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A preliminary evaluation of depletion modelling to assess New Zealand squid stocks

New Zealand Fisheries Assessment Report 2016/25

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EXECUTIVE SUMMARY

McGregor, V.; Tingley, G.A. (2016). A preliminary evaluation of depletion modelling to assess New Zealand squid stocks.

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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.

However squid have a very different life-cycle, which 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. The population is largest (by number) when it exists as eggs. However the earliest estimation of population size can be made on recruits using either a recruit survey or back-calculating from fishery driven depletion. It is this latter approach that we have investigated in this study.

Assessing squid stocks in-season is possible and has been done for a small number of fisheries. We fitted a De Lury depletion model based on that used in the Falkland Islands *Loligo gahi* fishery to the 2008 Auckland Islands squid fishery data. The intention was to provide an indication as to the likely applicability of this approach for modelling the New Zealand squid fisheries data in-season.

The 2008 Auckland Islands squid fishery dataset was chosen as it had appropriate observer length frequency data, commercial catch and effort data, and length-to-weight conversion parameters. The 2008 data were found to have sufficient signal to fit the depletion model and the modelled catches showed a good fit to the observed catches.

The model was found to be sensitive to changes in the assumed value of natural mortality. Further work, including using data from other seasons will be required to help determine an appropriate value or range of values to use in future stock assessments.

In terms of being able to assess this squid stock, this approach looks promising, providing that an appropriate value for natural mortality can be defined or estimated. The approach does need to be tested on a number of other fishery years to evaluate the likelihood that the method will succeed in any given year

1. INTRODUCTION

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. It will have a large standing stock which flows from one year to the next with increases due to growth and recruitment and losses due to natural and fishing mortality.

In contrast, most squid live for only about 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. For squid, the recruitment at the beginning of the season represents the maximum population size in numbers. Individually, the squid grow rapidly in size during the year but the population declines from the initial peak in numbers due to losses attributable to natural and fishing mortality, until, at the end of the season, the population declines to zero. The link between the population in year t_1 and that in year t_2 is through a large population of eggs which develop and hatch to produce the larval population that will eventually recruit as squid to the fishery. The population is largest (by number) 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 have investigated in this study.

Assessing squid stocks in-season is possible and has been done for a small number of fisheries, principally for the Patagonian shelf (Falklands/Argentina) stocks of *Doryteuthis (Loligo) gahi* and *Illex argentines* where De Lury (depletion) models have been successfully applied (Rosenberg et al. 1990; Beddington et al. 1990, Basson et al. 1996, Agnew et al. 1998). For a depletion assessment to work, the fishery needs to deplete the population during the fishing season to create sufficient contrast to enable the model to fit the observed data.

The input data needs are defined by the modelling approach and as the De Lury method calculates population size in numbers of animals rather than in biomass, specific data are required. The data required are (i) total catches (landings and discards) by weight, (ii) weight-based catch-per–unit-effort (CPUE), (iii) within-season biological time-series of length and weight, and, if there is sexual dimorphism in size, sex. Sexual maturity can also be informative in defining the probable onset of spawning and death. Weight-at-length and length distributions throughout the season are needed to accurately convert CPUE in weight into CPUE in numbers via a length-weight relationship.

To manage the squid fisheries, the New Zealand Exclusive Economic Zone (EEZ) is split into four Quota Management Areas (QMAs) (Figure 1). This analysis focussed on the trawl fishery that operates in QMA SQU 6T. This fishery was selected as previous work had shown that there was adequate biological data available and that the fishery did have a noticeable effect on CPUE (Hurst et al. 2012). As is seen in other squid fisheries, the recorded landings from the Auckland Islands fishery are highly variable between years (Figure 2). The landings have usually been well below the TACC, except for 1994 and 2004 (note that the fishing year 1 October – 30 September is represented by the latter year, e.g. 1993/94 becomes 1994).

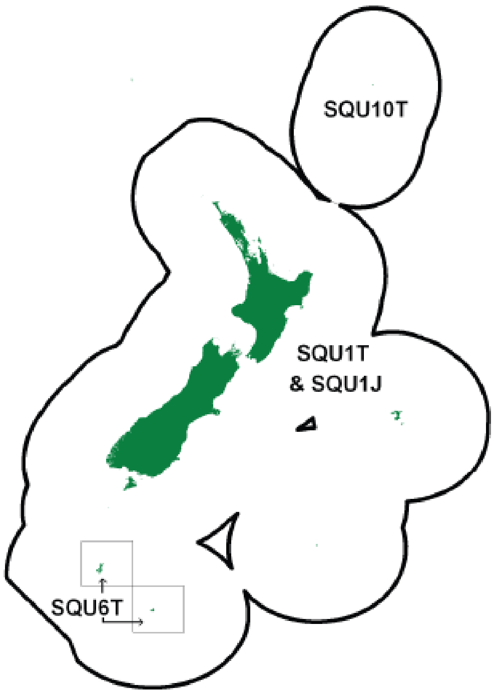

Figure 1: The New Zealand EEZ and Quota Management Areas (QMAs) for squid.

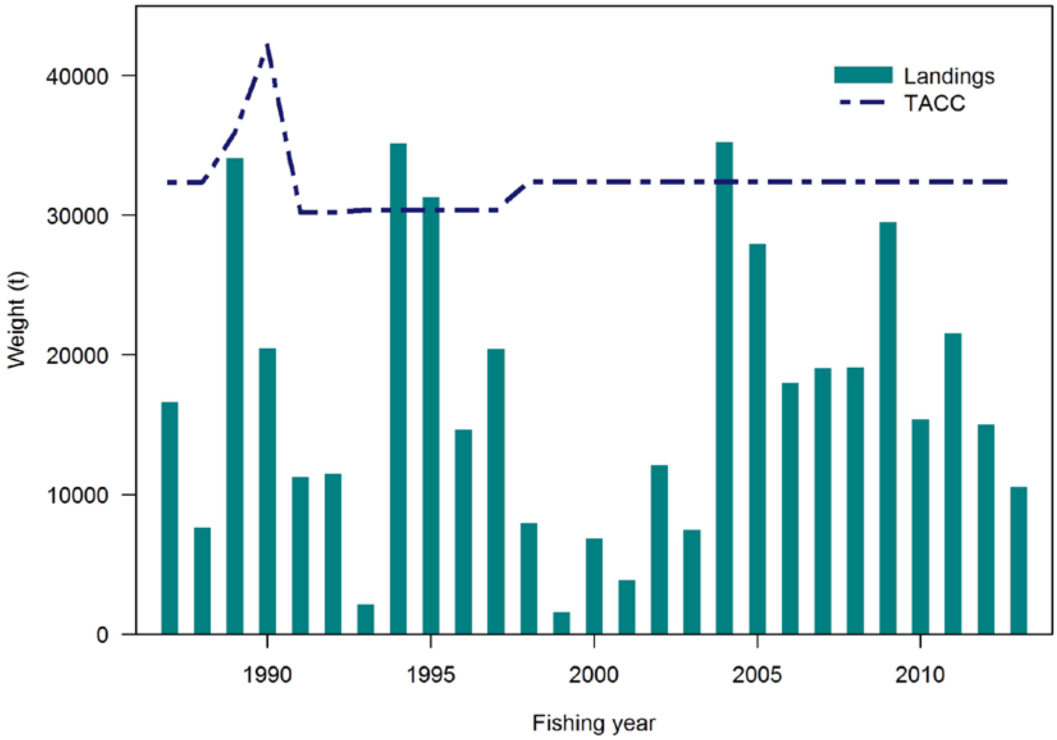

Figure 2: Annual reported landings and Total Allowable Commercial Catch (TACC) limits for the Auckland Islands (SQU 6T) commercial squid fishery.

This analysis draws extensively on the work of (Hurst et al. 2012), including for example, consideration of age, growth, and initial ideas on cohort structure and timing of the peak in CPUE in the Snares Shelf fishery. This project has neither repeated nor updated this work but has taken the existing state of knowledge and developed it where necessary to enable initial modelling of some of the historic data.

Using a stock assessment for an annual species to provide advice for management implies the development of a different management paradigm, an issue that is briefly discussed together with options for developing the assessment itself.

2. METHODS

2.1 Biology

2.1.1 Natural mortality

Hurst et al. (2012) found no estimates of natural mortality for New Zealand arrow squid. Roa-Ureta & Arkhipkin (2007) used a daily natural mortality rate of 0.0133 (d^{-1}) for the Falkland Islands *L. gahi* fishery. Other reported values include 0.06 per week (about 0.009 per day) for *L. gahi* in Falkland Islands (McAllister et al. 2004), 0.05–0.25 per week (about 0.007–0.036 per day) for *Loligo forbesi* in the UK (Young et al. 2004) and 0.06 per week (about 0.009 per day) for *Illex argentines* in the Southwest Atlantic (Basson et al. 1995). The depletion model that follows was fitted using M=0.008 (d^{-1}) as the base case and four alternative values (Table 1) to test the sensitivity of the model to the assumed value of natural mortality.

Table 1: Values for natural mortality M (d^{-1}) used in the depletion model.

Model	$M(d^{-1})$	$P(Survive\ 1\ month \mid M) = e^{-M\times 30.5}$
M_{020}	0.0020	0.94
M_{050}	0.0050	0.86
M_{080}	0.0080	0.78
M_{133}	0.0133	0.67
M_{170}	0.0170	0.60

2.2 Characterisation

Only the 2008 fishery was considered. The catch and effort data used were from Hurst et al. (2012). The data were from the Ministry for Primary Industries catch-effort database “warehou” and consisted of all fishing and landing events associated with a set of fishing trips that reported a positive landing of arrow squid. The estimated arrow squid catch associated with the fishing events were reported on Catch Effort Landing Returns (CELR), Trawl Catch Effort Returns (TCER), Lining Trip Catch Effort Returns (LTCER) and Trawl Catch Effort and Processing Returns (TCEPR). Most (99%) of the catch was recorded on forms that recorded latitude and longitude of each trawl tow.

In order to establish an appropriate CPUE index, it was important to consider a dataset that would most likely be representative of abundance. The catch and effort data were assessed with respect to vessel selection, target species, temporal (week or day) and spatial (latitude and longitude) scales.

With respect to target species, it was clear that most of the catch came from declared squid target tows (Figure 3). For the purpose of fitting the CPUE, the dataset excluded all catch and effort from tows not targeting squid.

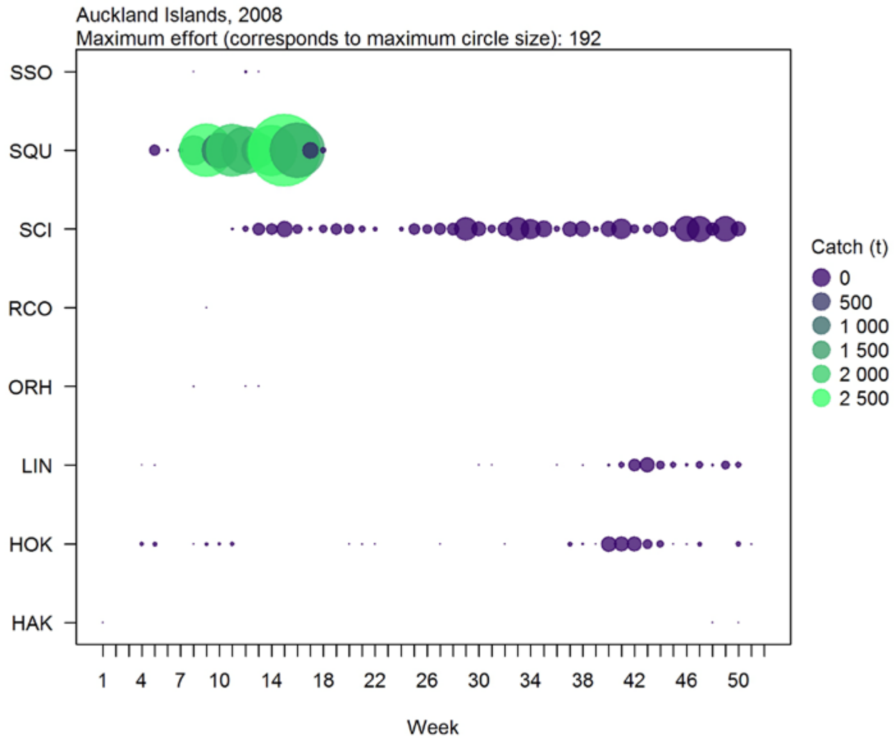

Figure 3: Squid catch and effort by target species and week for the Auckland Islands (SQU 6T) squid trawl fishery in 2008. Effort is the number of tows. Week 1 is the first week in January.

Having selected only those tows where squid were targeted, the spatial distribution was then assessed. Figure 4 shows two distinct fishing locations, while Figure 5 shows the pattern in latitude across all weeks. The dataset of tows south of -50º 24' latitude, the southern fishery, lacked sufficient vessels overlapping across the weeks (Figure 6) to consider a separate CPUE for the southern fishery. The dataset of tows north of -50º 24' latitude, the northern fishery, was similar with respect to the make-up of the fleet as the entire Auckland Islands dataset (Figures 7 and 8).

Two CPUE models were fitted. Model 1 used the dataset from the whole area and Model 2 used the dataset where tows were north of -50º 24' latitude.

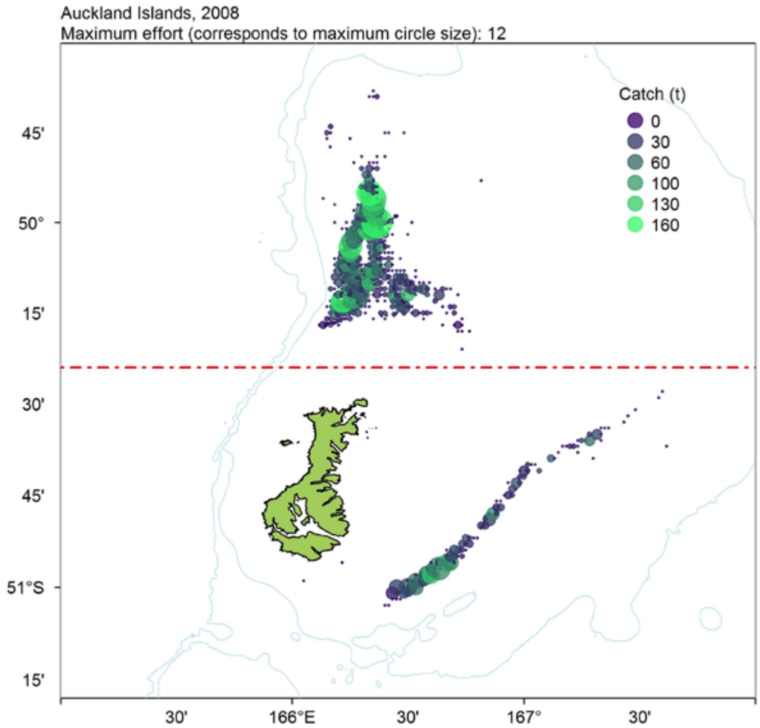

Figure 4: Squid catch (circle colour) and effort (circle size) displayed spatially for the 2008 fishing season for the Auckland Islands (SQU 6T) squid trawl fishery. The red dashed line represents the division between the northern and southern fisheries.

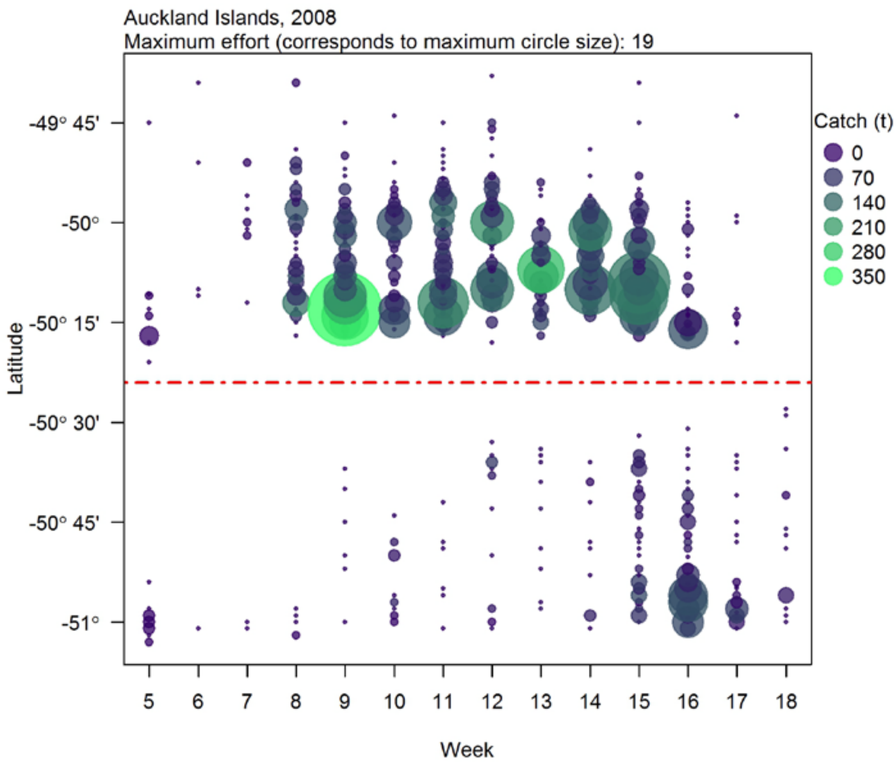

Figure 5: Squid catch (circle colour) and effort (circle size) displayed with respect to latitude and week for the Auckland Islands (SQU6T) squid trawl fishery. The red dashed line represents the division between the northern and southern fisheries. Week 5 is the fifth week in the calendar year.

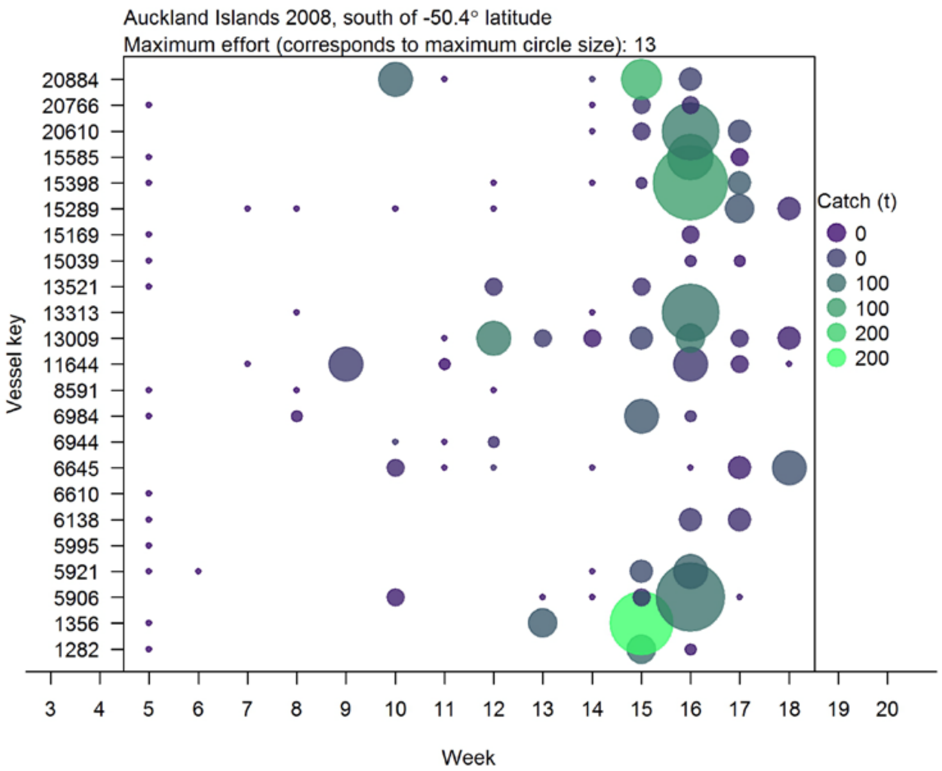

Figure 6: Squid catch (circle colour) and effort (circle size) by vessel and week for the Auckland Islands (SQU 6T) squid trawl, southern fishery, 2008. Week 5 is the fifth week in the calendar year.

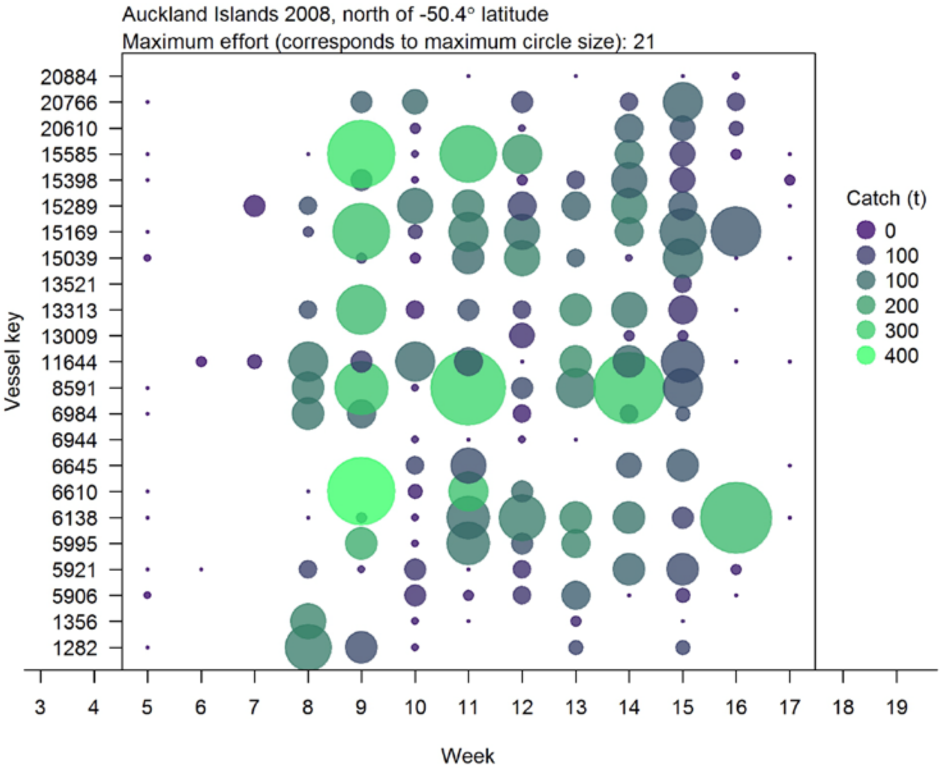

Figure 7: Squid catch (circle colour) and effort (circle size) by vessel and week for the Auckland Islands (SQU 6T) squid trawl, northern fishery, 2008. Week 5 is the fifth week in the calendar year.

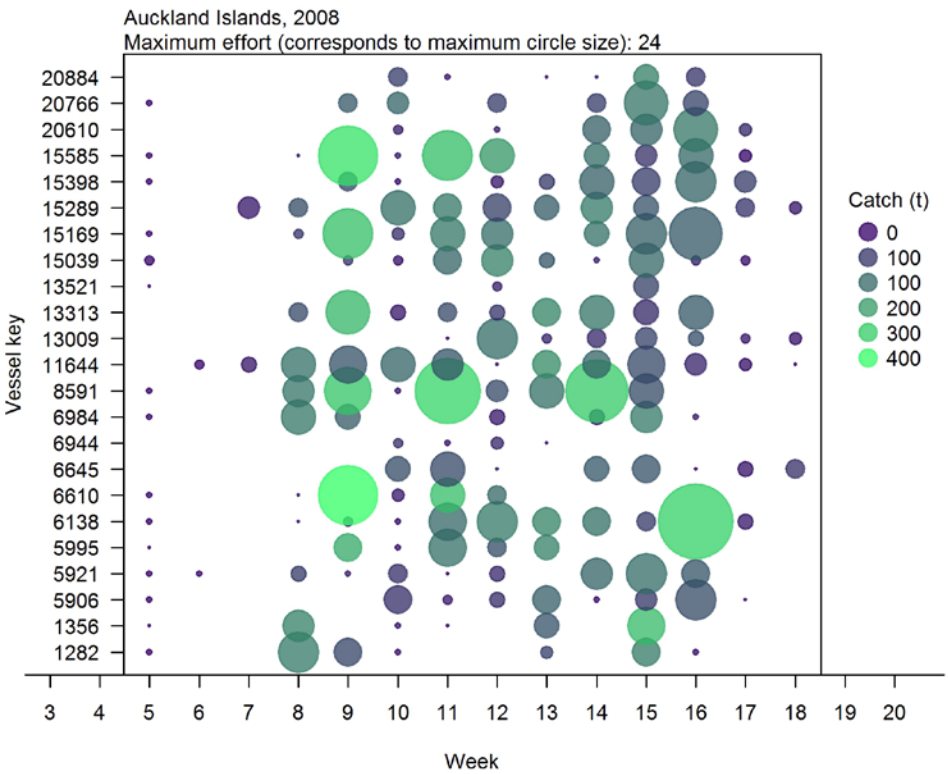

Figure 8: Squid catch (circle colour) and effort (circle size) by vessel and week for the Auckland Islands (SQU 6T) squid trawl, whole fishery, 2008. Week 5 is the fifth week in the calendar year.

2.2.1 Core vessel selection

For both models (Model 1 for the whole area, Model 2 for the area north of -50° 24' latitude), a core fleet of vessels was selected. Core vessels were required to have four or more consecutive weeks with at least four records per week. For Model 1, this retained 19 out of 23 vessels, 93% of the records and 94% of the catch. For Model 2 this retained 17 out of 23 vessels, 93% of the records and 93% of the catch. The fraction of catch retained for Model 1 by week for a range of criteria values are in Table 2 and the fraction of vessels retained, catch retained and records retained over all weeks are in Table 3. An alternative core vessel selection requiring vessels to have three or more consecutive weeks with at least six records per week was investigated for the whole area and this was called Model 1b. This selection retained 21 out of 23 vessels, 98% of the catch and 98% of the records.

Table 2: Fraction of catch retained for core vessels selected with a range of criteria for number of weeks (3 to 5) and number of records per week (4 to 7) for Model 1.

		Week													
n. weeks	n. records	5	6	7	8	9	10	11	12	13	14	15	16	17	18
3	4	0.97	1	1	1	1	0.94	0.99	0.95	0.99	1	0.97	1	1	1
3	5	0.97	1	1	1	1	0.94	0.99	0.95	0.99	1	0.97	1	1	1
3	6	0.97	1	1	1	1	0.94	0.99	0.95	0.99	1	0.97	1	1	1
3	7	0.63	1	1	0.98	0.85	0.84	0.84	0.79	0.95	0.96	0.86	0.89	0.92	0.85
4	4	0.94	1	1	0.86	1	0.85	0.98	0.95	0.91	0.98	0.79	0.96	1	1
4	5	0.57	1	1	0.7	0.81	0.78	0.85	0.85	0.86	0.92	0.66	0.85	0.83	1
4	6	0.53	1	1	0.57	0.73	0.77	0.77	0.65	0.76	0.85	0.5	0.74	0.73	0.85
5	4	0.55	1	1	0.7	0.69	0.75	0.7	0.69	0.68	0.9	0.6	0.83	0.81	1
5	5	0.55	1	1	0.7	0.69	0.75	0.69	0.61	0.65	0.87	0.57	0.76	0.73	0.85
5	6	0.2	0.77	1	0.51	0.62	0.64	0.68	0.53	0.57	0.78	0.41	0.61	0.69	0.85

Table 3: Fraction of vessels, catch and records retained for core vessels selected with a range of criteria for number of weeks (3 to 5) and number of records per week (4 to 7) over all weeks (5-18) for Model 1.

n.weeks	n.records	Vessels retained	Catch retained	Records retained
3	4	0.91	0.98	0.98
3	5	0.91	0.98	0.98
3	6	0.91	0.98	0.98
3	7	0.78	0.88	0.89
4	4	0.83	0.93	0.94
4	5	0.70	0.81	0.83
4	6	0.57	0.70	0.72
5	4	0.61	0.72	0.76
5	5	0.57	0.70	0.73
5	6	0.43	0.60	0.61

2.3 CPUE

The CPUE model was fitted for the whole area (Model 1), with the alternative core vessel selection (Model 1b) and then for only those tows in the northern fishery (Model 2). The method was the same for all models.

For weeks 9 to 18, a new daily CPUE was fitted at the completion of each week (all series started in week 5). At the completion of each week, the ‘current week’ is the week just completed. For each of these fitted CPUEs, a moving weekly CPUE was created, such that,

$$CPUE_d^{week} = \frac{1}{7}\sum_{i=d-6}^{d}[CPUE_i] \qquad \text{Eqn 1}$$

This was then smoothed, such that,

$$CPUE_d^{smooth} = S\left(CPUE_{1:d}^{week}\right)_d \qquad \text{Eqn 2}$$

where S was the R function *lowess()*, a locally weighted smoothing function. The resulting CPUE time series for the whole area (Model 1) are shown in Figure 9. The first week with a CPUE fitted is week 11 as current weeks 9–10 had fewer than two vessels that met the core vessel selection criteria.

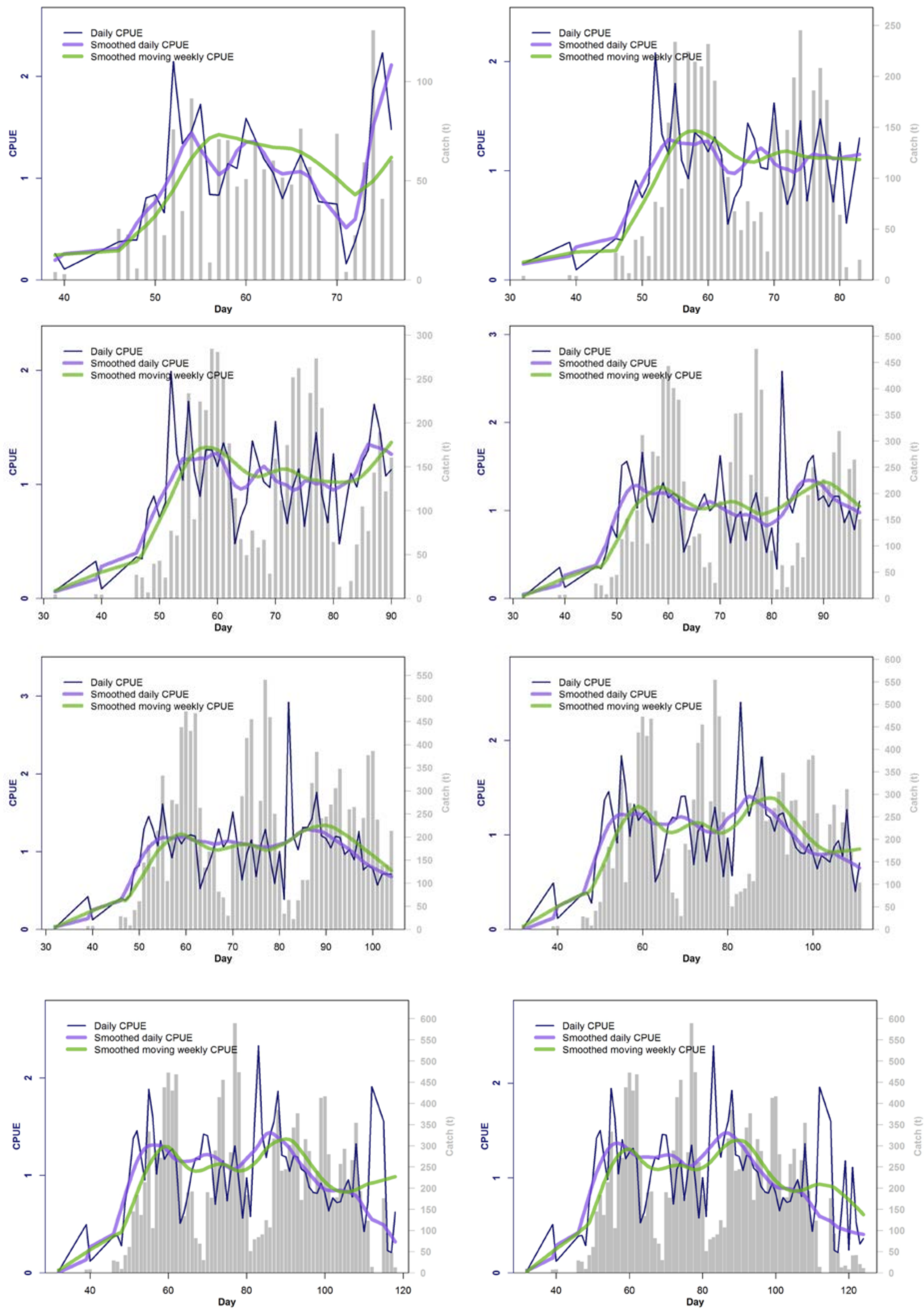

Figure 9: Daily and weekly normalised CPUE series fitted at the completion of each week for weeks 11 to 18 for Model 1 (the whole area).

The smoothed weekly CPUE series (green line) was used to calculate the numbers caught (Section 2.5), which the depletion model was fitted to. The CPUE series at the completion of each week became very similar from about week 12 onwards (Figure 10). The CPUE series for the whole area with the alternative core vessel selection criteria (Model 1a) was very similar to Model 1 (Figure 11). The CPUE series for the northern fishery only (Model 2) was similar to that for the whole area for weeks 11 to 15, but dropped lower from around day 100 (Figure 11). At this stage, only the Model 1 CPUE is used for the depletion model, but if future work is done on this area, fitting to the northern fishery at least as a comparison may be necessary.

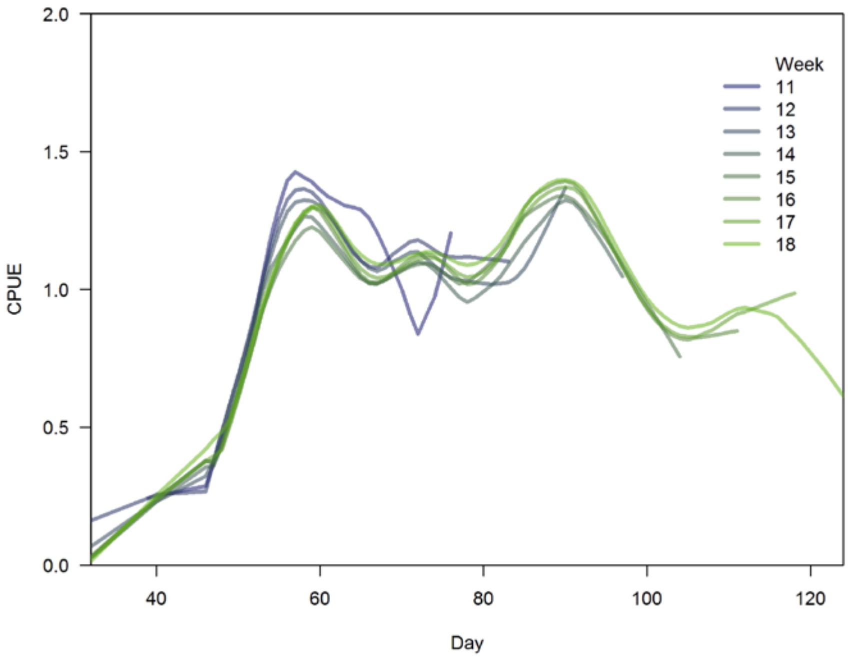

Figure 10: Daily CPUE fitted at the completion of each week for weeks 11 to 18 for Model 1 (the whole area).

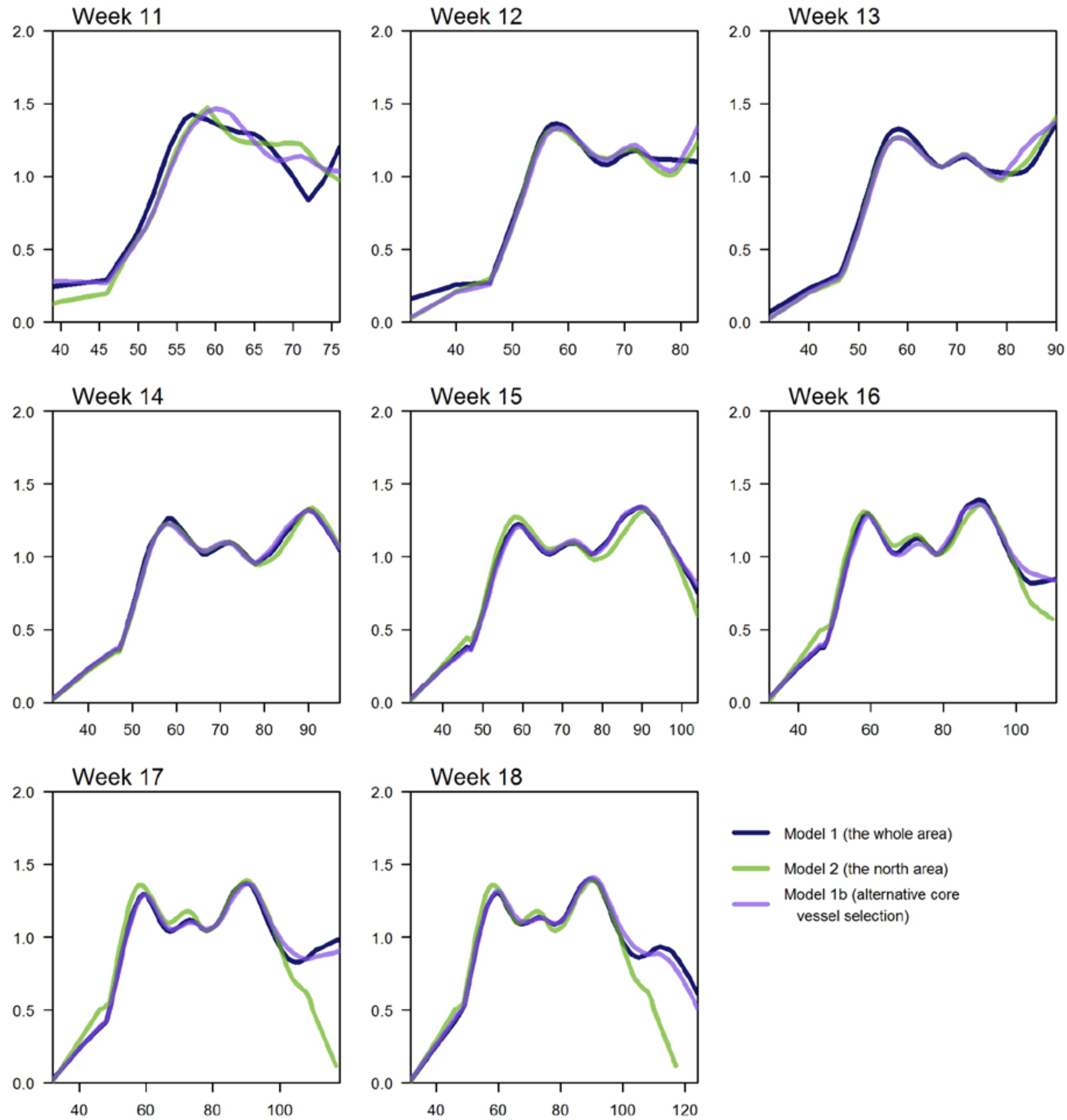

Figure 11: CPUE fitted at the completion of weeks 11 to 18 for the whole area (dark purple line) and for the northern fishery (green line).

2.4 Mean length

The observer data (as described in Hurst et al. (2012)) were used in converting the CPUE (kg/tow) into numbers caught. The mean length for each week and the number of tows sampled each week were assessed with respect to the likely quality of these data for the purpose of the depletion model.

The mean lengths by week for the northern and southern fisheries are shown in Figure 12 and the spatial distribution of the weekly mean lengths in Figure 13. There did not appear to be much pattern in the spatial distribution of mean length, but when the mean length for the northern and southern fisheries separately and combined were compared (Figure 12), the southern fishery can be seen to have had larger animals. However, due to the numbers of tows sampled, the mean lengths in the northern fishery generally had a greater effect on the total mean length for the whole area. Figure 14 shows the spatial distribution of the number of tows sampled by week. Generally, there were more tows sampled in the northern fishery, except in week 16 which had more tows in the southern fishery. This explains why the drop in mean length in the northern fishery in week 16 did not affect the mean length for the whole fishery. This drop in mean also came from only two tows, and is unlikely to be representative of the fishery. A similar situation occurred for other weeks which also have a small number of tows sampled.

The mean length series is quite flat. Given the fast growth rate of squid, the flat series is possibly due to new cohorts coming into the fishery. The representativeness of the series could also be affected by inadequate sampling of the fishery.

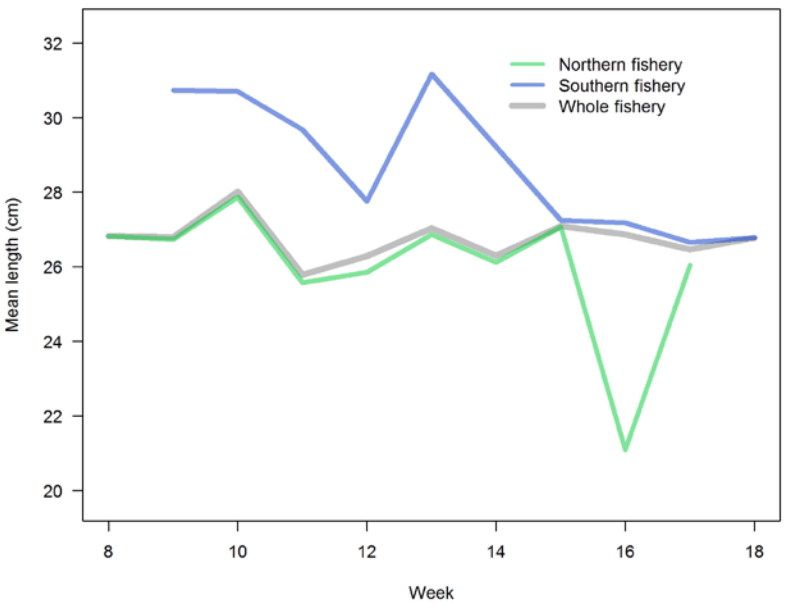

Figure 12: Mean length at week from Observer data for the whole area (grey line), the northern fishery (green line) and the southern fishery (blue line) for weeks 8 to 18.

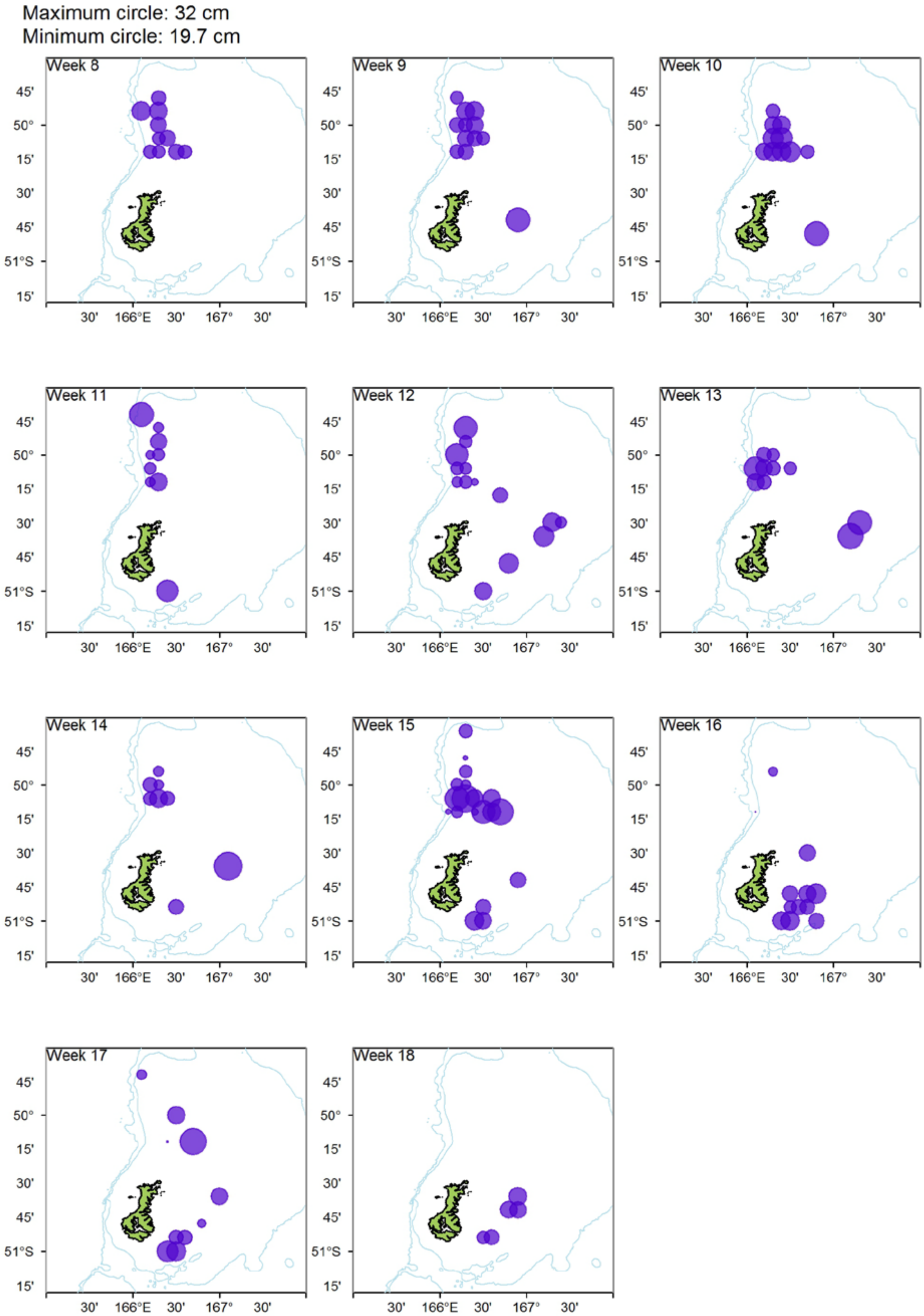

Figure 13: Spatial distribution of mean length as calculated from the Observer data for weeks 8 to 18.

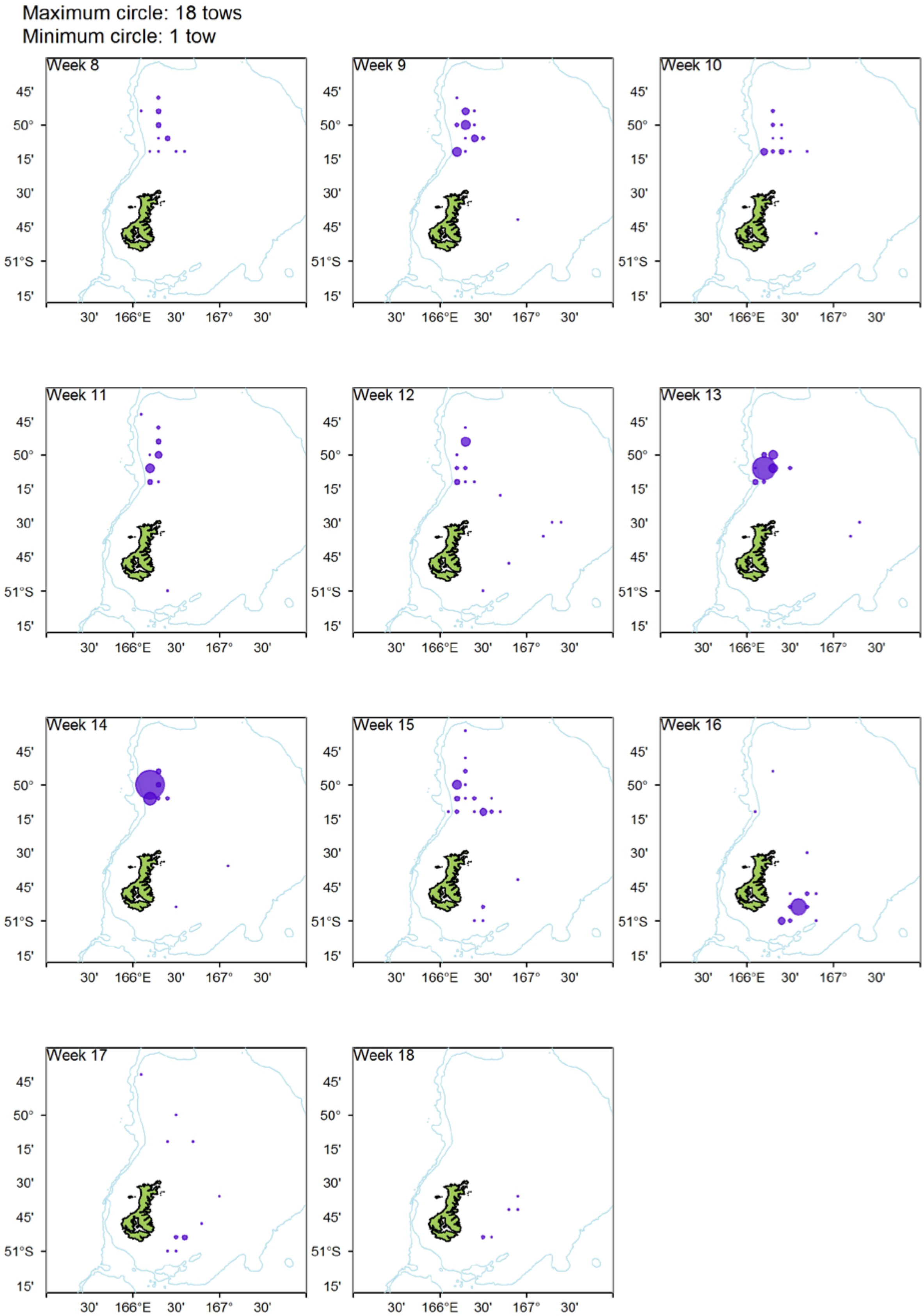

Figure 14: Spatial distribution of number of tows sampled as calculated from the Observer data for weeks 8 to 18.

2.5 Converting CPUE to numbers caught

The depletion model uses numbers caught by week. The standardised CPUE (Section 2.3) was converted to numbers caught by multiplying it by the number of tows in each week and dividing by the mean weight of each squid as calculated from the length frequency distribution.

Mean weight at week w was calculated using the length frequency data from Hurst et al. (2012) such that

$$\mu_w = \left(\frac{\sum_l[\varphi(l_w) \times n_{l,w}]}{\sum_l[n_{l,w}]}\right)/1000 \qquad \text{Eqn 3}$$

where

μ_w is the mean squid weight for week w

l is the length bin such that $l \in \{10, \ldots, 43\}$

$n_{l,w}$ is the number at length l in week w

$\varphi(l)$ is the length to weight conversion function and is such that $\varphi(l|a = 0.0136, b = 3.16) = 0.0136 \times l^{3.16}$

The parameters $a = 0.0136$ and $b = 3.16$ are from Hurst et al. (2012).

The numbers caught in week w were calculated as

$$C_w = \frac{CPUE_w \times T_w}{\mu_w}$$

where

T_w is the number of tows for week w

$CPUE_w$ is the CPUE for week w and is in $\frac{kg}{tow}$

μ_w is the mean weight for week w and is in kg

Once calculated, the vector of numbers caught was then smoothed using the R function *lowess()*, a locally weighted smoothing function.

The resulting numbers caught by week are shown with the smoothed weekly CPUE in Figure 15. The peaks in numbers caught seem to sometimes lag after the peaks in CPUE.

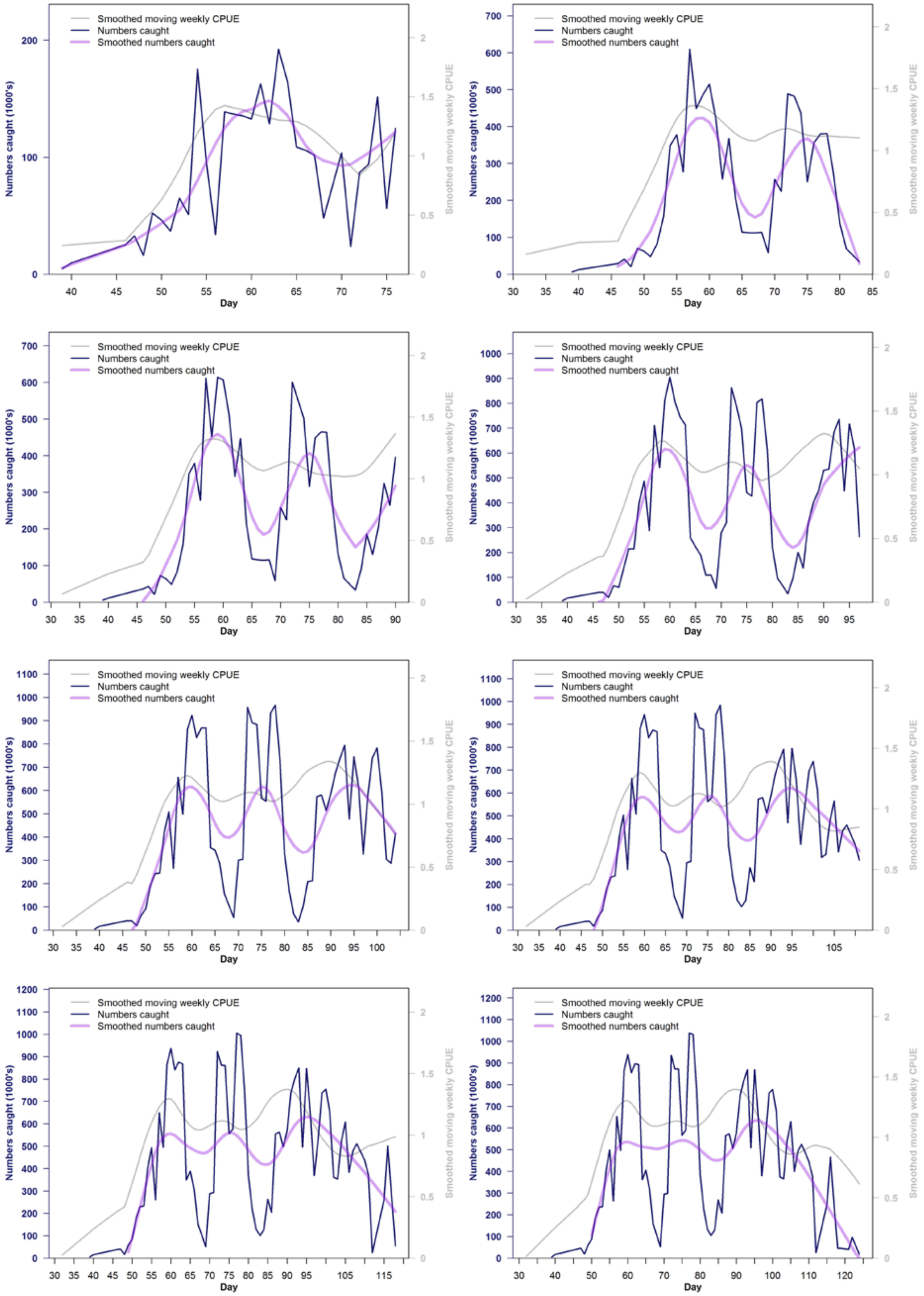

Figure 15: Normalised smoothed CPUE (grey line), numbers caught (dark blue line) and smoothed numbers caught (purple line) for current week=11-18 in 5 day increments, left to right. The first plot starts later as the earlier days dropped out due to core vessel selection.

2.6 Modelling Depletion

Given that the CPUE series was similar for the whole area and the northern fishery for most weeks (Section 2.3), the exploratory nature of this work, and the fact that the whole area had a slightly longer time series, the depletion model was only fitted to the whole area.

2.6.1 Identifying cohorts

Prior to fitting a depletion model to the series of numbers caught, the approximate timing of recruitment of the cohorts were identified by eye, looking for local modes in the numbers caught per tow series. Figure 16 shows the obtained series of numbers caught (Section 2.5) with the estimated recruitment of the separate cohorts shown as grey dotted lines. At most, there appear to be four recruitment cohorts.

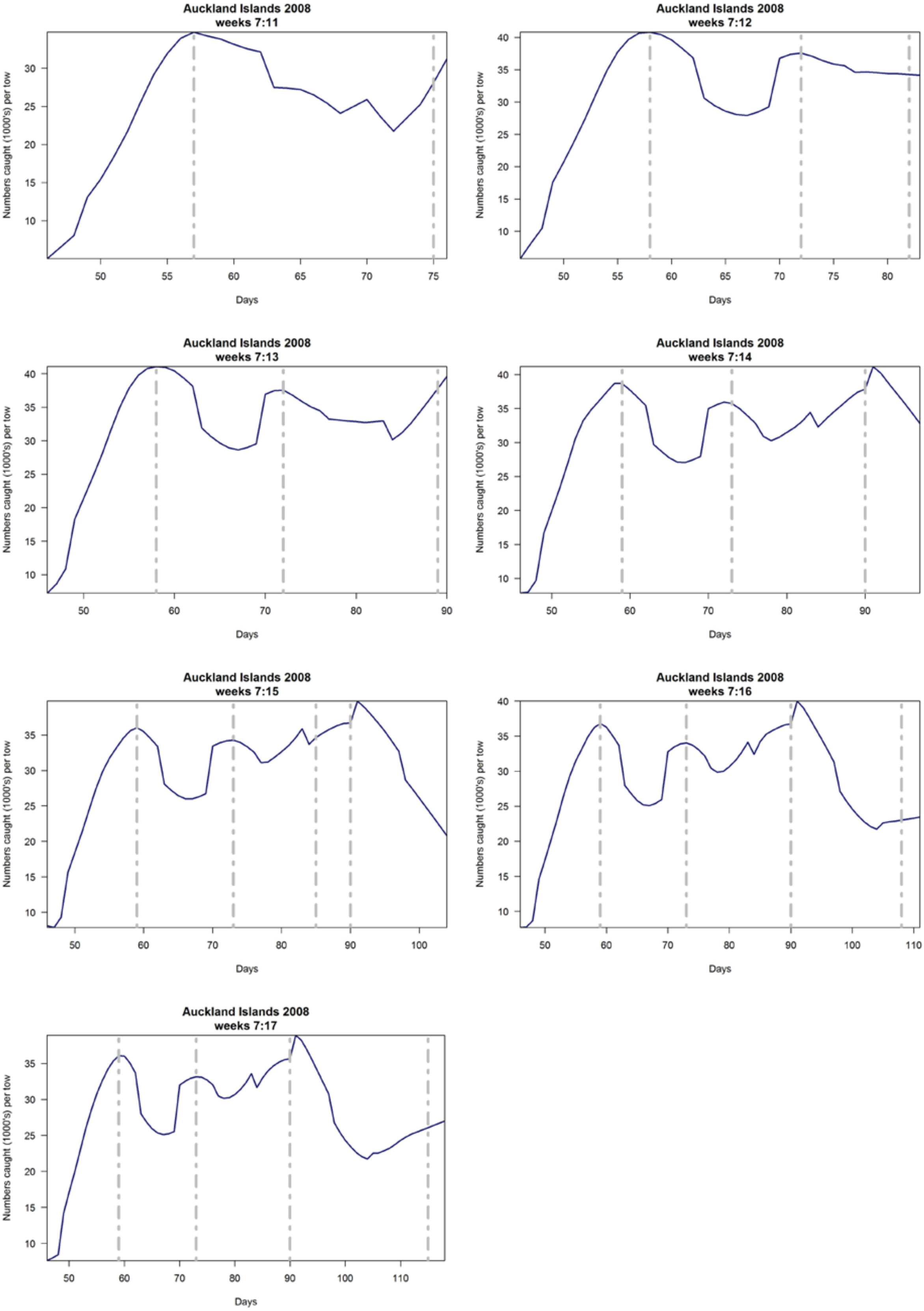

Figure 16: Estimated cohort peaks (recruitment) shown on the numbers caught (thousands) per tow for current week=11:17.

2.6.2 Depletion model

The depletion model fitted was based on that used in the Falkland Islands (Roa-Ureta, 2012). This depletion model allowed for pulses of recruitment (cohorts) to enter the population. The timing of recruitment of each cohort was estimated (by sight in this case) prior to fitting the depletion model (Section 2.6.1). The depletion model (represented by Equation 4) estimated the number of squid in each cohort. The symbols in Equation 4 are defined in Table 4.

The Falklands model could also allow for relaxation of the assumption that response of catch to effort and abundance is directly proportional, through the hyper-parameters α and β in Equation 4. These parameters allow for hyperstability and hyperdepletion. They were not used in this case (both α and β were set to 1) as it was believed that there would not be sufficient information in the data to estimate these adequately and to validate their appropriateness would require testing across a more extensive dataset.

$$C_t = kE_t^{\alpha} N_t^{\beta} e^{\frac{-M}{2}}$$
$$= kE_t^{\alpha}\left(N_0 e^{-Mt} + \sum_j \left(P_j \mathbb{I}_{\{D_j \le t\}} e^{-M(t-D_j)}\right) - e^{\frac{-M}{2}} \sum_{i=1}^{t-1}\left(C_i e^{-M(t-i-1)}\right)\right)^{\beta} e^{\frac{-M}{2}} \qquad \text{Eqn 4}$$

Free parameters: N_0, $\{P_i\}$, k

$$\mathbb{I}_{\{D_j \le t\}} = \begin{cases} 1, & D_j \le t \\ 0, & otherwise \end{cases}$$

Table 4: List of symbols used in mathematical notation.

Description	Symbol
Expected catch (millions of animals)	C
Effort (number of tows)	E
Abundance (millions of animals)	N
Time-step (days)	t
Scaling (1/number of tows)	k
Abundance response	α
Effort response	β
Natural mortality (1/day)	M
Initial abundance (millions of animals)	N_0
Perturbation index	j
Abundance perturbations (cohorts) (millions of animals)	$\{P_j\}$
Timing of abundance perturbations (days)	$\{D_j\}$

The model was run for each week, with the depletion at the end of each week calculated as,

$$depletion_w = 1 - \frac{population|fishing}{population|\ no\ fishing} \qquad \text{Eqn 5}$$

The depletion is not a prediction of the final depletion for the season, but an estimation of what the depletion was at the conclusion of each week of fishing. To predict future population size as the end of the season is approached (i.e. beyond the ‘current’ week) more work will be required to assess inter-annual patterns, and to determine typical (and the range of) end of season effort patterns.

The sensitivity of the model to assumptions about natural mortality (M) was tested. The model was run using a range of values of M (Table 1) and the estimated depletion at each week compared. $M = 0.008$ (Model M_{080}) was considered the base case.

3. RESULTS

3.1 Estimated Depletion

For the base model ($M = 0.008$), the depletion calculated at each week generally sat around 20–40% and dropped to 7% in week 14 (Table 5).

Table 5: Estimated depletion for current weeks 11 to 17.

Weeks 8:11	Weeks 8:12	Weeks 8:13	Weeks 8:14	Weeks 8:15	Weeks 8:16	Weeks 8:17
29%	24%	17%	7%	43%	38%	29%

The estimates of depletion were sensitive to the assumed fixed value of M. Figure 17 shows the depletion calculated at the conclusion of each week for the various assumed values of M. When natural mortality was lower, depletion was generally higher. The log-likelihoods which are minimised for each model are shown in Figure 18. Generally, and especially for weeks 13–15, the log-likelihood tends to be bigger for larger values of M, suggesting a worse fit to the data.

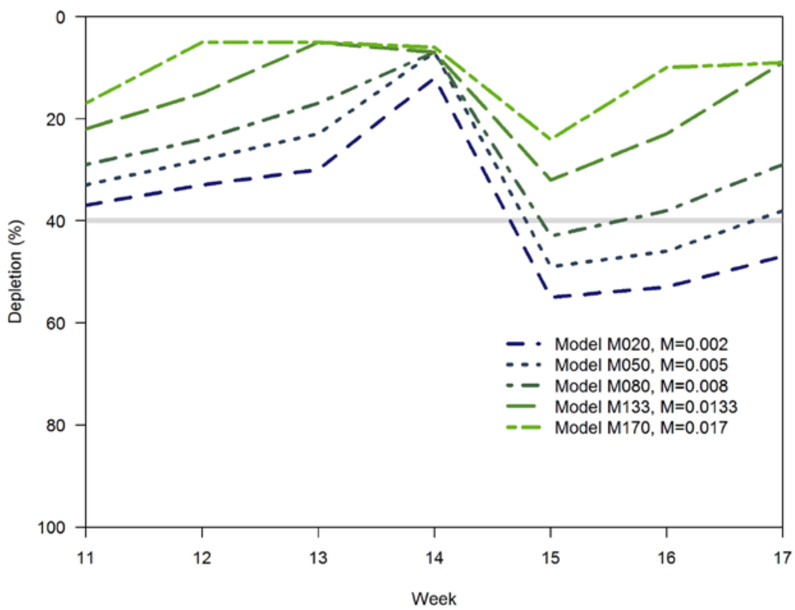

Figure 17: Depletion calculated at each week 11-17 for six different values of M.

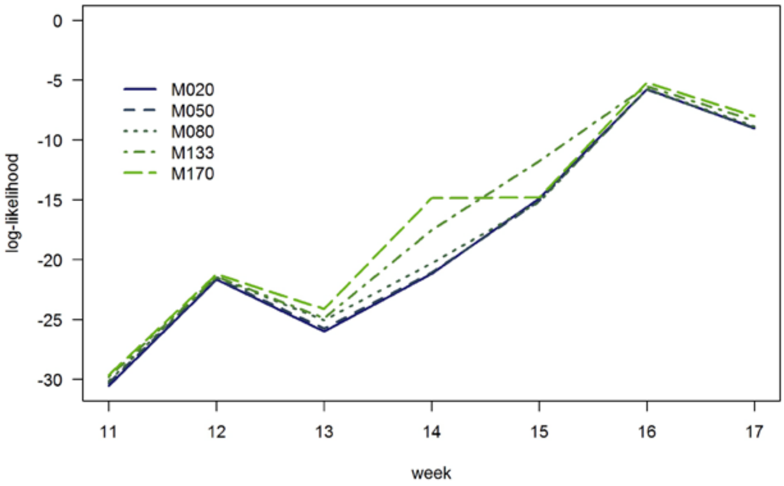

Figure 18: Calculated log-likelihood at each week for models M020-M170.

For the base model ($M = 0.008$), the fits to the data were consistently good (Figures 19 and 20). The model was fitted to the numbers caught, and the effort (number of tows) was entered. Hence, when the fitted numbers caught were multiplied by the number of tows as in Figure 19, the model fitted the observed zeros perfectly where these points had zero tows. The number of squid estimated in each cohort are in Table 6.

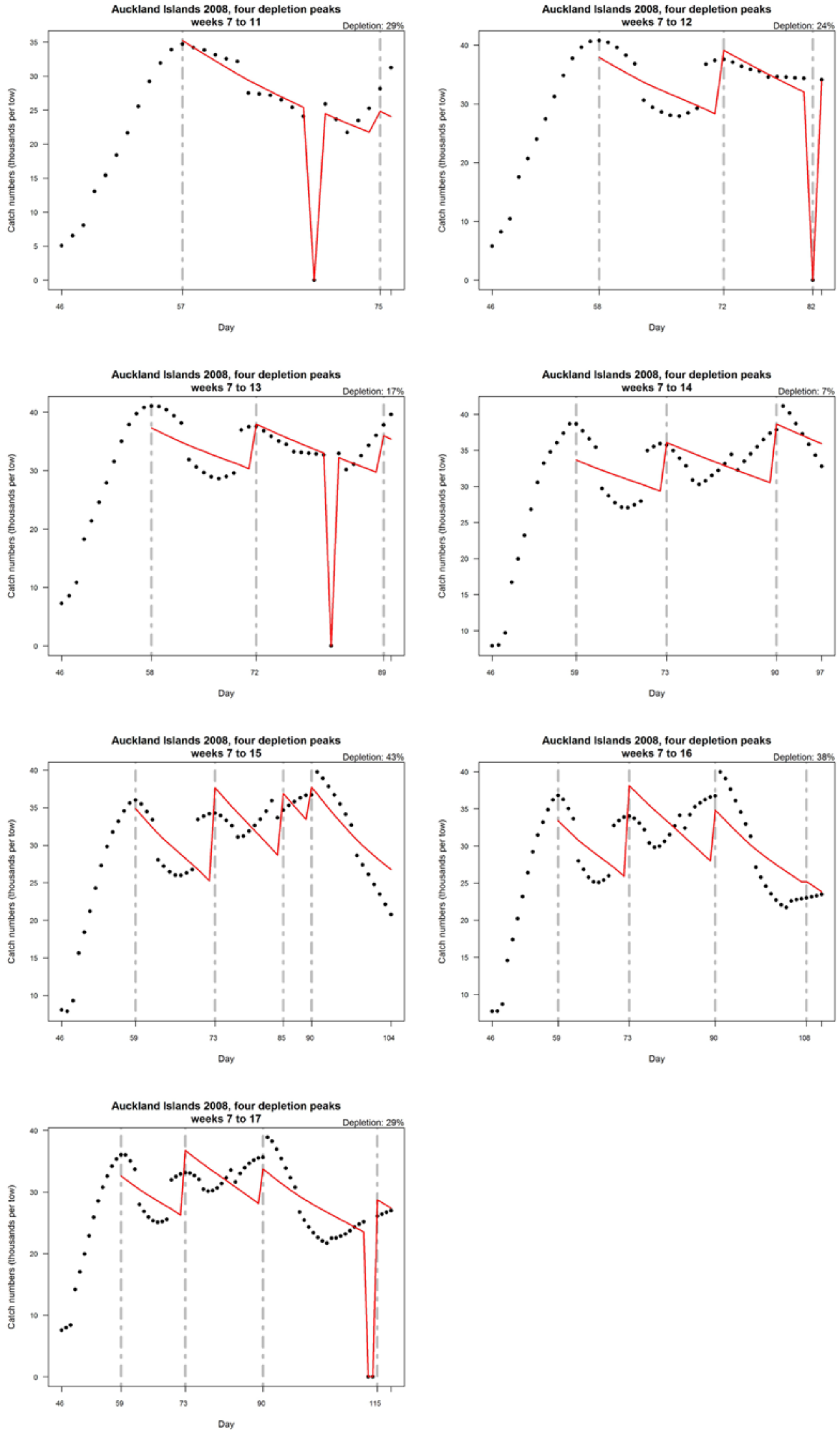

Figure 19: Fits of the base case depletion model (red line) to the catch in numbers (thousands) per tow data (black circles) for current weeks 11 to 17.

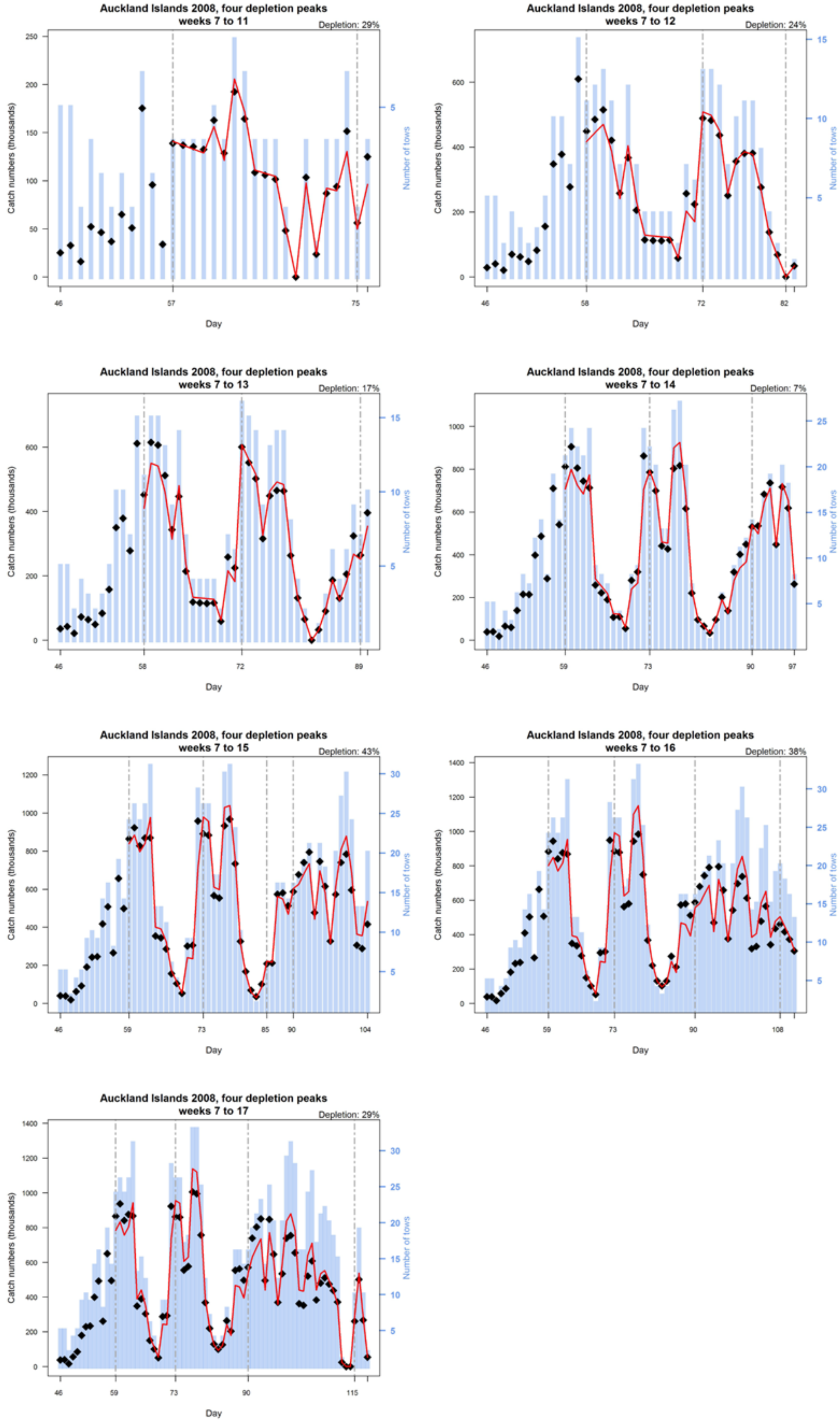

Figure 20: Fits of the base case depletion model (red line) to the catch in numbers data (black diamonds) for current weeks 11 to 17. Blue bars are the number of tows in each day.

Table 6: Estimated numbers (millions) from the base case depletion model for the cohorts at the conclusion of each week 11 to 17. The initial and largest cohort is highlighted blue.

Week 11		Week 12		Week 13		Week 14		Week 15		Week 16		Week 17	
No.	**Day**	**No.**	**Day**	**No.**	**Day**	**No.**	**Day**	**No.**	**Day**	**No.**	**Day**	**No.**	**Day**
1.6	57	2.7	58	4.8	58	13.6	59	2.1	59	3.8	59	3.8	59
0.2	75	0.8	72	1.1	72	2.9	73	0.8	73	1.1	73	1.3	73
		0.2	82	0.9	89	3.4	90	0.5	85	0.7	90	0.7	90
								0.3	90	0.04	108	0.7	115

4. DISCUSSION

This approach to stock assessment has been successfully applied to the squid stocks around the Falkland Islands (Rosenberg et al. 1990; Beddington et al. 1990, Basson et al. 1996, Agnew et al. 1998), and it was therefore thought it that it might work for New Zealand squid stocks.

The CPUE from the 2008 fishing season in SQU 6T does have sufficient signal to enable the depletion model to be fitted, a core requirement of this approach. The model was also able to fit to the data convincingly. For an in-season management strategy that relies on estimating the current depletion as the season progresses, this looks a promising approach.

The approach used here of smoothing the CPUE was done to make the model more robust, but may not be ideal for this and hence fitting the model to non-smoothed data should be considered in future work.

In conclusion, the findings presented here suggest that this approach may be appropriate, but they remain preliminary and leave a number of issues to be further addressed.

Prior to considering developing a full-scale or trial in-season implementation of this assessment approach, those areas identified for further investigation should be explored, especially where appropriate data are available. These should be the subject of a follow-on project. Specifically these areas of work include:

- Defining the proportion of fishing years where the squid fishery has generated a decline in CPUE sufficient to enable an adequate model fit to be achieved.
- Defining relevant parameters that describe the recruitment of individual cohorts (timing, cohort size, mean length and mean weight).
- Understanding inter-annual patterns in weight-at-length, in recruitment, and in the spatial distribution of abundance and mean length.
- Exploring the range of plausible values of natural mortality, M.

An appropriate value, or range of values for natural mortality are yet to be determined. The depletion estimated in this study suggested that there was sensitivity to changes in natural mortality, with depletion generally higher for lower values of M. There was also some variability in the quality of the fit of predicted values of catch to observed catches in response to changing M. This does not seem to have a pattern linking it with natural mortality and possible causes need further investigation. It may be that there is a more appropriate likelihood function for this model and data. Roa-Ureta (2012) tested both normal and lognormal likelihood functions for each situation, with the most appropriate decided on a case-by-case basis. In this study, the lognormal model was used.

5. MANAGEMENT IMPLICATIONS

With a more-or-less annual life-cycle and lack of a standing stock spanning more than one year, squid fisheries require a different management approach to most longer lived fish species. Essentially, the setting of a fixed annual or multiyear total allowable catch (TAC) is inappropriate for squid fisheries as this will fail to protect the stock in years of low recruitment and will also lead to under-exploitation in years with very large recruitments.

There are, however, other approaches to management that could provide for sustainable exploitation. These include, a very precautionary fixed TAC, or a TAC that is updated within the season based on some assessment of the stock early in the season (typically a pre-recruit or new recruit vessel-based survey), or updated by an in-season stock assessment. Approaches that do not apply a TAC are also possible, in which relative or absolute levels of escapement of spawning squid would be set based on survey or assessment results.

Within season stock assessments do require a different, more flexible and focussed approach to data collection from the fishery and data preparation for the assessment. The fishery data (catch, effort, location) and observer data (mean length by date and location, weight at length) would require near-real time processing to support a within season assessment to support timely advice to managers.

Although at an early stage, this approach to assessment does look reasonably promising in terms of being able to support an in-season management strategy that relies on estimating the current depletion as the season progresses.

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