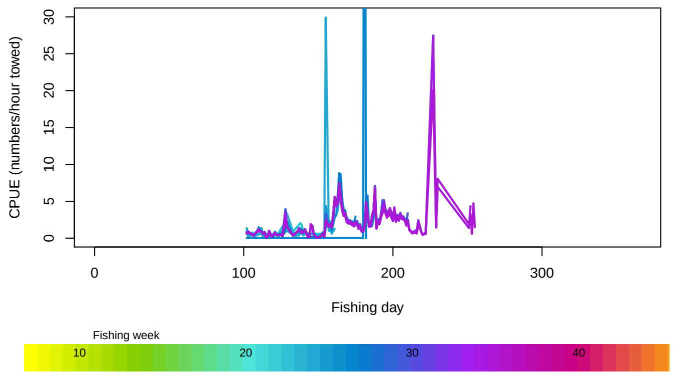

Figure C2: CPUE in numbers per hour towed for Auckland Islands 1991.

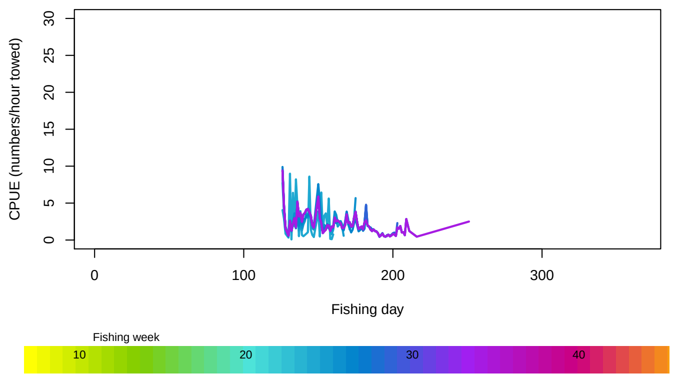

Figure C3: CPUE in numbers per hour towed for Auckland Islands 1992.

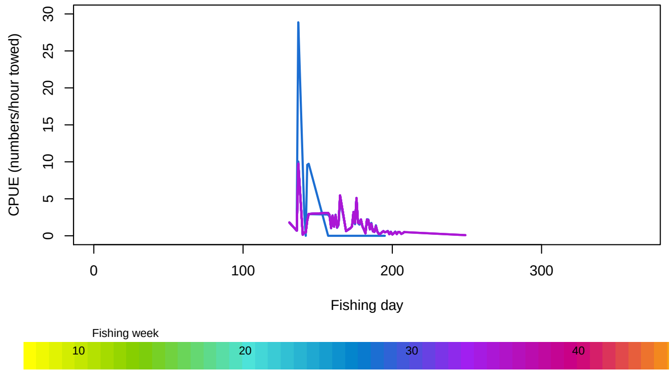

Figure C4: CPUE in numbers per hour towed for Auckland Islands 1993.

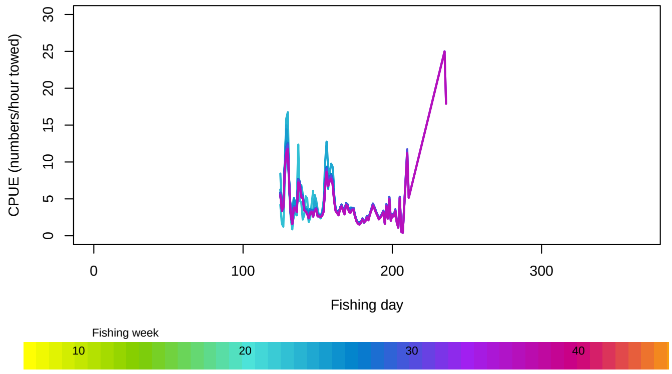

Figure C5: CPUE in numbers per hour towed for Auckland Islands 1994.

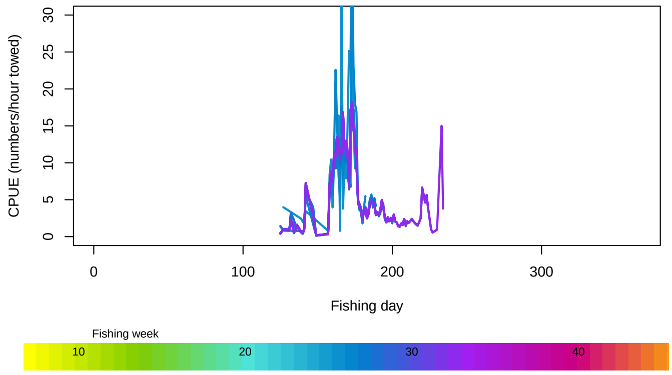

Figure C6: CPUE in numbers per hour towed for Auckland Islands 1995.

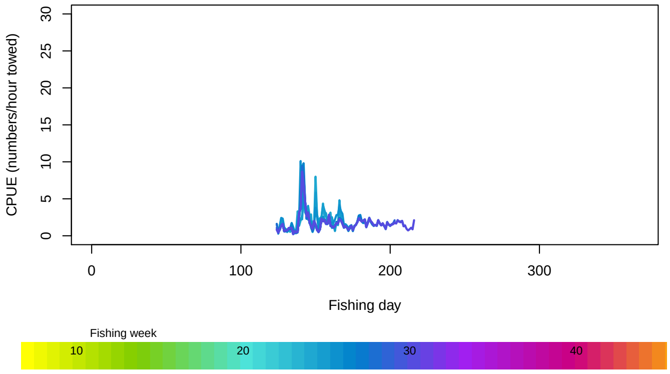

Figure C7: CPUE in numbers per hour towed for Auckland Islands 1996.

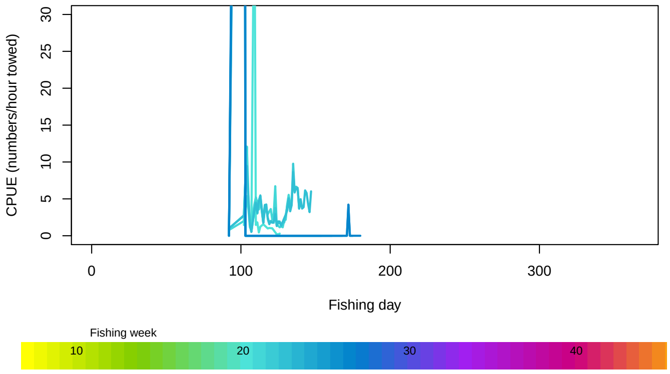

Figure C8: CPUE in numbers per hour towed for Auckland Islands 1997.

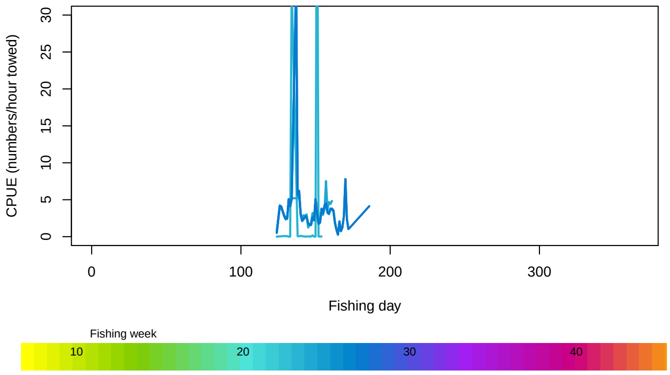

Figure C9: CPUE in numbers per hour towed for Auckland Islands 1998.

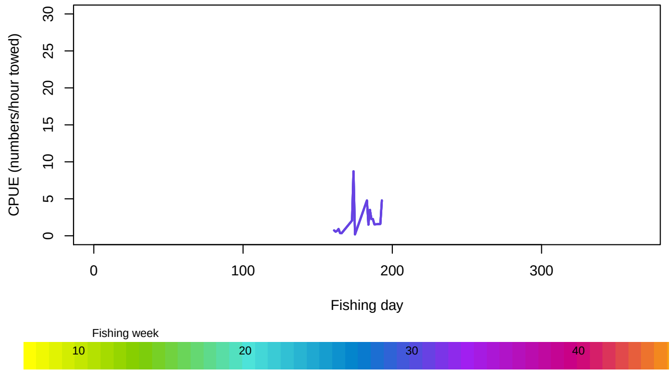

Figure C10: CPUE in numbers per hour towed for Auckland Islands 1999.

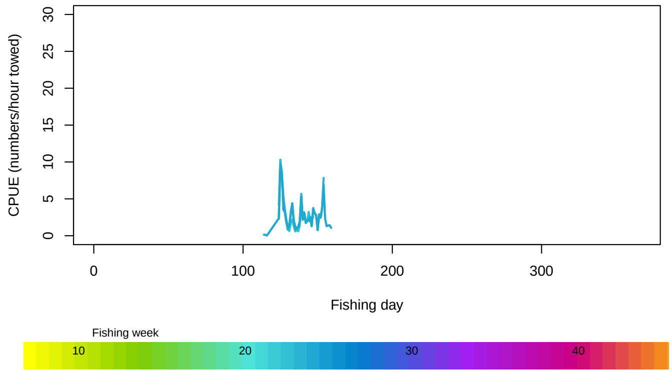

Figure C11: CPUE in numbers per hour towed for Auckland Islands 2000.

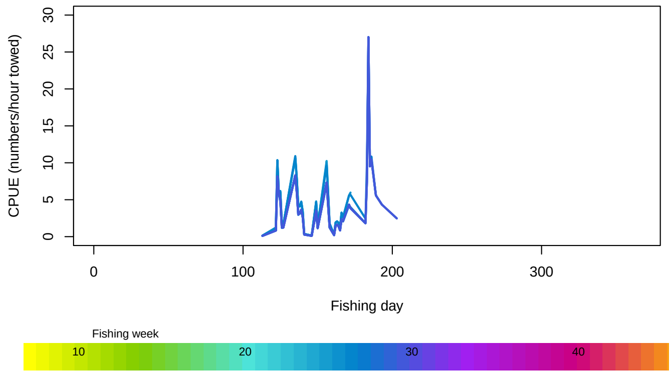

Figure C12: CPUE in numbers per hour towed for Auckland Islands 2001.

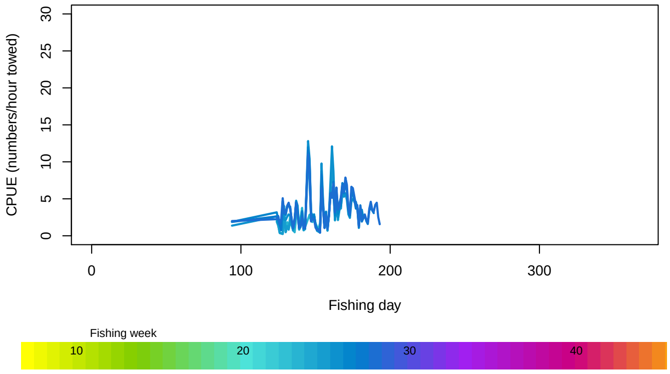

Figure C13: CPUE in numbers per hour towed for Auckland Islands 2002.

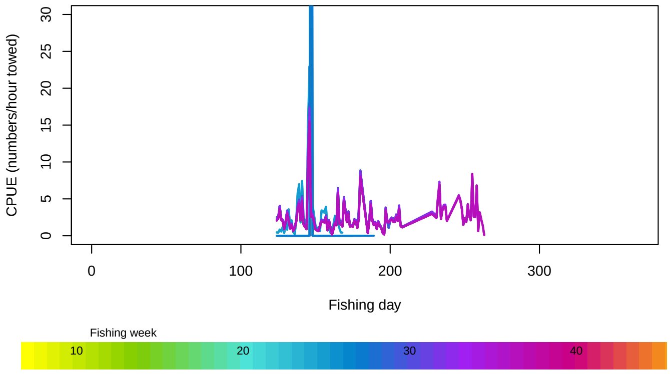

Figure C14: CPUE in numbers per hour towed for Auckland Islands 2003.

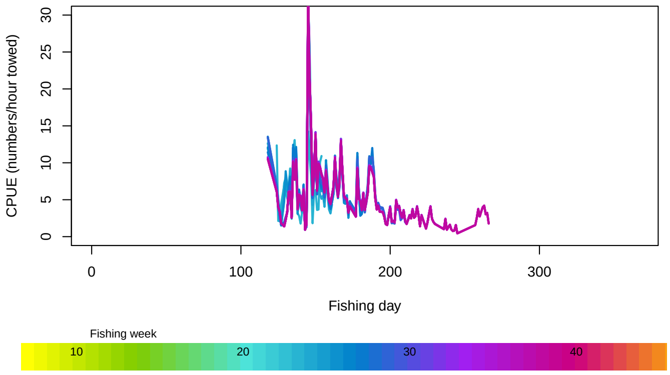

Figure C15: CPUE in numbers per hour towed for Auckland Islands 2004.

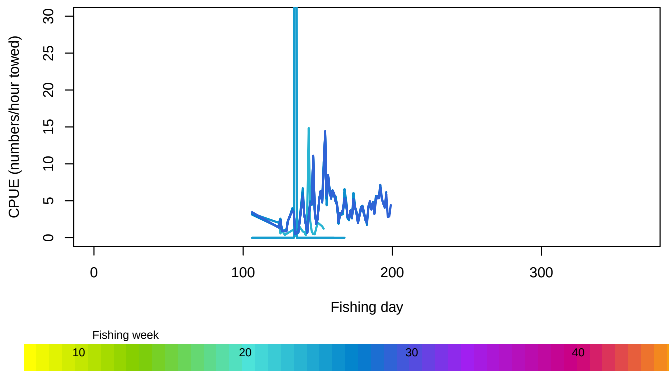

Figure C16: CPUE in numbers per hour towed for Auckland Islands 2005.

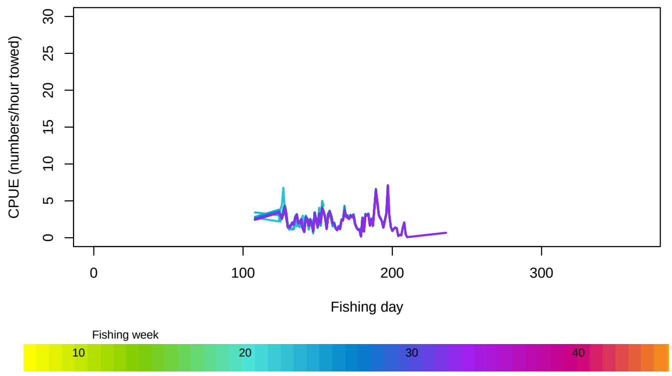

Figure C17: CPUE in numbers per hour towed for Auckland Islands 2006.

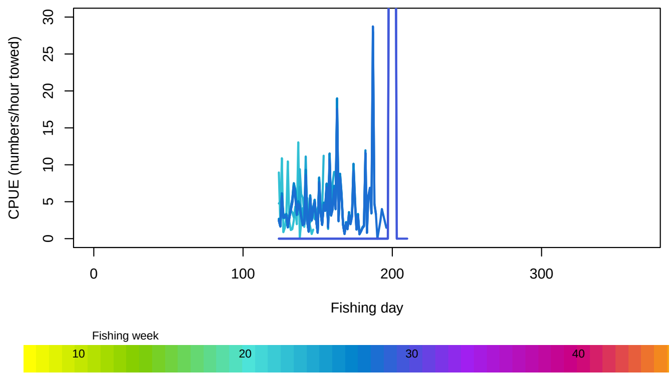

Figure C18: CPUE in numbers per hour towed for Auckland Islands 2007.

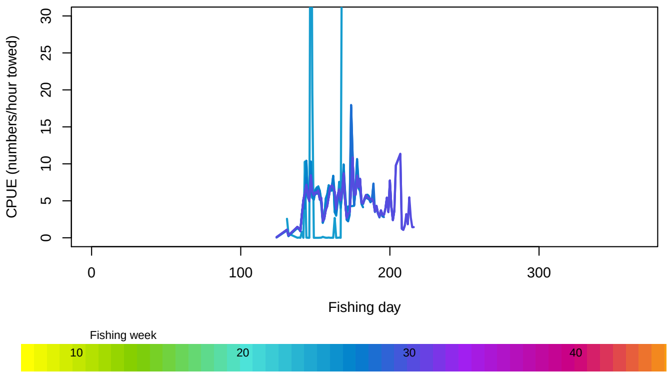

Figure C19: CPUE in numbers per hour towed for Auckland Islands 2008.

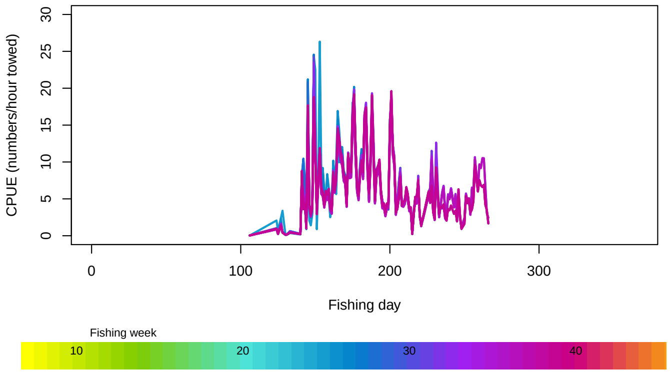

Figure C20: CPUE in numbers per hour towed for Auckland Islands 2009.

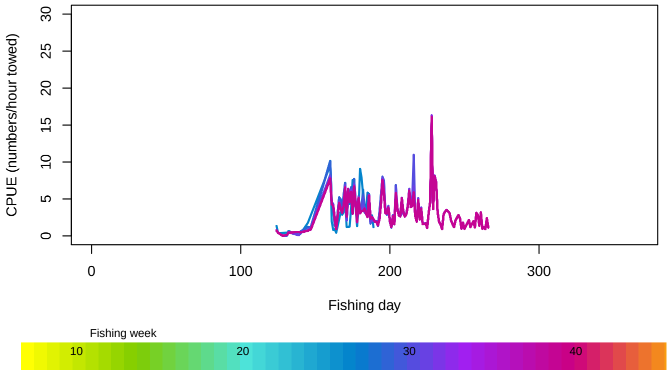

Figure C21: CPUE in numbers per hour towed for Auckland Islands 2010.

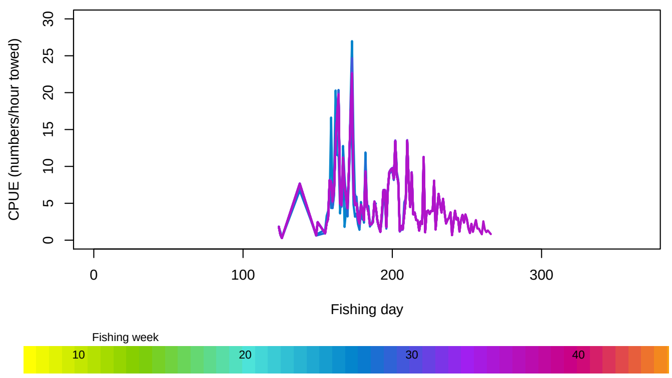

Figure C22: CPUE in numbers per hour towed for Auckland Islands 2011.

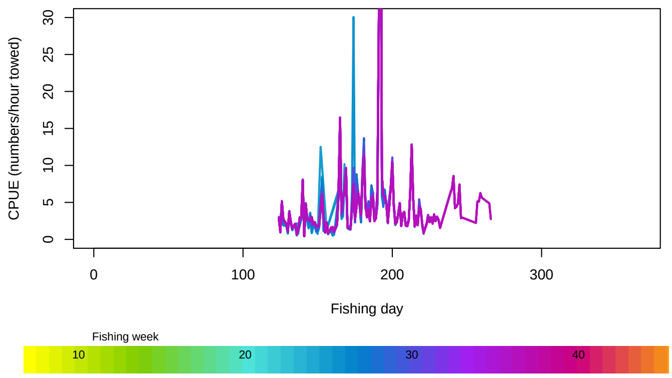

Figure C23: CPUE in numbers per hour towed for Auckland Islands 2012.

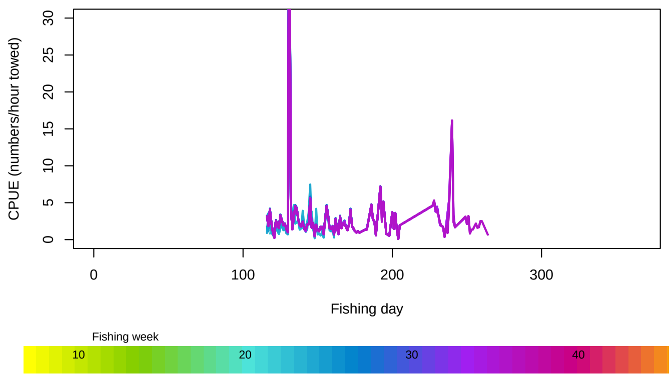

Figure C24: CPUE in numbers per hour towed for Auckland Islands 2013.

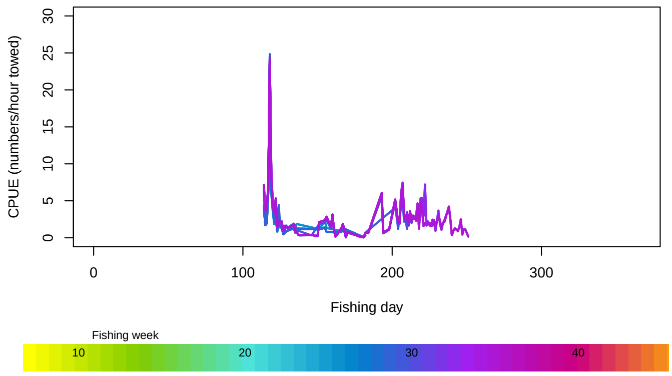

Figure C25: CPUE in numbers per hour towed for Auckland Islands 2014.

.3.2. Snares

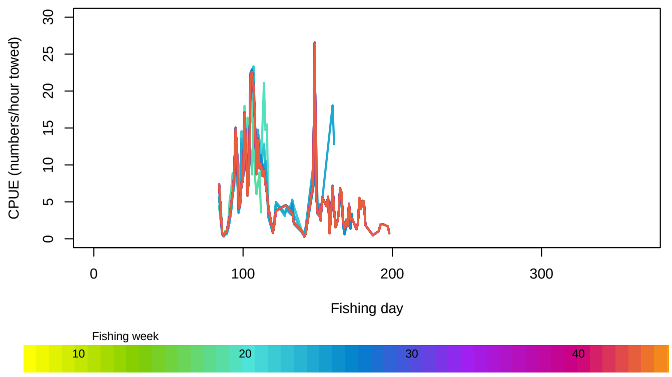

Figure C26: CPUE in numbers per hour towed for the Snares 1990.

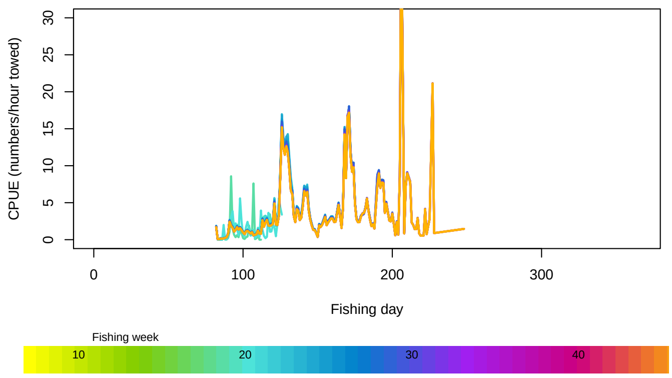

Figure C27: CPUE in numbers per hour towed for the Snares 1991.

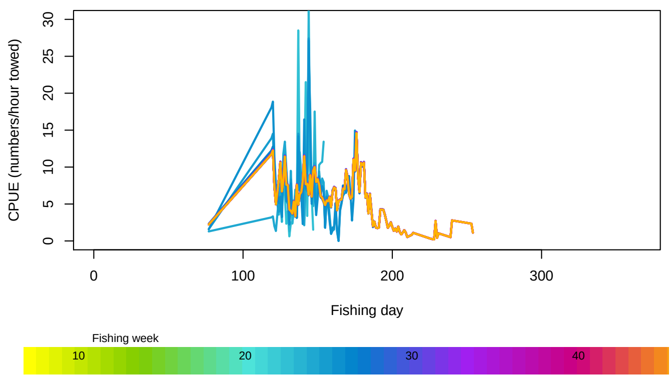

Figure C28: CPUE in numbers per hour towed for the Snares 1992.

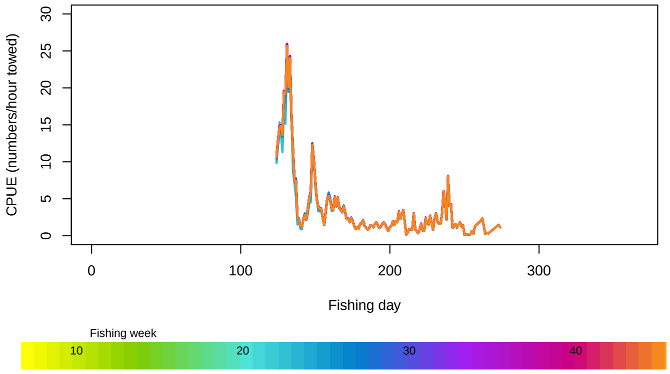

Figure C29: CPUE in numbers per hour towed for the Snares 1993.

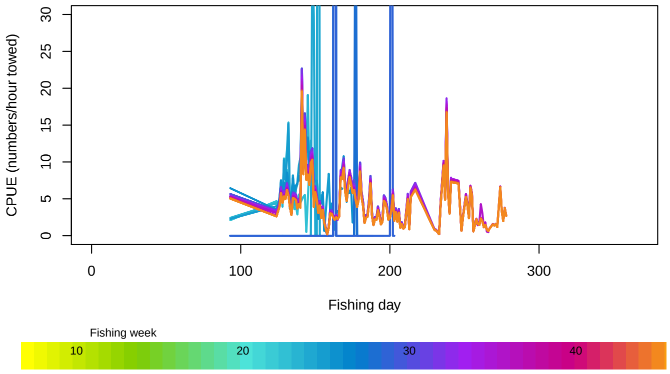

Figure C30: CPUE in numbers per hour towed for the Snares 1994.

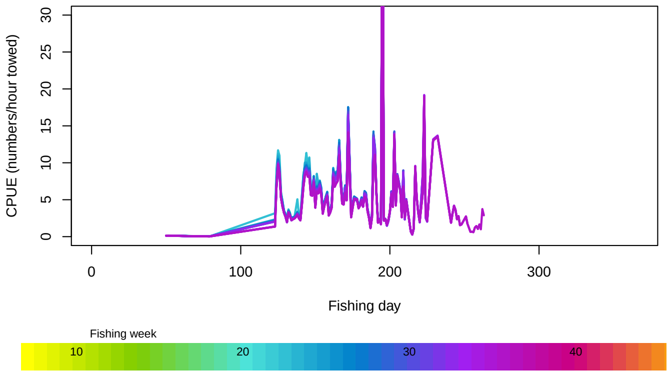

Figure C31: CPUE in numbers per hour towed for the Snares 1995.

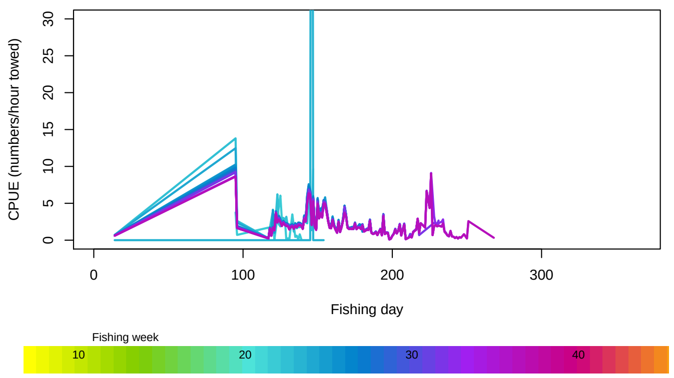

Figure C32: CPUE in numbers per hour towed for the Snares 1996.

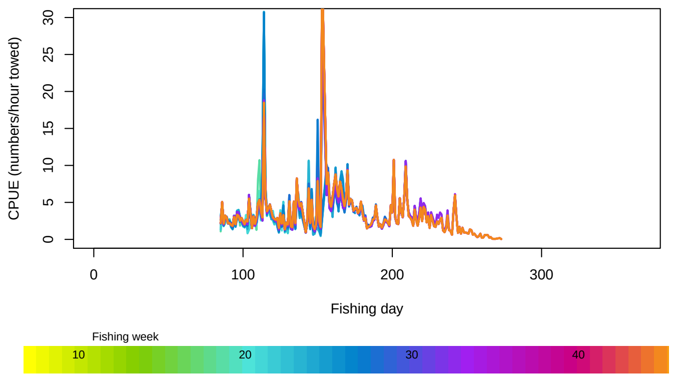

Figure C33: CPUE in numbers per hour towed for the Snares 1997.

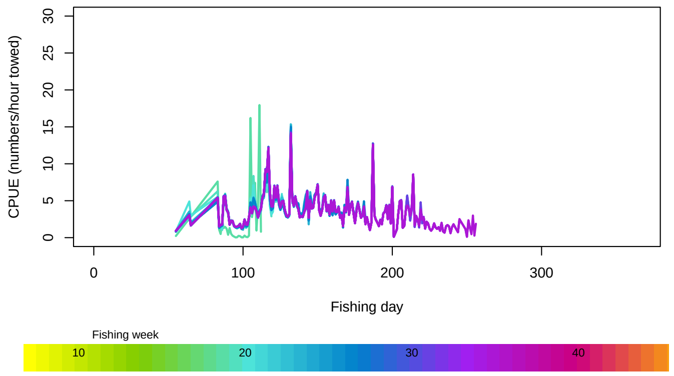

Figure C34: CPUE in numbers per hour towed for the Snares 1998.

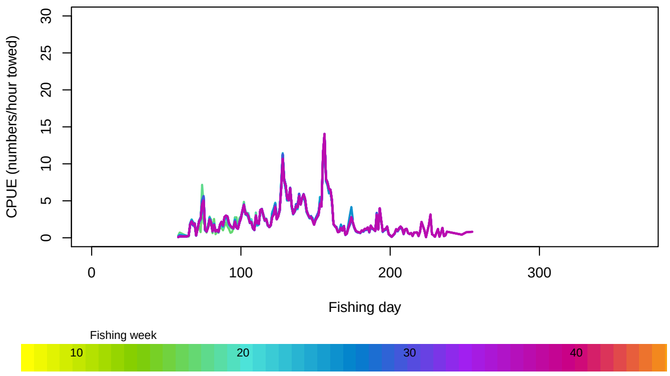

Figure C35: CPUE in numbers per hour towed for the Snares 1999.

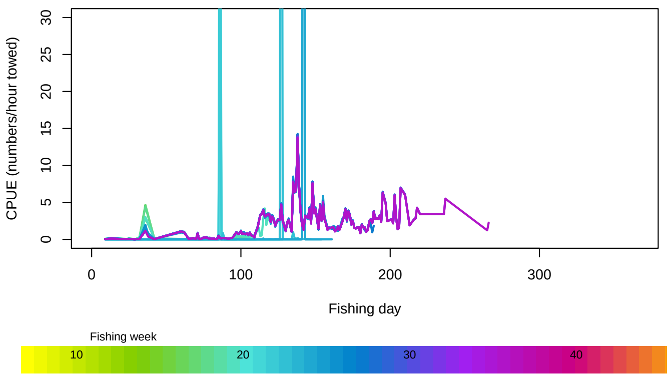

Figure C36: CPUE in numbers per hour towed for the Snares 2000.

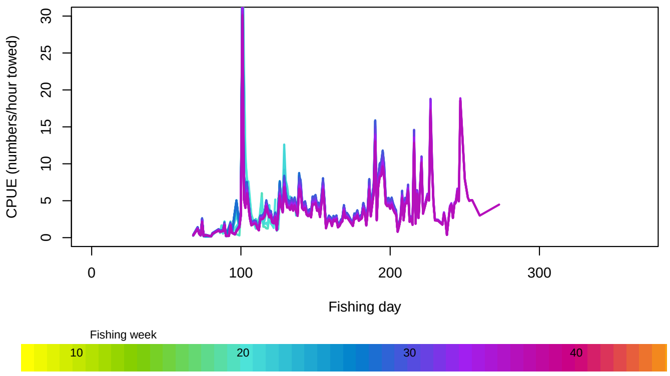

Figure C37: CPUE in numbers per hour towed for the Snares 2001.

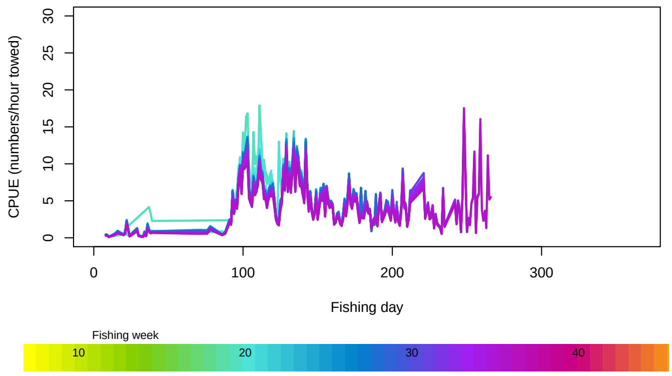

Figure C38: CPUE in numbers per hour towed for the Snares 2002.

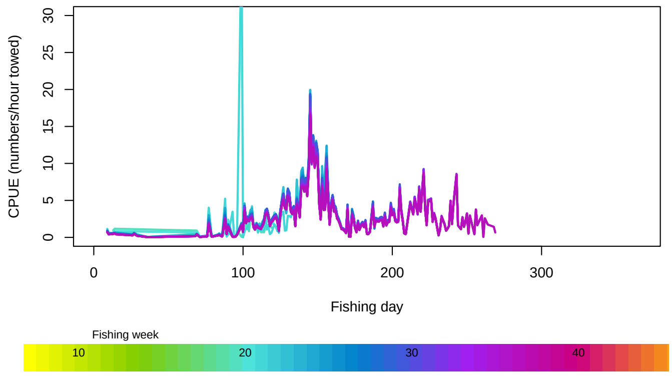

Figure C39: CPUE in numbers per hour towed for the Snares 2003.

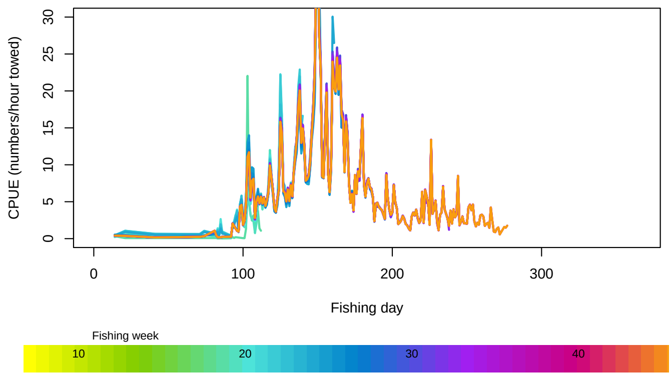

Figure C40: CPUE in numbers per hour towed for the Snares 2004.

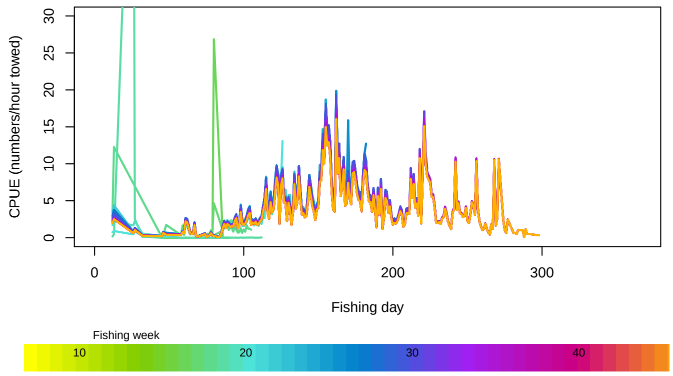

Figure C41: CPUE in numbers per hour towed for the Snares 2005.

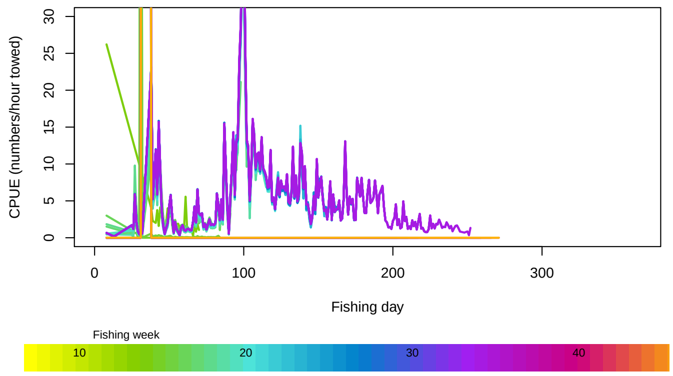

Figure C42: CPUE in numbers per hour towed for the Snares 2006.

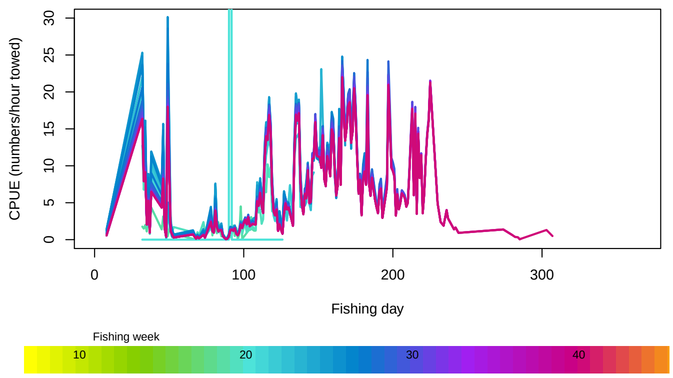

Figure C43: CPUE in numbers per hour towed for the Snares 2007.

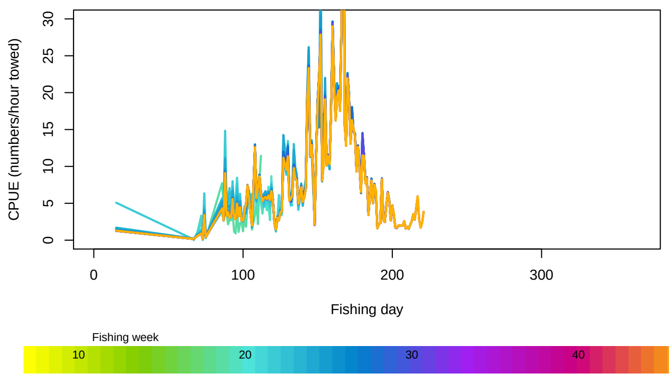

Figure C44: CPUE in numbers per hour towed for the Snares 2008.

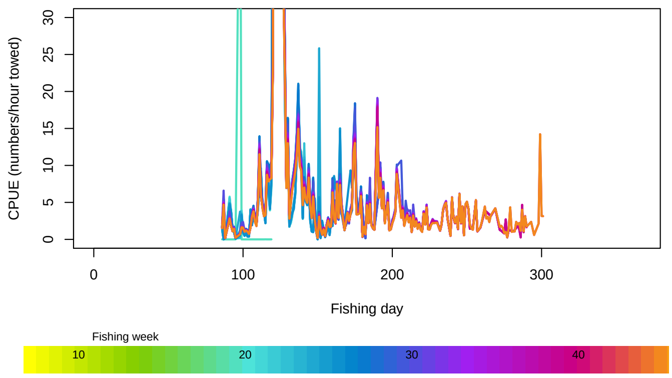

Figure C45: CPUE in numbers per hour towed for the Snares 2009.

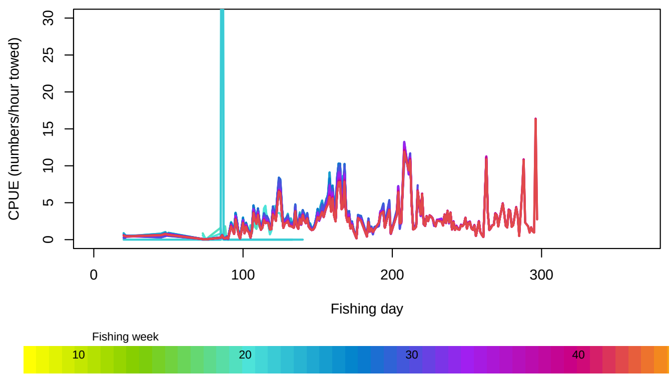

Figure C46: CPUE in numbers per hour towed for the Snares 2010.

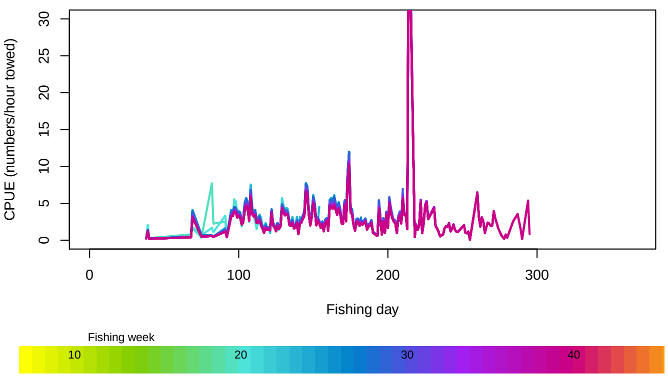

Figure C47: CPUE in numbers per hour towed for the Snares 2011.

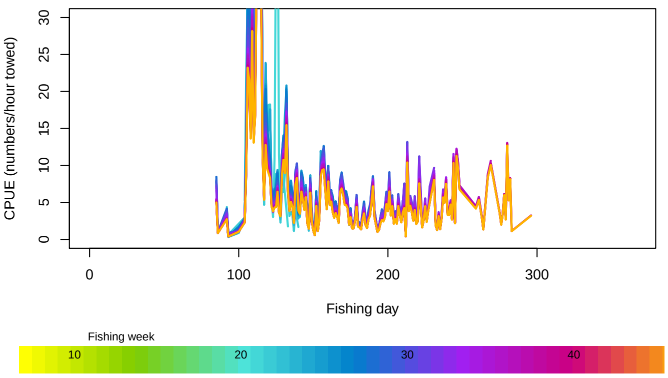

Figure C48: CPUE in numbers per hour towed for the Snares 2012.

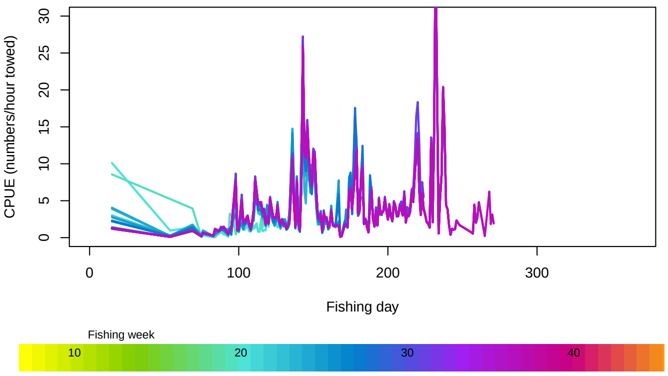

Figure C49: CPUE in numbers per hour towed for the Snares 2013.

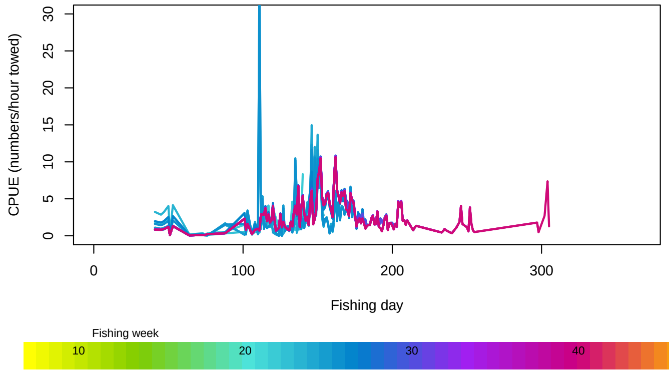

Figure C50: CPUE in numbers per hour towed for the Snares 2014.

.4. Appendix D Depletion model fits to observed catches

.4.1. Auckland Islands

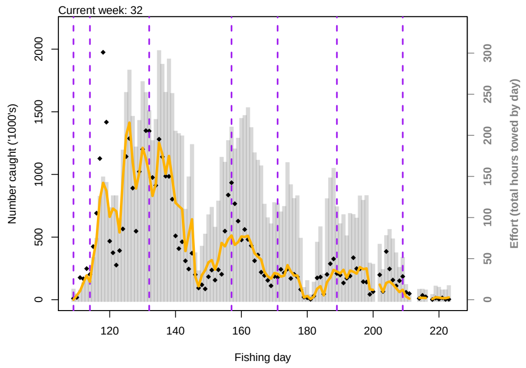

Figure D1: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 1990, up to and including fishing week 32. Fishing day 1 corresponds to the 01 October.

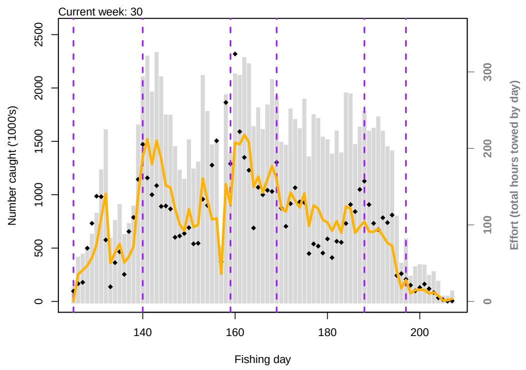

Figure D2: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 1994, up to and including fishing week 30. Fishing day 1 corresponds to the 01 October.

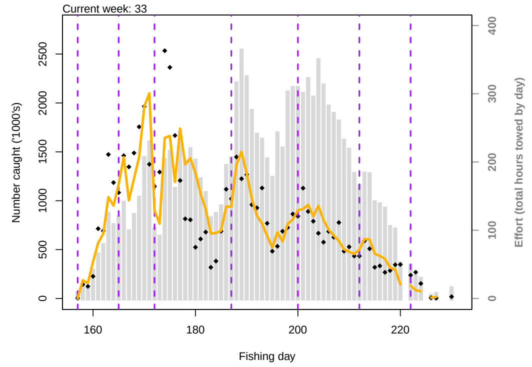

Figure D3: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 1995, up to and including fishing week 33. Fishing day 1 corresponds to the 01 October.

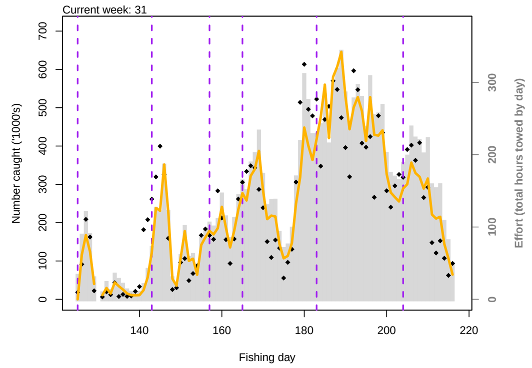

Figure D4: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 1996, up to and including fishing week 31. Fishing day 1 corresponds to the 01 October.

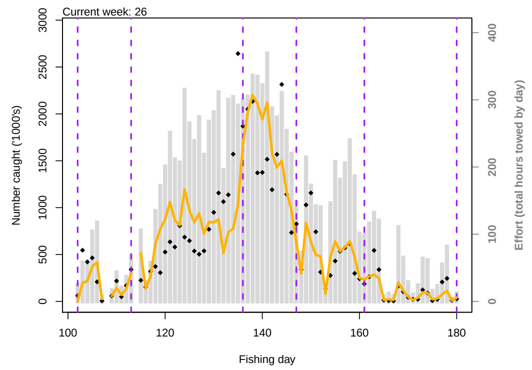

Figure D5: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 1997, up to and including fishing week 26. Fishing day 1 corresponds to the 01 October.

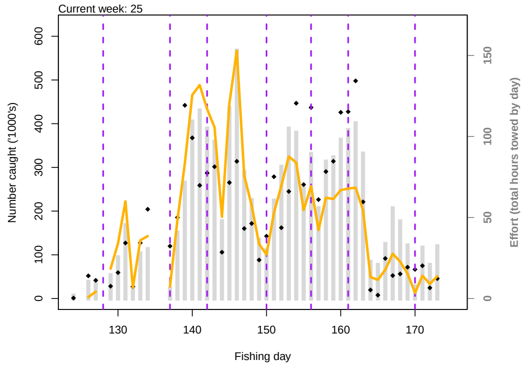

Figure D6: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 1998, up to and including fishing week 25. Fishing day 1 corresponds to the 01 October.

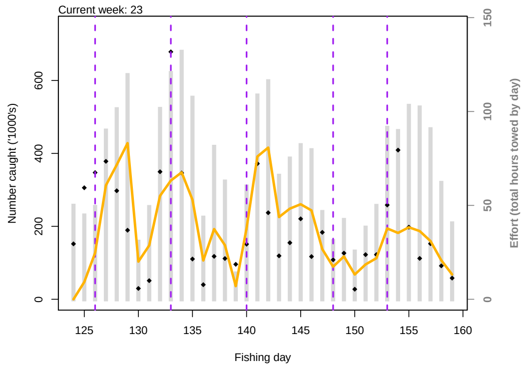

Figure D7: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 2000, up to and including fishing week 23. Fishing day 1 corresponds to the 01 October.

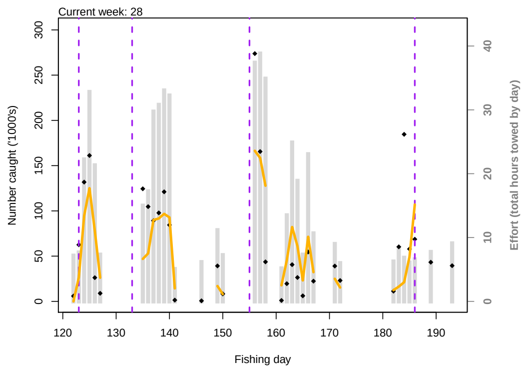

Figure D8: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 2001, up to and including fishing week 28. Fishing day 1 corresponds to the 01 October.

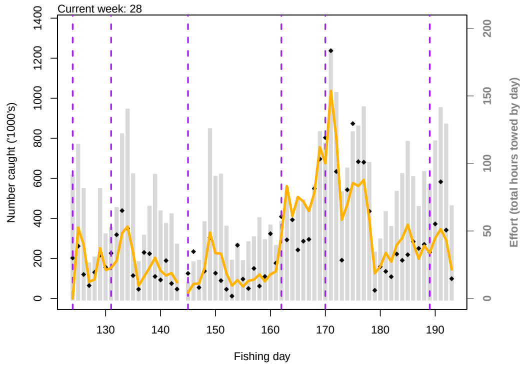

Figure D9: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 2002, up to and including fishing week 28. Fishing day 1 corresponds to the 01 October.

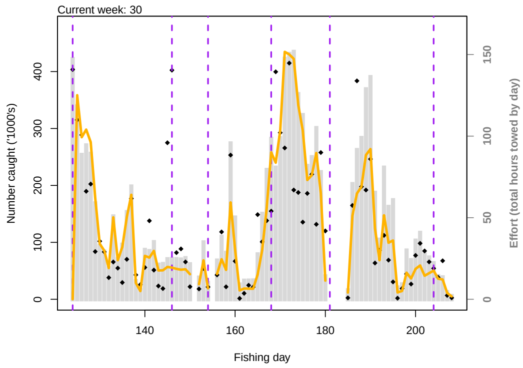

Figure D10: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 2003, up to and including fishing week 30. Fishing day 1 corresponds to the 01 October.

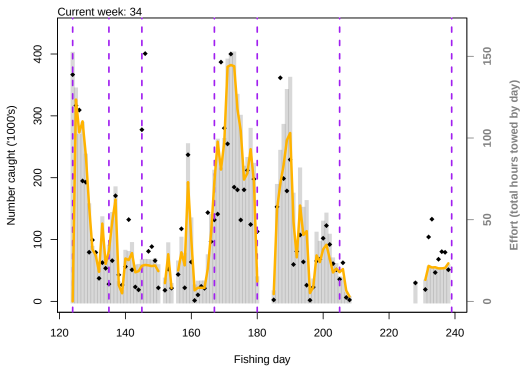

Figure D11: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 2003, up to and including fishing week 34. Fishing day 1 corresponds to the 01 October.

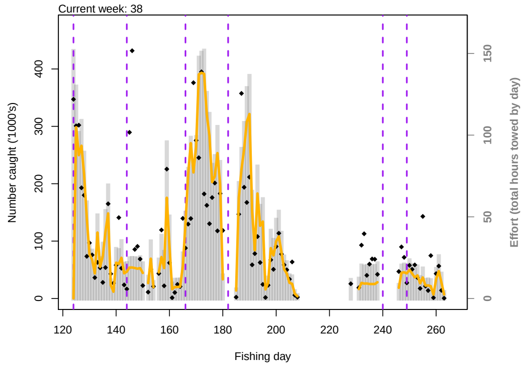

Figure D12: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 2003, up to and including fishing week 38. Fishing day 1 corresponds to the 01 October.

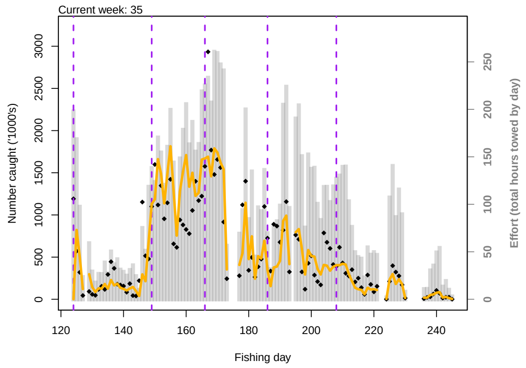

Figure D13: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 2004, up to and including fishing week 35. Fishing day 1 corresponds to the 01 October.

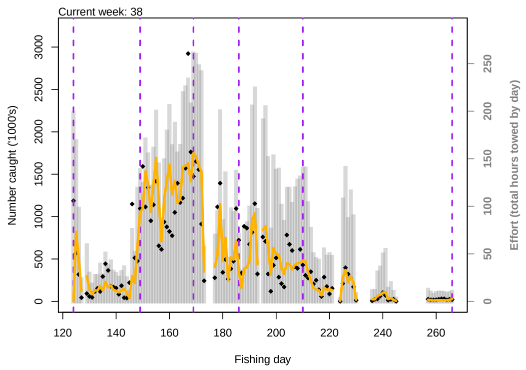

Figure D14: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 2004, up to and including fishing week 38. Fishing day 1 corresponds to the 01 October.

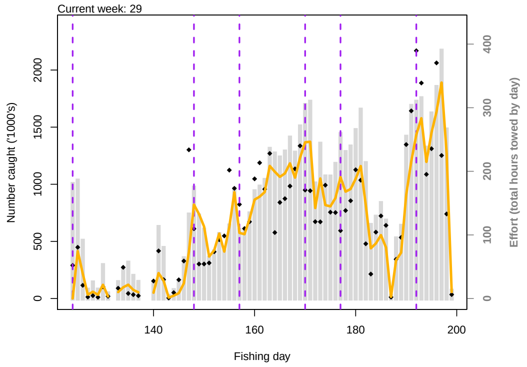

Figure D15: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 2005, up to and including fishing week 29. Fishing day 1 corresponds to the 01 October.

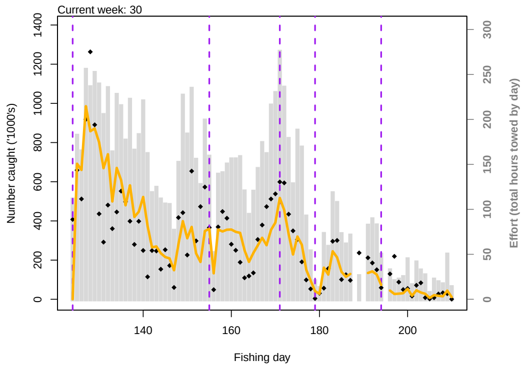

Figure D16: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 2006, up to and including fishing week 30. Fishing day 1 corresponds to the 01 October.

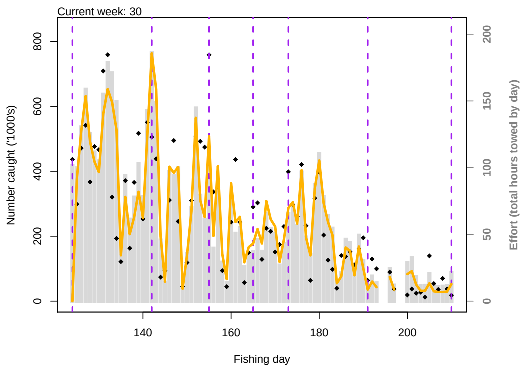

Figure D17: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 2007, up to and including fishing week 30. Fishing day 1 corresponds to the 01 October.

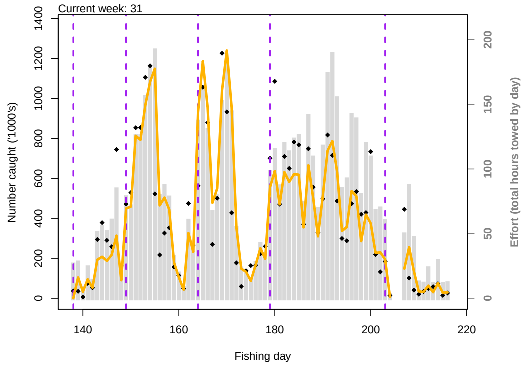

Figure D18: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 2008, up to and including fishing week 31. Fishing day 1 corresponds to the 01 October.

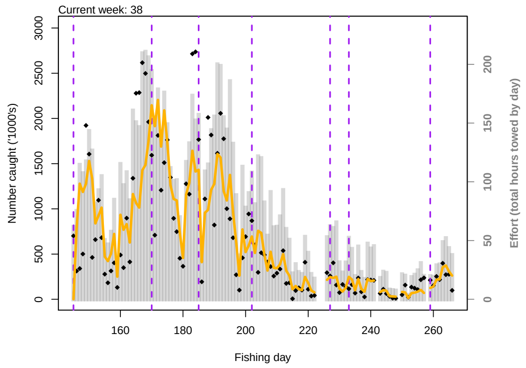

Figure D19: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 2009, up to and including fishing week 38. Fishing day 1 corresponds to the 01 October.

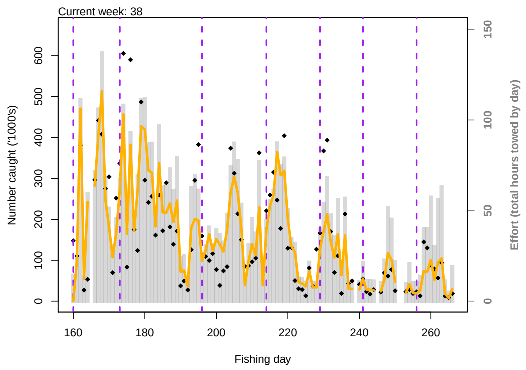

Figure D20: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 2010, up to and including fishing week 38. Fishing day 1 corresponds to the 01 October.

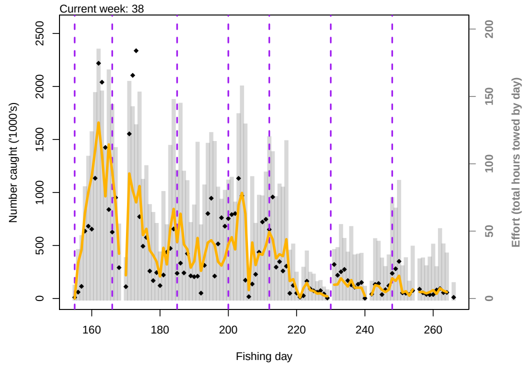

Figure D21: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 2011, up to and including fishing week 38. Fishing day 1 corresponds to the 01 October.

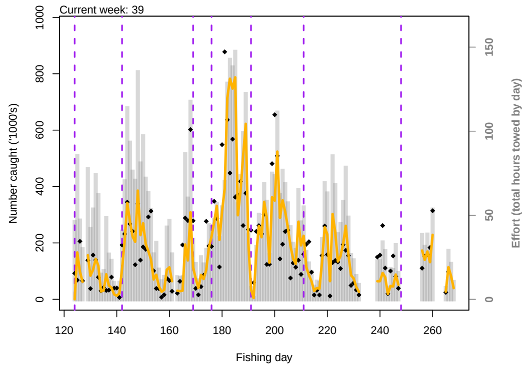

Figure D22: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 2012, up to and including fishing week 39. Fishing day 1 corresponds to the 01 October.

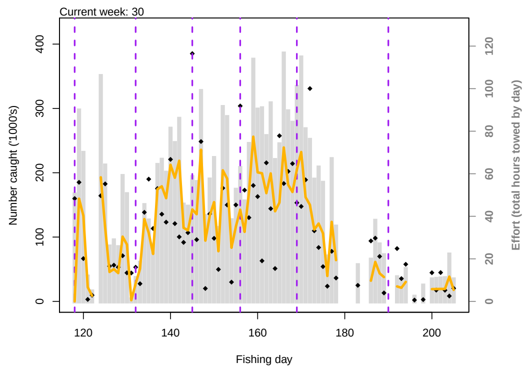

Figure D23: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 2013, up to and including fishing week 30. Fishing day 1 corresponds to the 01 October.

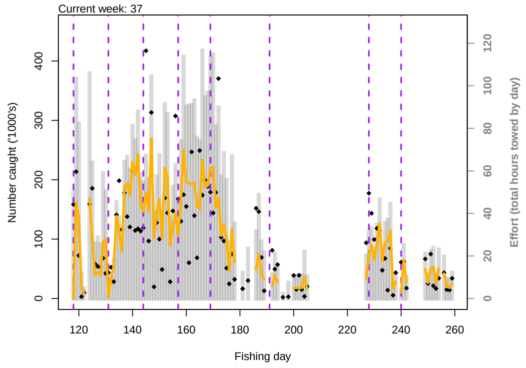

Figure D24: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 2013, up to and including fishing week 37. Fishing day 1 corresponds to the 01 October.

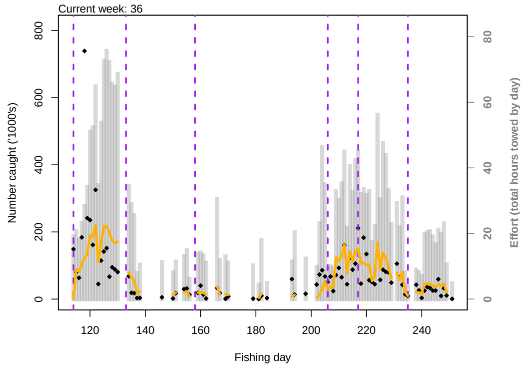

Figure D25: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for Auckland Islands 2014, up to and including fishing week 36. Fishing day 1 corresponds to the 01 October.

.4.2. Snares

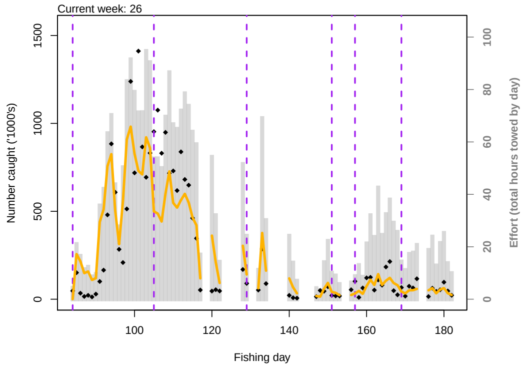

Figure D26: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 1990, up to and including fishing week 26. Fishing day 1 corresponds to the 01 October.

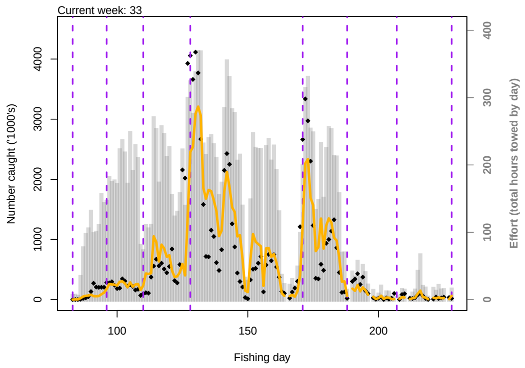

Figure D27: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 1991, up to and including fishing week 33. Fishing day 1 corresponds to the 01 October.

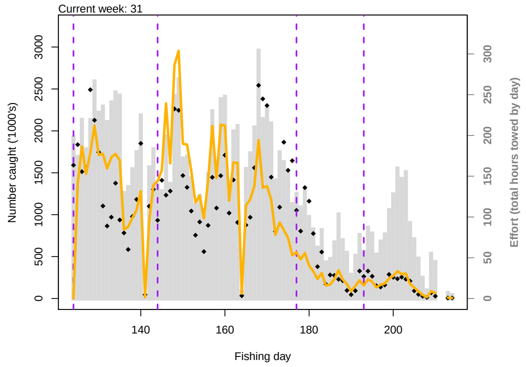

Figure D28: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 1992, up to and including fishing week 31. Fishing day 1 corresponds to the 01 October.

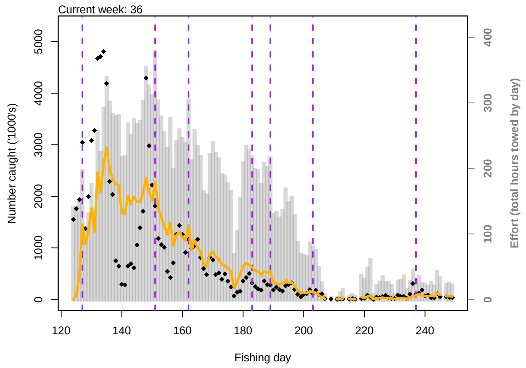

Figure D29: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 1993, up to and including fishing week 36. Fishing day 1 corresponds to the 01 October.

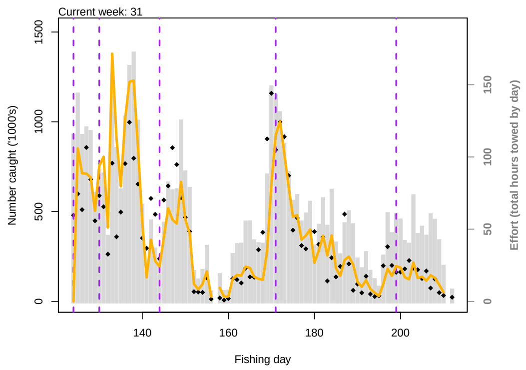

Figure D30: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 1994, up to and including fishing week 31. Fishing day 1 corresponds to the 01 October.

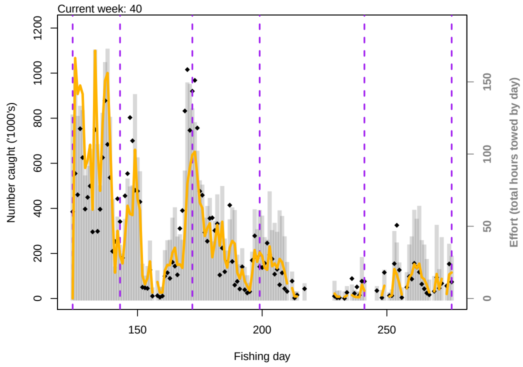

Figure D31: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 1994, up to and including fishing week 40. Fishing day 1 corresponds to the 01 October.

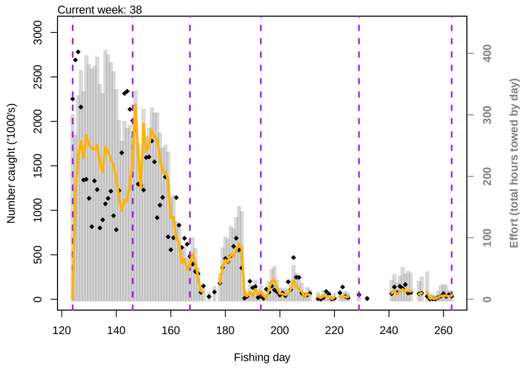

Figure D32: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 1995, up to and including fishing week 38. Fishing day 1 corresponds to the 01 October.

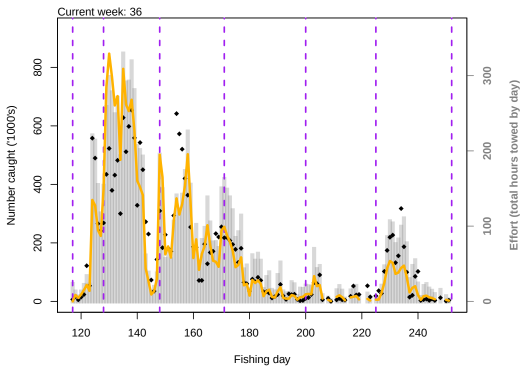

Figure D33: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 1996, up to and including fishing week 36. Fishing day 1 corresponds to the 01 October.

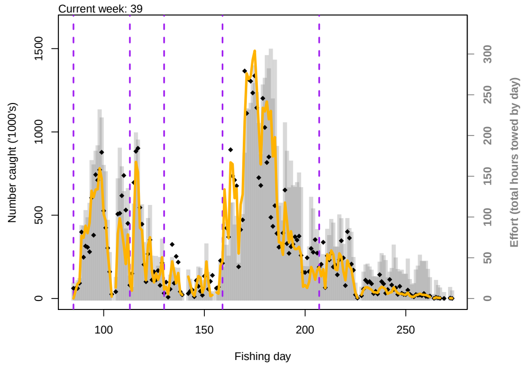

Figure D34: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 1997, up to and including fishing week 39. Fishing day 1 corresponds to the 01 October.

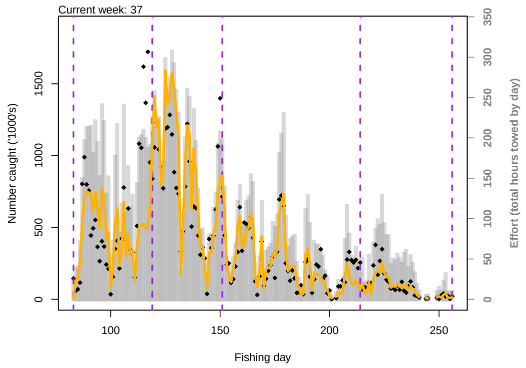

Figure D35: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 1998, up to and including fishing week 37. Fishing day 1 corresponds to the 01 October.

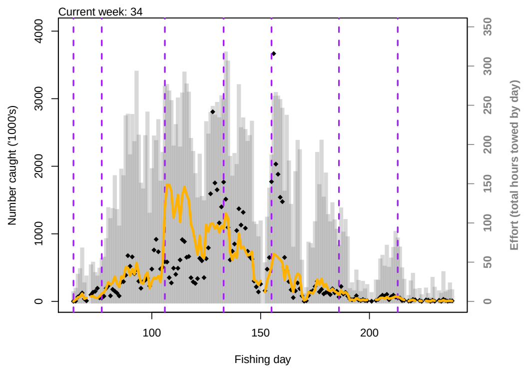

Figure D36: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 1999, up to and including fishing week 34. Fishing day 1 corresponds to the 01 October.

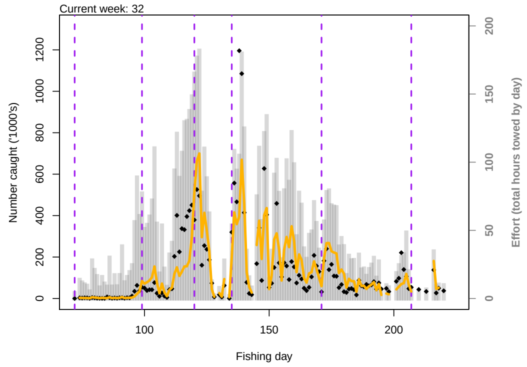

Figure D37: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 2000, up to and including fishing week 32. Fishing day 1 corresponds to the 01 October.

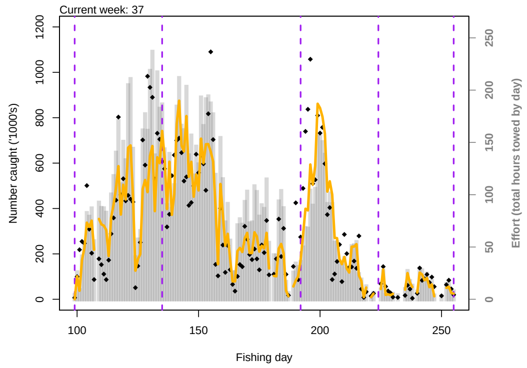

Figure D38: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 2001, up to and including fishing week 37. Fishing day 1 corresponds to the 01 October.

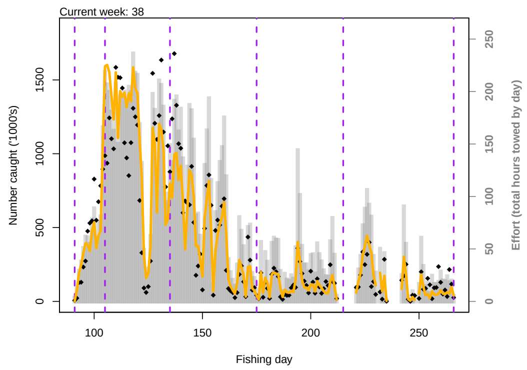

Figure D39: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 2002, up to and including fishing week 38. Fishing day 1 corresponds to the 01 October.

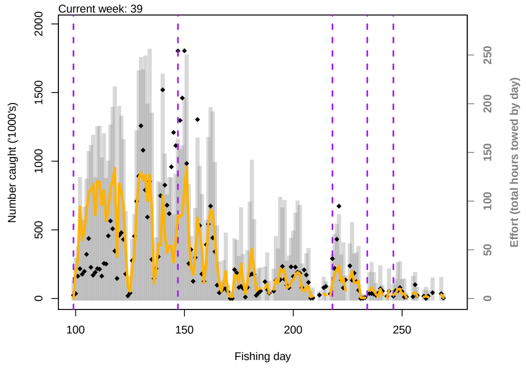

Figure D40: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 2003, up to and including fishing week 39. Fishing day 1 corresponds to the 01 October.

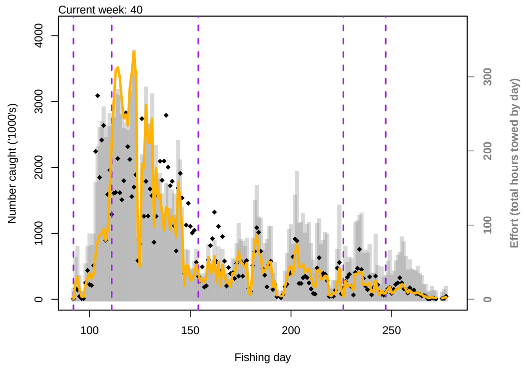

Figure D41: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 2004, up to and including fishing week 40. Fishing day 1 corresponds to the 01 October.

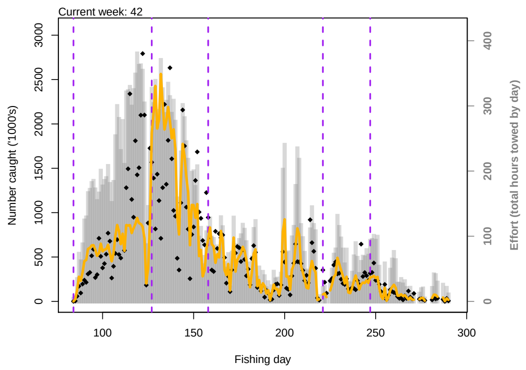

Figure D42: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 2005, up to and including fishing week 42. Fishing day 1 corresponds to the 01 October.

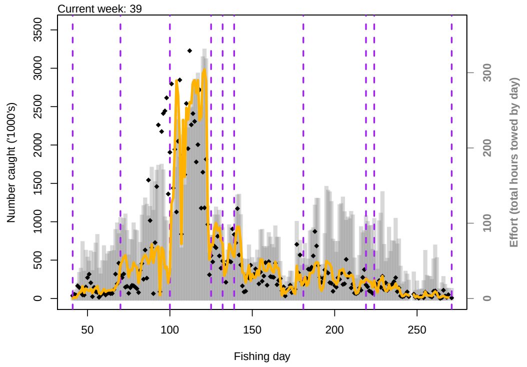

Figure D43: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 2006, up to and including fishing week 39. Fishing day 1 corresponds to the 01 October.

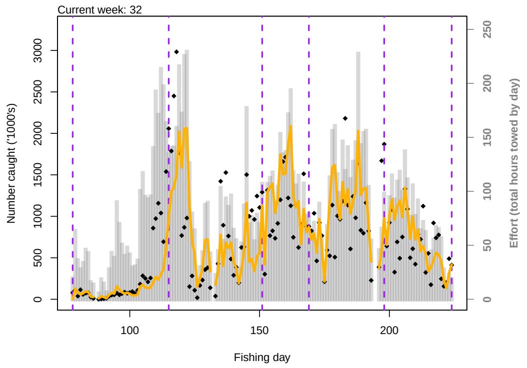

Figure D44: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 2007, up to and including fishing week 32. Fishing day 1 corresponds to the 01 October.

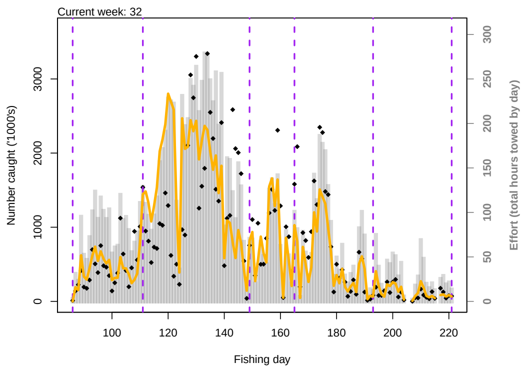

Figure D45: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 2008, up to and including fishing week 32. Fishing day 1 corresponds to the 01 October.

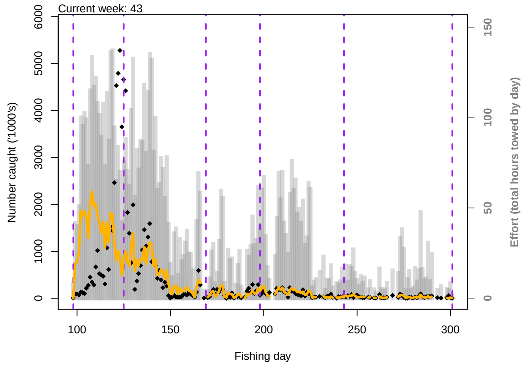

Figure D46: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 2009, up to and including fishing week 43. Fishing day 1 corresponds to the 01 October.

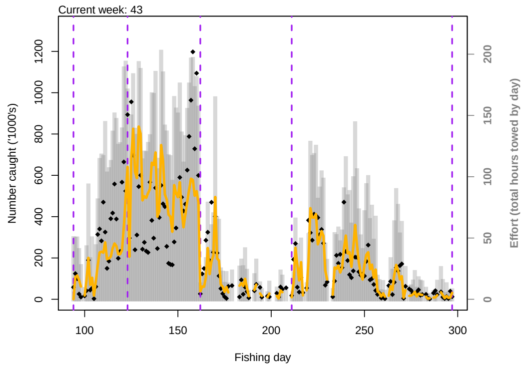

Figure D47: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 2010, up to and including fishing week 43. Fishing day 1 corresponds to the 01 October.

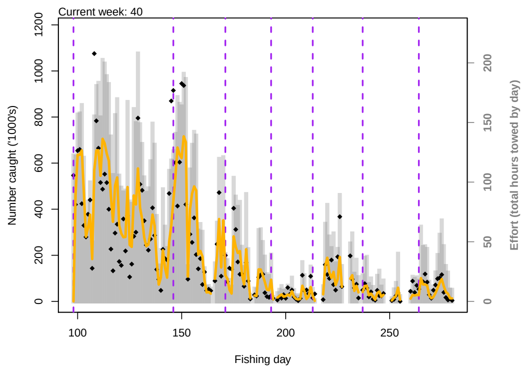

Figure D48: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 2011, up to and including fishing week 40. Fishing day 1 corresponds to the 01 October.

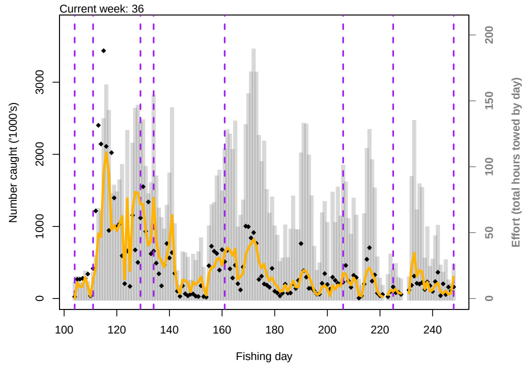

Figure D49: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 2012, up to and including fishing week 36. Fishing day 1 corresponds to the 01 October.

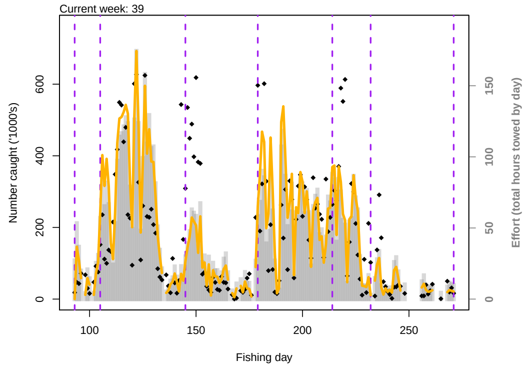

Figure D50: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 2013, up to and including fishing week 39. Fishing day 1 corresponds to the 01 October.

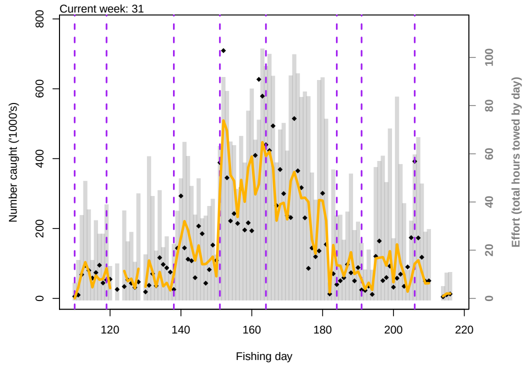

Figure D51: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 2014, up to and including fishing week 31. Fishing day 1 corresponds to the 01 October.

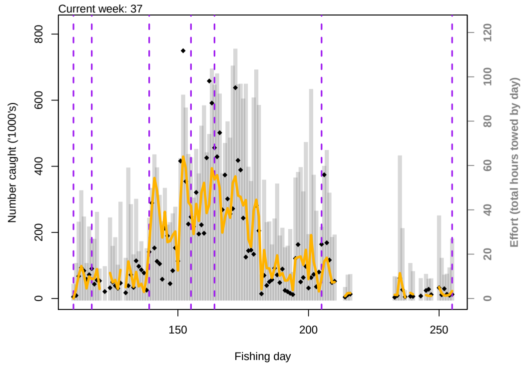

Figure D52: Observed catches in numbers (black dots), estimated catches from the depletion model (orange lines), observed effort as hours towed (grey bars) and timings of population pulses (purple lines) for the Snares 2014, up to and including fishing week 37. Fishing day 1 corresponds to the 01 October.

.5. Appendix E Depletion estimates

.5.1. Auckland Islands

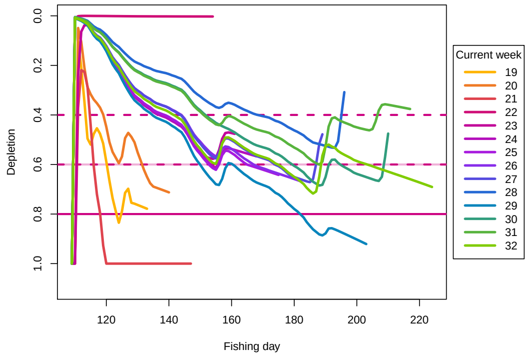

Figure E1: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 1990.

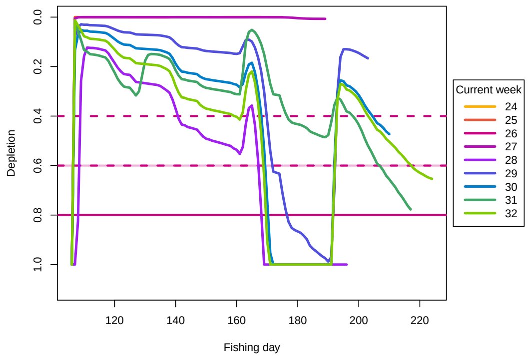

Figure E2: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 1991.

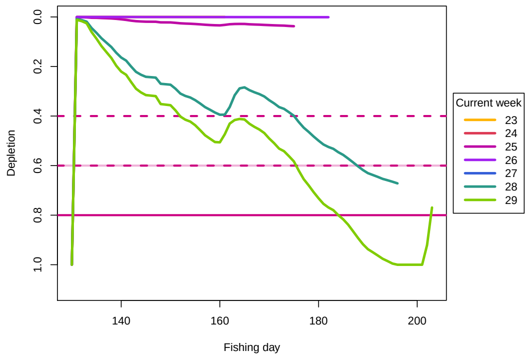

Figure E3: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 1992.

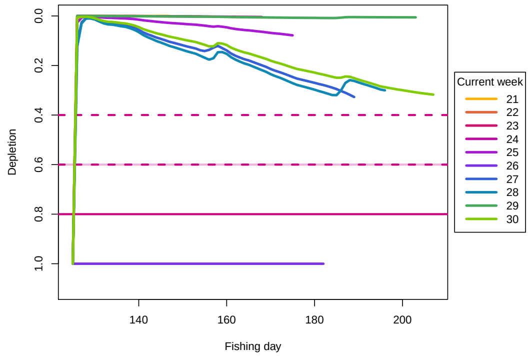

Figure E4: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 1994.

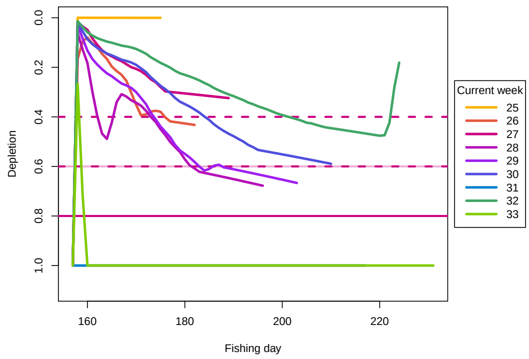

Figure E5: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 1995.

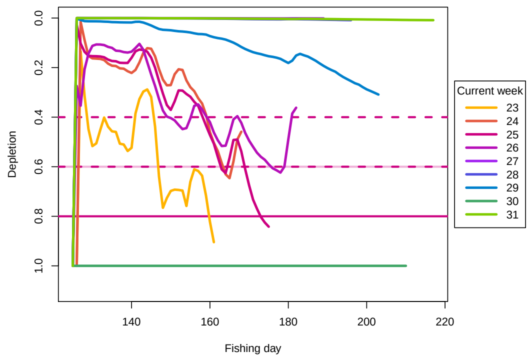

Figure E6: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 1996.

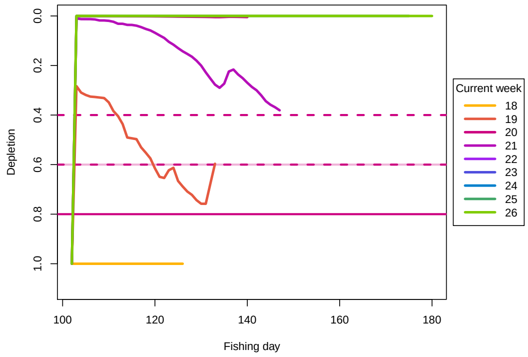

Figure E7: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 1997.

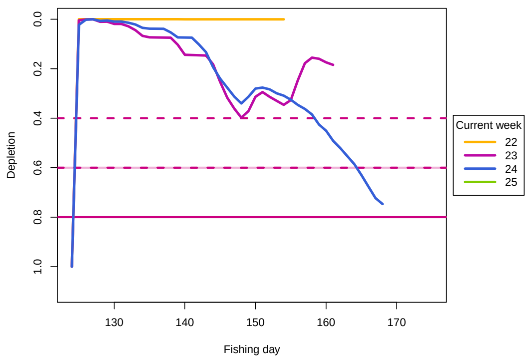

Figure E8: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 1998.

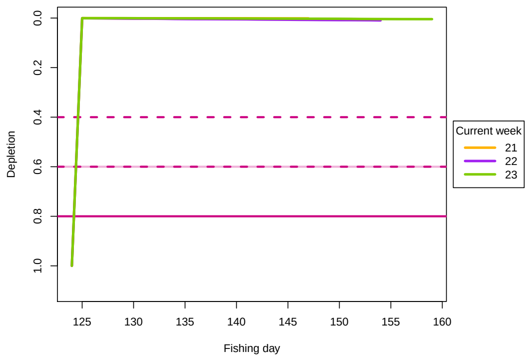

Figure E9: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 2000.

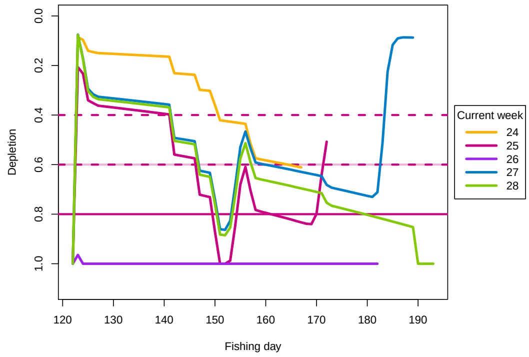

Figure E10: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 2001.

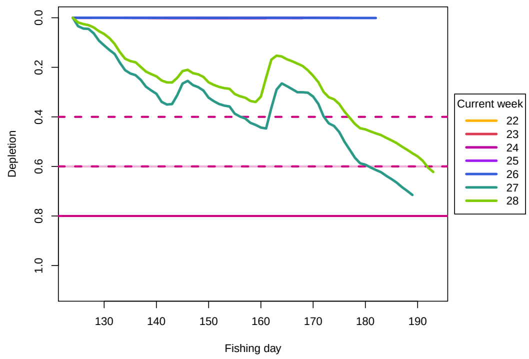

Figure E11: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 2002.

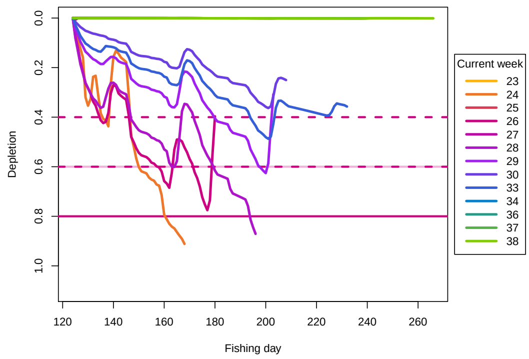

Figure E12: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 2003.

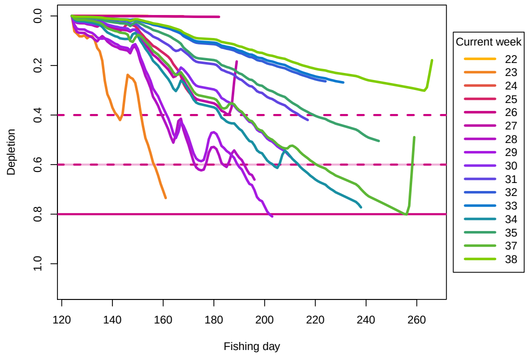

Figure E13: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 2004.

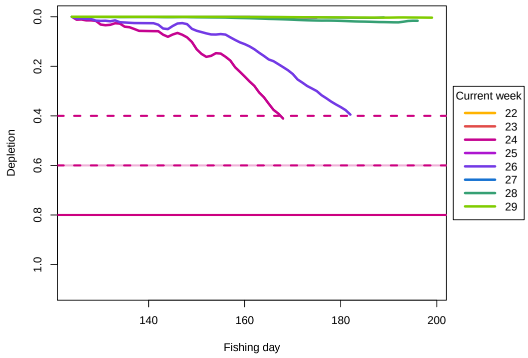

Figure E14: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 2005.

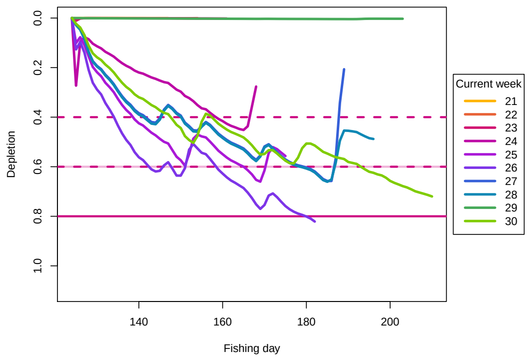

Figure E15: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 2006.

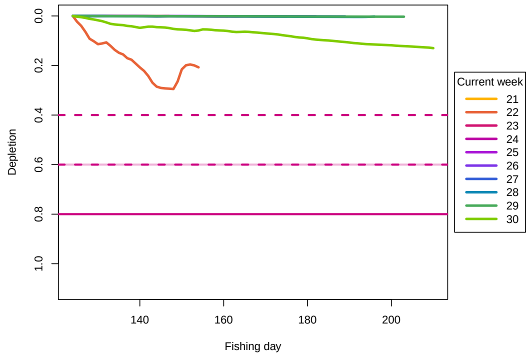

Figure E16: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 2007.

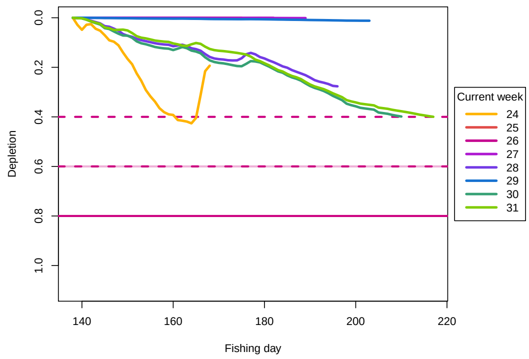

Figure E17: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 2008.

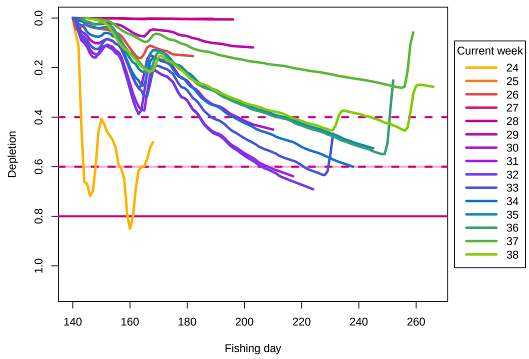

Figure E18: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 2009.

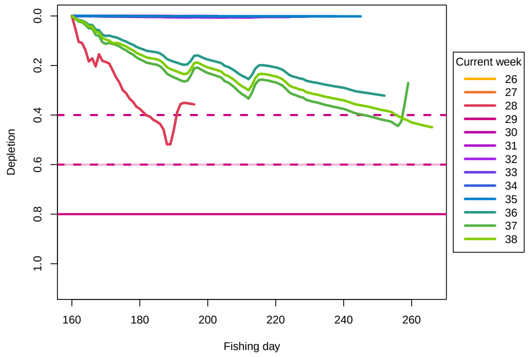

Figure E19: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 2010.

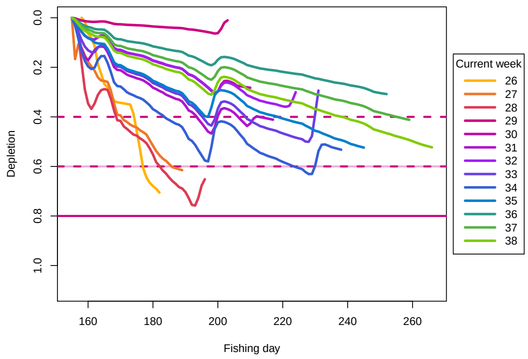

Figure E20: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 2011.

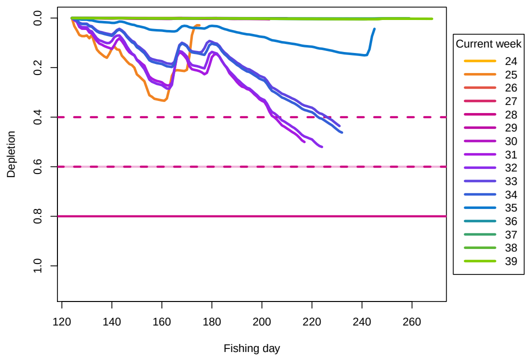

Figure E21: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 2012.

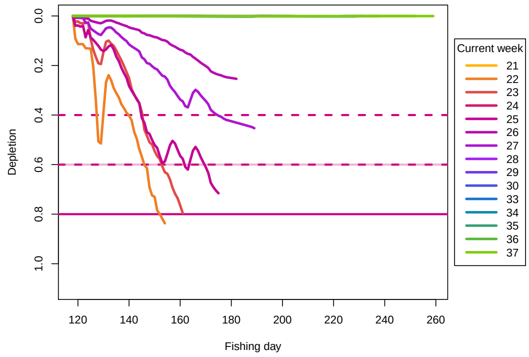

Figure E22: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 2013.

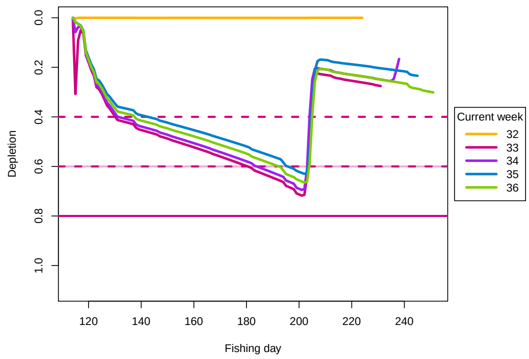

Figure E23: Estimated depletion for each 'current' week (mimicking real-time) for Auckland Islands 2014.

.5.2. Snares

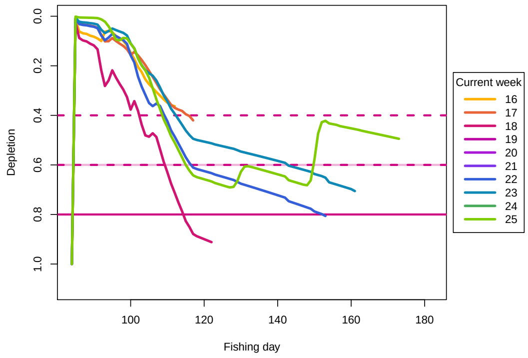

Figure E24: Estimated depletion for each ’current’ week (mimicking real-time) for the Snares 1990.

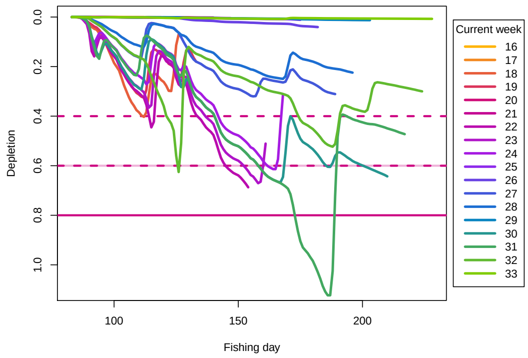

Figure E25: Estimated depletion for each ’current’ week (mimicking real-time) for the Snares 1991.

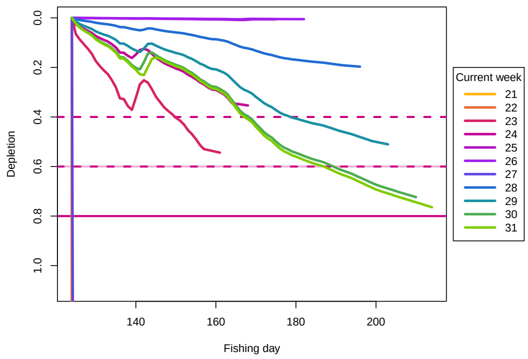

Figure E26: Estimated depletion for each ’current’ week (mimicking real-time) for the Snares 1992.

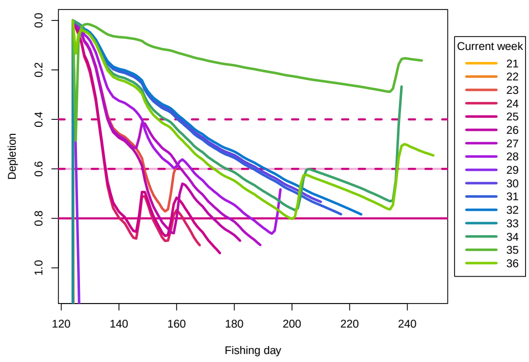

Figure E27: Estimated depletion for each ’current’ week (mimicking real-time) for the Snares 1993.

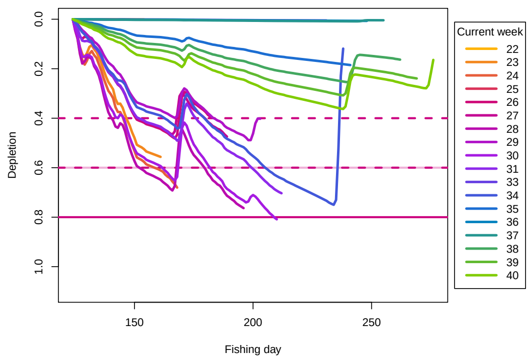

Figure E28: Estimated depletion for each ’current’ week (mimicking real-time) for the Snares 1994.

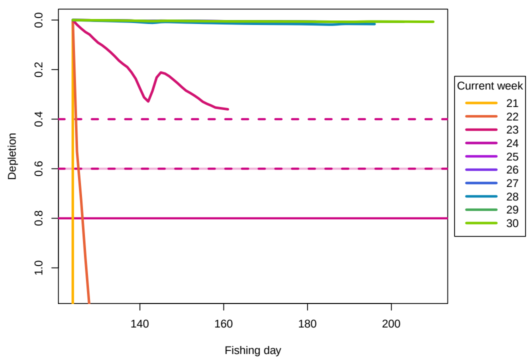

Figure E29: Estimated depletion for each ’current’ week (mimicking real-time) for the Snares 1995.

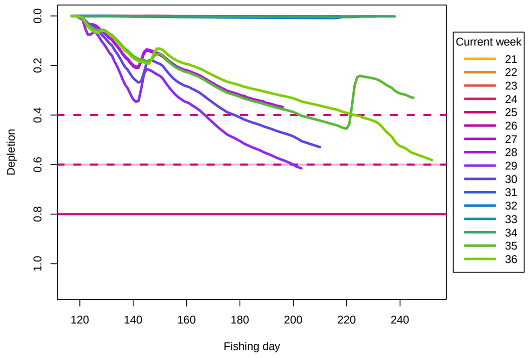

Figure E30: Estimated depletion for each 'current' week (mimicking real-time) for the Snares 1996.

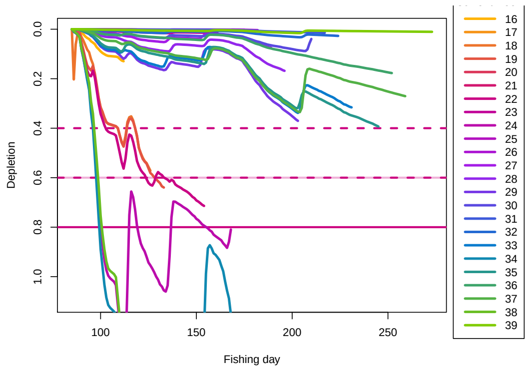

Figure E31: Estimated depletion for each 'current' week (mimicking real-time) for the Snares 1997.

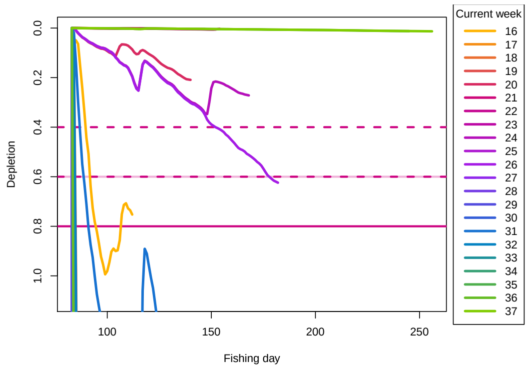

Figure E32: Estimated depletion for each 'current' week (mimicking real-time) for the Snares 1998.

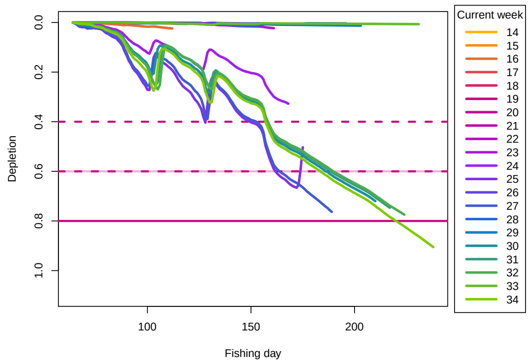

Figure E33: Estimated depletion for each ’current’ week (mimicking real-time) for the Snares 1999.

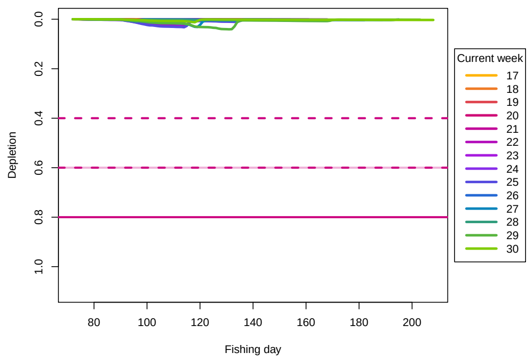

Figure E34: Estimated depletion for each ’current’ week (mimicking real-time) for the Snares 2000.

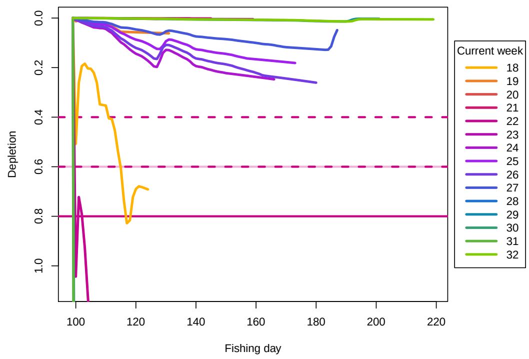

Figure E35: Estimated depletion for each ’current’ week (mimicking real-time) for the Snares 2001.

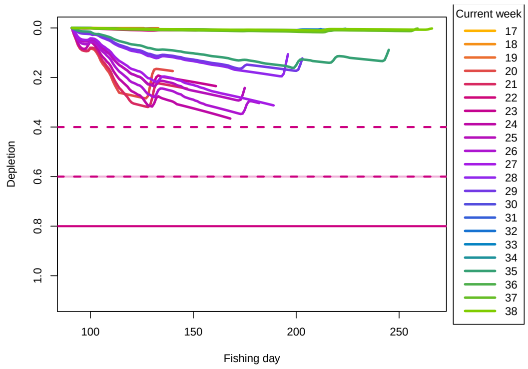

Figure E36: Estimated depletion for each 'current' week (mimicking real-time) for the Snares 2002.

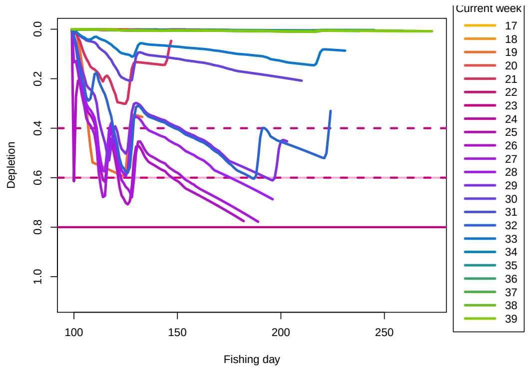

Figure E37: Estimated depletion for each 'current' week (mimicking real-time) for the Snares 2003.

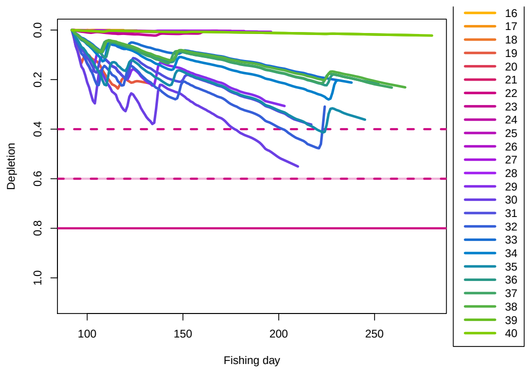

Figure E38: Estimated depletion for each 'current' week (mimicking real-time) for the Snares 2004.

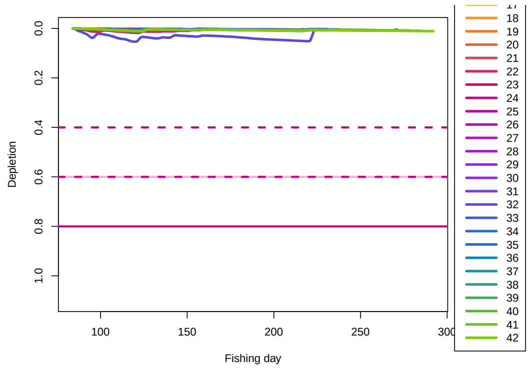

Figure E39: Estimated depletion for each 'current' week (mimicking real-time) for the Snares 2005.

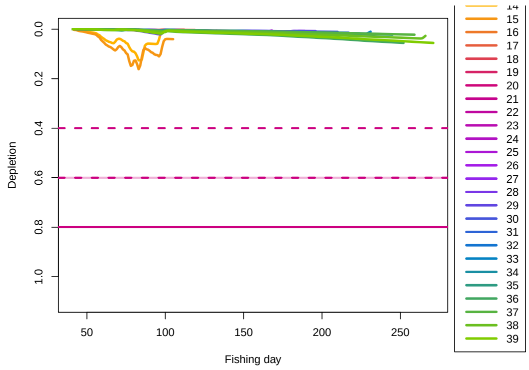

Figure E40: Estimated depletion for each 'current' week (mimicking real-time) for the Snares 2006.

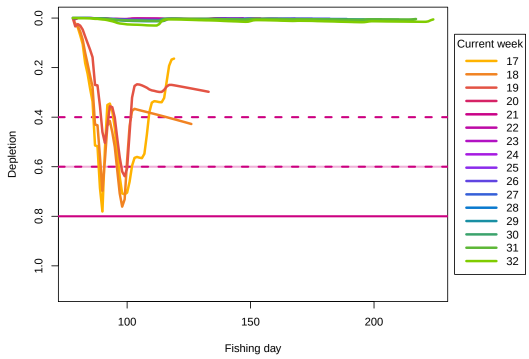

Figure E41: Estimated depletion for each 'current' week (mimicking real-time) for the Snares 2007.

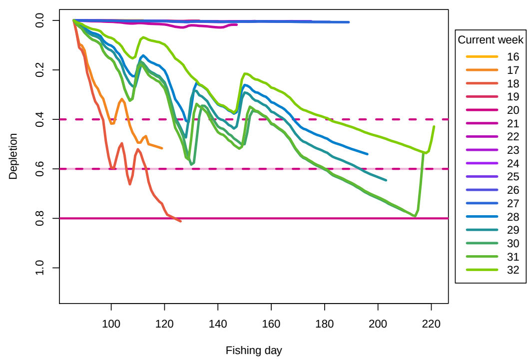

Figure E42: Estimated depletion for each ’current’ week (mimicking real-time) for the Snares 2008.

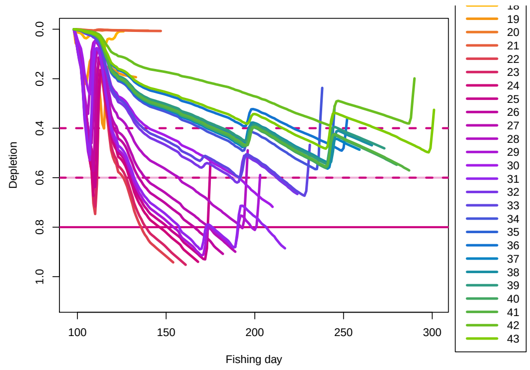

Figure E43: Estimated depletion for each ’current’ week (mimicking real-time) for the Snares 2009.

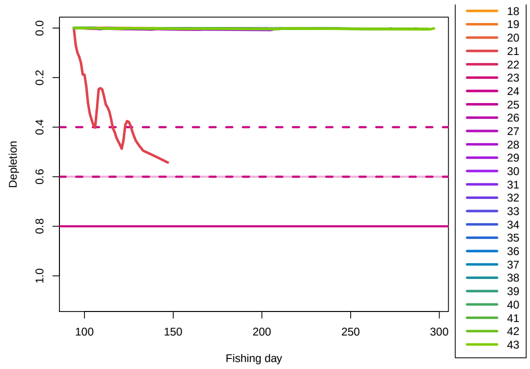

Figure E44: Estimated depletion for each ’current’ week (mimicking real-time) for the Snares 2010.

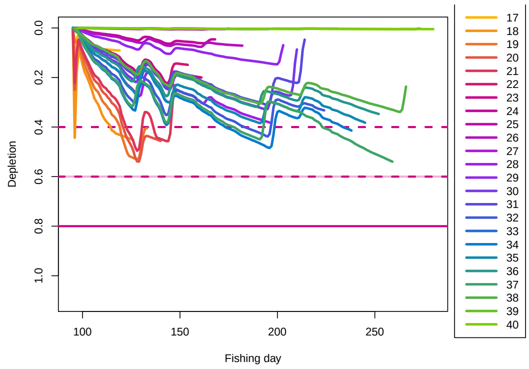

Figure E45: Estimated depletion for each 'current' week (mimicking real-time) for the Snares 2011.

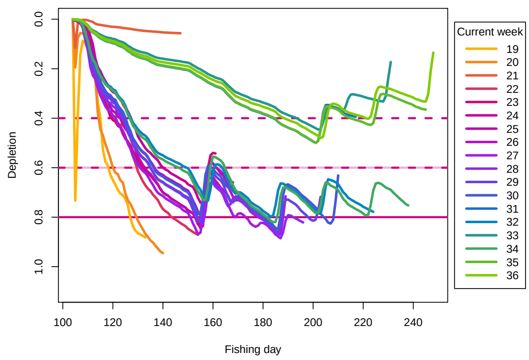

Figure E46: Estimated depletion for each 'current' week (mimicking real-time) for the Snares 2012.

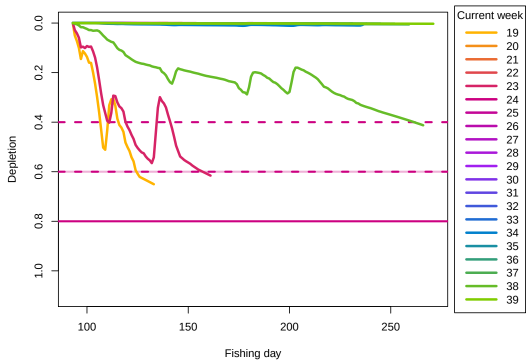

Figure E47: Estimated depletion for each 'current' week (mimicking real-time) for the Snares 2013.

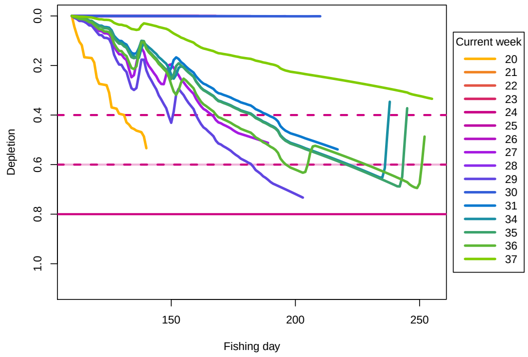

Figure E48: Estimated depletion for each ’current’ week (mimicking real-time) for the Snares 2014.