Appendix 1 Ocean quahog assessment working group members

The working group met October 17-20 and December 19-22 at the NEFSC in Woods Hole, MA to work on the ocean quahog stock assessment. Members, contributors and attendees are listed alphabetically below.

Working group:

Jessica Coakley (MAFMC)
Bob Glenn (Mass. DMR)
Dan Hennen (NEFSC, Assessment Lead)
Tom Hoff (Wallace and Associates)
Larry Jacobson (NEFSC, Subcommittee Chair)
Daphne Munroe (Rutgers)
Eric Powell (University of Southern Mississippi)

Contributors/attendees:

Tom Alspach (SeaWatch International)
Nicole Charriere (NEFSC)
Toni Chute (NEFSC)
Wendy Gabriel (MAFMC SSC, NEFSC)
Scott Gallagher (WHOI)
Jon Hare (NEFSC)
Deborah Hart (NEFSC)
Robert Johnston (NEFSC)
Chris Legault (NEFSC)
Roger Mann (VIMS)
Michael Martin (NEFSC)
Vic Nordahl (NEFSC)
Jeff Normant (NJ DFW)
Loretta O'Brien (NEFSC)
Jennifer O'Dwyer (NY DEC)
Doug Potts (GARFO)
Robert RUssell (ME DMR) Mark Terceiro (NEFSC)
Dave Wallace (Wallace and Associates)
Jim Weinberg (NEFSC)

Appendix 2 VMS

A Vessel Monitoring System (VMS) is used to monitor the location and movement of commercial fishing vessels in the EEZ for certain fisheries. The system uses satellite-based communications from on-board transceiver units that report location at prescribed intervals. The VMS system reports vessel location at least once an hour in the clam fishery.

VMS data can be used to determine the approximate location of vessels during fishing operations. This is done by counting all returns (pings) from the system where the boat was moving at <5 knots (i.e. where the positions recorded one hour apart are less than 5 nm apart). The assumption being that any vessels moving between 0 and 5 knots are likely to be fishing rather than docked or transiting. VMS can approximate effort, and identify fishing locations, but not landings data.

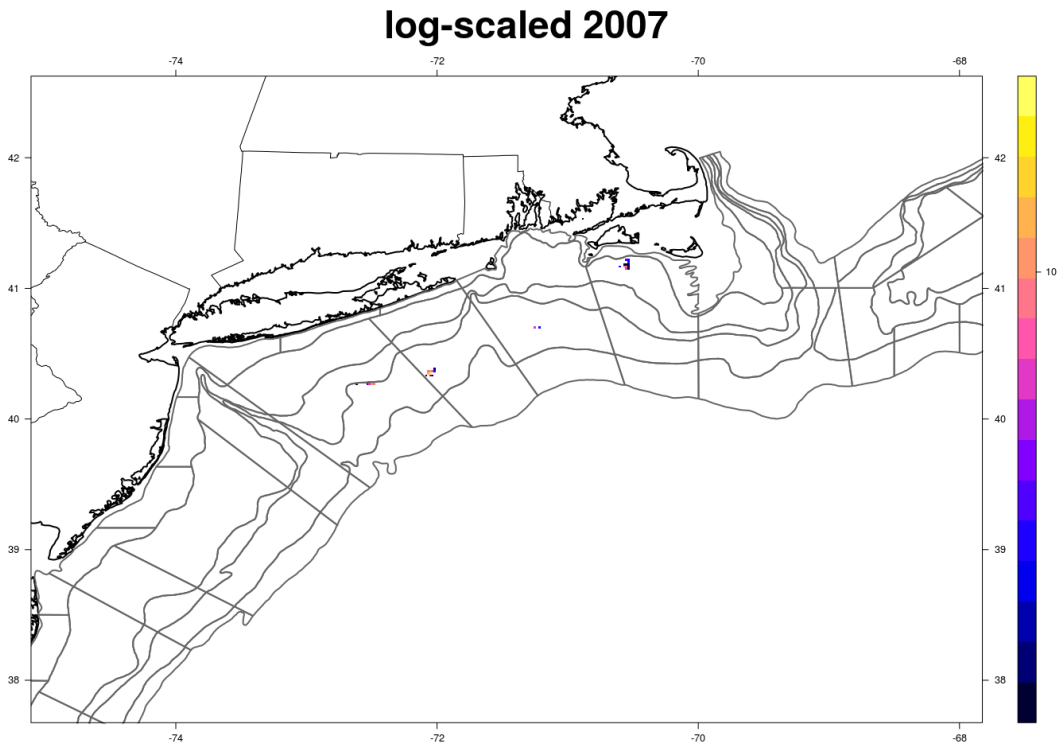

Figure 129: Locations of VMS compliant vessels fishing for ocean quahog in 2007. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2007 are not shown.

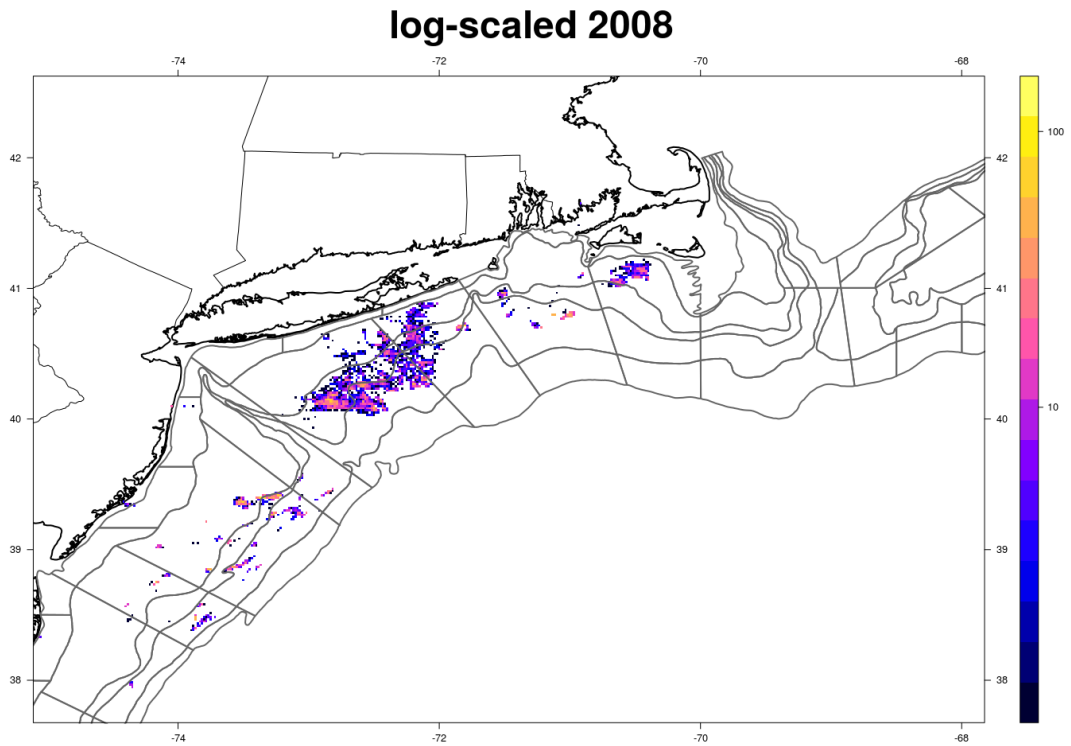

Figure 130: Locations of VMS compliant vessels fishing for ocean quahog in 2008. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2008 are not shown.

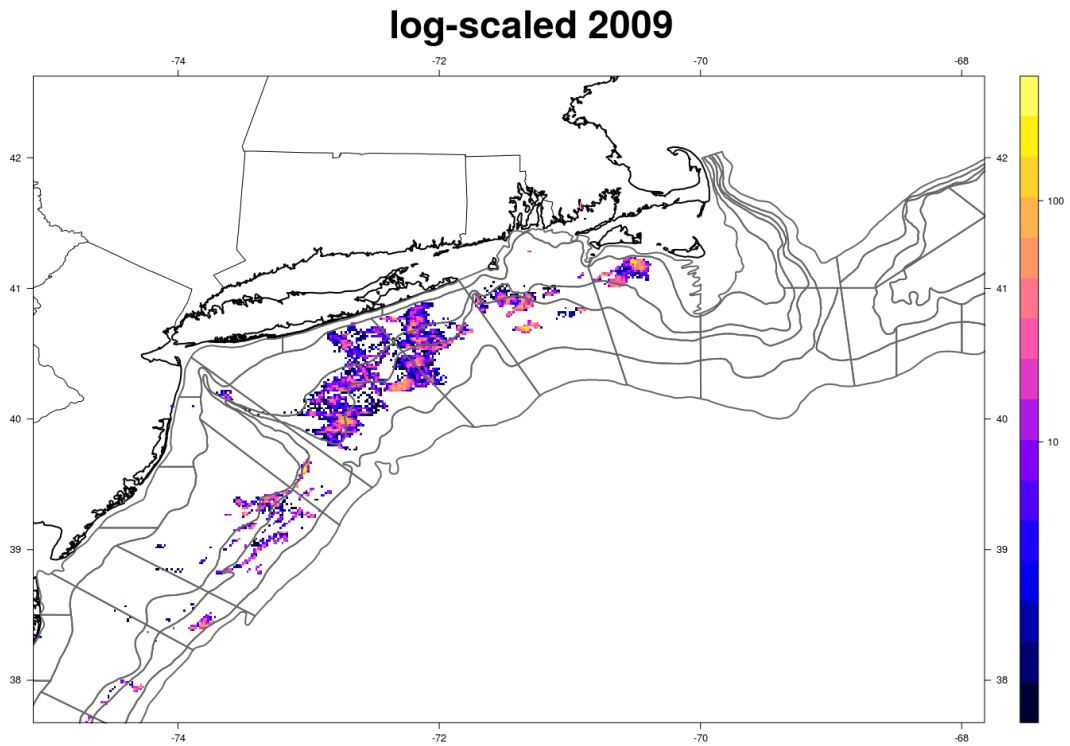

Figure 131: Locations of VMS compliant vessels fishing for ocean quahog in 2009. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2009 are not shown.

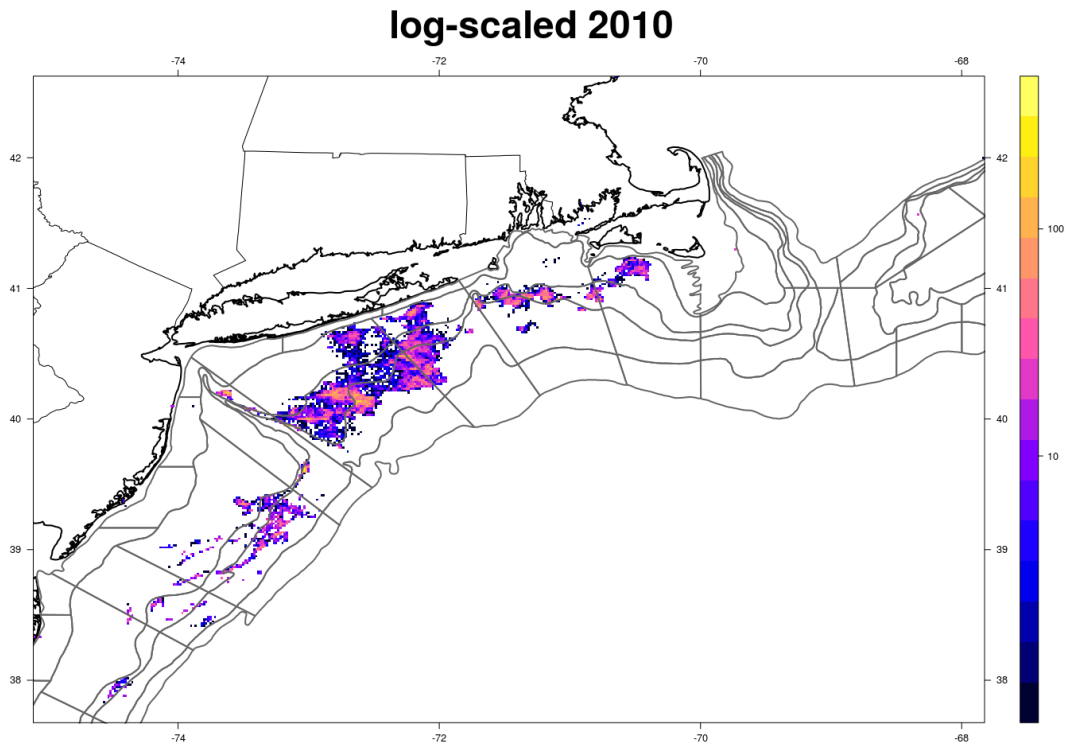

Figure 132: Locations of VMS compliant vessels fishing for ocean quahog in 2010. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2010 are not shown.

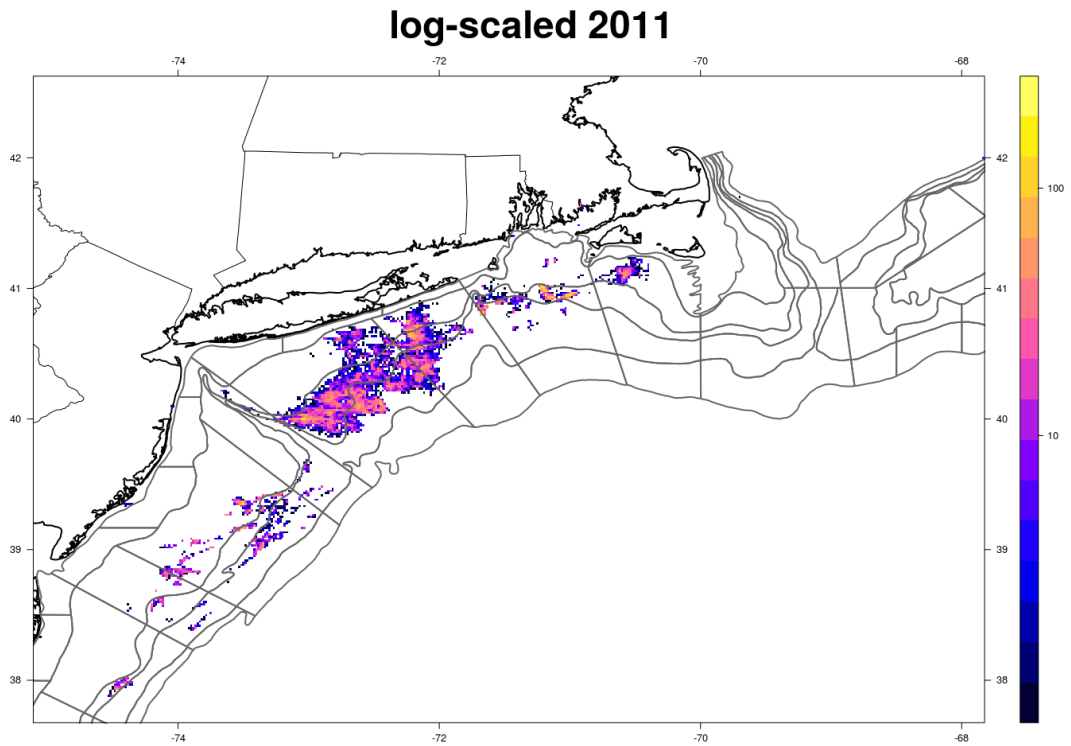

Figure 133: Locations of VMS compliant vessels fishing for ocean quahog in 2011. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2011 are not shown.

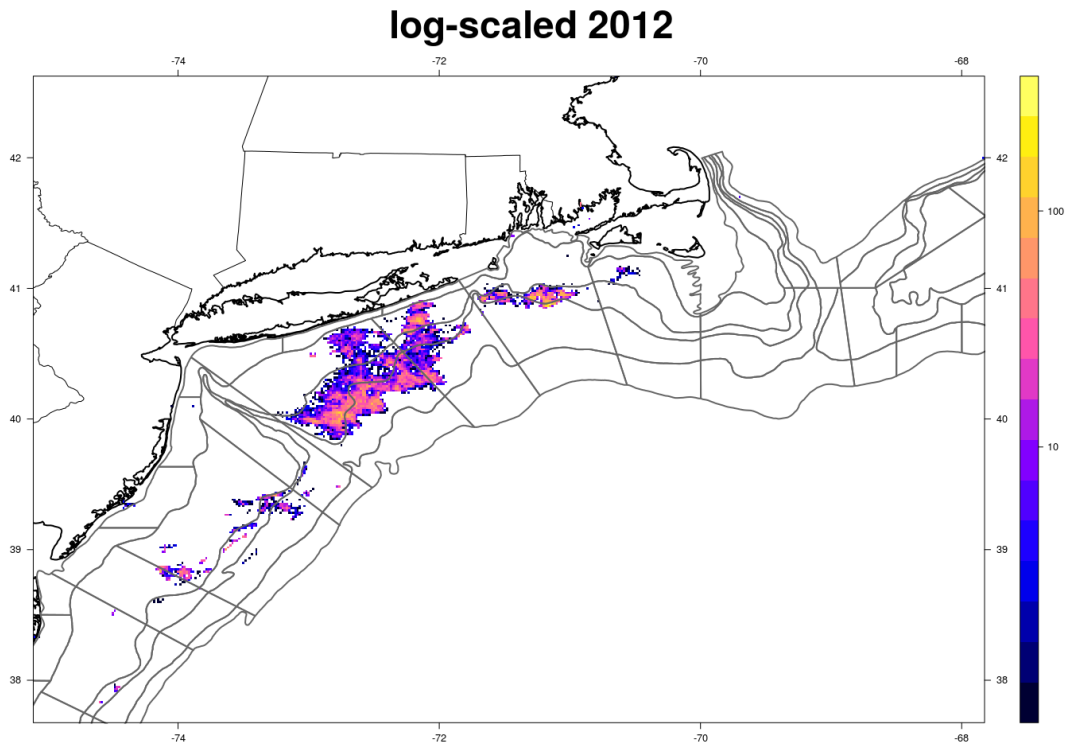

Figure 134: Locations of VMS compliant vessels fishing for ocean quahog in 2012. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2012 are not shown.

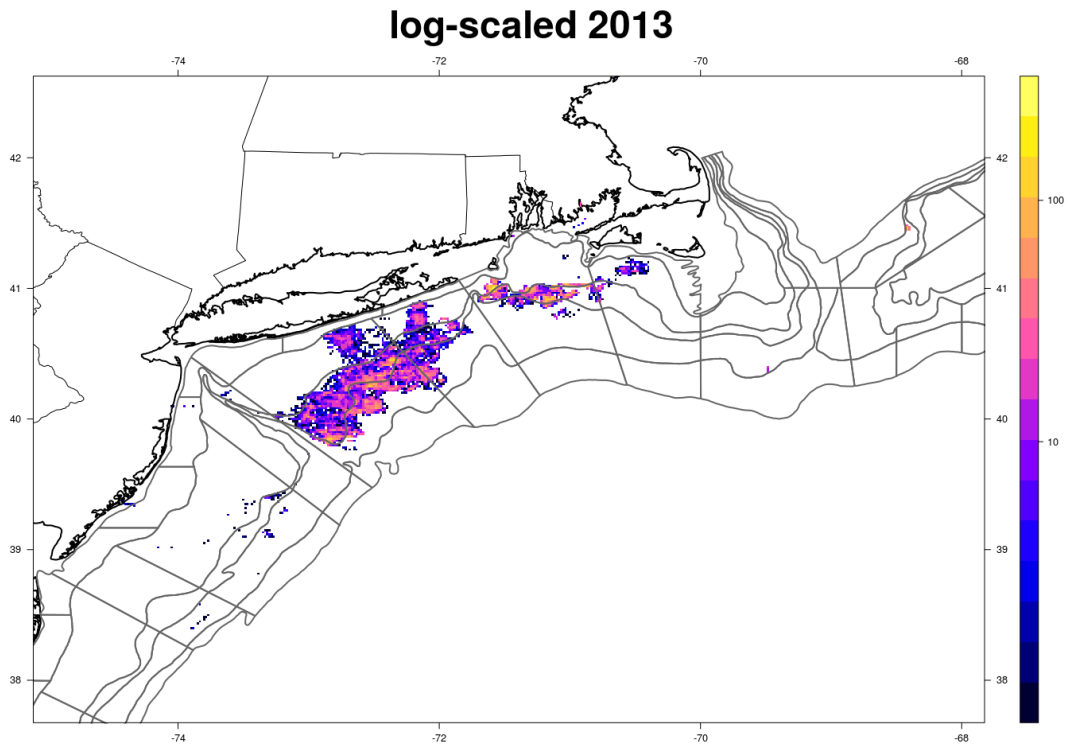

Figure 135: Locations of VMS compliant vessels fishing for ocean quahog in 2013. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2013 are not shown.

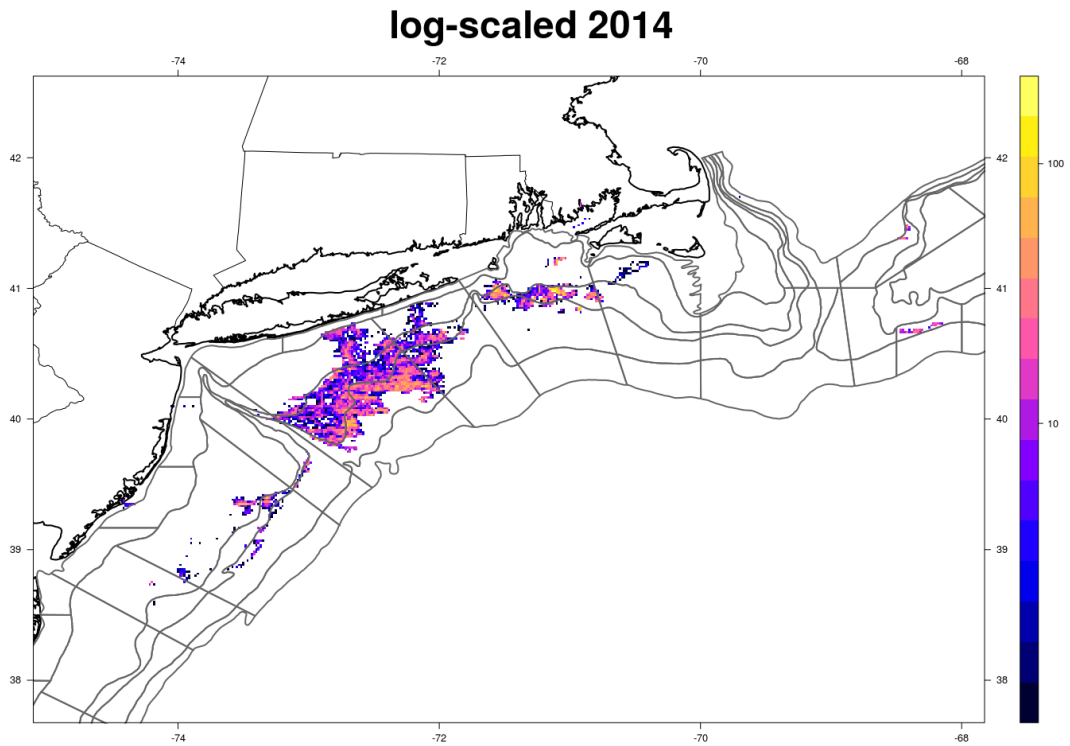

Figure 136: Locations of VMS compliant vessels fishing for ocean quahog in 2014. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2014 are not shown.

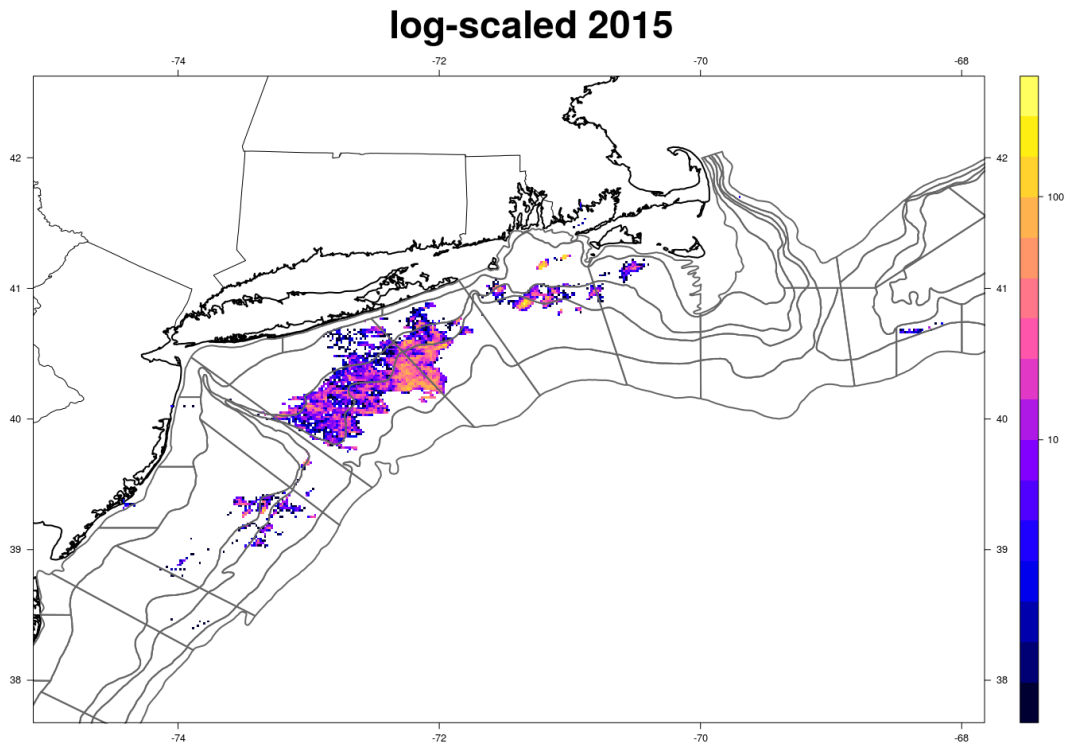

Figure 137: Locations of VMS compliant vessels fishing for ocean quahog in 2015. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2015 are not shown.

Appendix 3 Depletion analysis

Ocean quahog depletion experiments aboard commercial fishing vessels (Figure 139) were analyzed using standard Patch methodology (Rago et al. 2006) except that NEFSC employed a new method for calculating the hit matrix (Hennen et al. 2012). Sixteen of the nineteen ocean quahog depletion experiments worked well (estimated efficiency$<$ 1.0 and cv$<$ 2.0). Estimated densities ranged from 0.015 - 0.385 clams per ft^2 (Table 36). Estimated efficiencies for commercial dredges ranged from 0.164 - 0.878 for ocean quahog. These values are similar to values from previous assessments (Figure 138).

Capture efficiency estimates for the RD depend on the commercial efficiency estimates and setup tows (Northeast Fisheries Science Center 2013). Maps of the tow sequences from the depletion plots (Figures 140 - 157) generally show thorough coverage of study sites with high degrees of overlap between tows (Hennen et al. 2012). Overlap between the setup tows and the depletion sequence was variable, but in general improved over time (Figures 140 - 157). The hit matrices generated for patch model analysis were resolved to approximately 1 cm spatial resolution (Figures 158 - 176 - for illustration, not shown to full resolution). In general the current estimates of MCD efficiency are lower and density higher, resulting in higher estimates of RD efficiency.

It is usually possible to diagnose the cause of poor efficiency estimates using the diagnostic plots. Patch model diagnostics include examining the catch vs. expected catch and, trends in catch per unit of effective area, and likelihood residuals (Figures 192 - 195). For example, one depletion study that did not produce reasonable estimates (Figure 192) had its highest catch on the 8th tow of the depletion sequence, which had a very low effective area swept (a measure of the area swept that deprecates areas already covered). Altering this value toward the expected catch changes the Patch model results to estimated values that closely agree with results from the other three OQ depletion experiments. Inclinometer and pressure sensors did not indicate any mechanical problems during this tow and the tow was of normal length. In short there was no apriori reason to exclude this tow from the depletion sequence. However, the results from this experiment were not well estimated (cv$>$ 2.0) so it was excluded from the assessment.

Table 36: Estimates of FV efficiency, density, RV efficiency and set up density from 19 depletion experiments for ocean quahog.

Site	Tows	Efficiency	CVe	Density	CVd	RVefficiency	CVRVe	SetupD	CVsuD
OQ00 01	22	0.878	0.279	0.084	0.191	0.003	0.933	0.000	0.913
OQ00 02	16	0.682	0.308	0.051	0.246	0.145	0.853	0.007	0.816
OQ00 03	27	0.541	0.597	0.090	0.501	0.082	0.788	0.007	0.608
OQ02 01	24	0.381	0.205	0.354	0.148	0.082	0.180	0.029	0.103
OQ02 02	22	0.652	0.167	0.185	0.107	0.132	0.218	0.024	0.191
OQ02 03	20	0.652	0.136	0.089	0.103	0.268	0.236	0.024	0.212
OQ02 04	24	0.229	0.535	0.076	0.440	0.049	0.997	0.004	0.894
OQ05 01	20	0.164	0.630	0.081	0.480	0.148	0.497	0.012	0.129
OQ05 02	21	0.360	0.139	0.053	0.080	0.150	0.237	0.008	0.223
OQ05 03	20	0.561	0.089	0.101	0.080	0.100	0.296	0.010	0.285
OQ05 04	17	0.714	0.103	0.030	0.082	0.141	0.131	0.004	0.102
OQ05 06	20	0.498	0.227	0.165	0.161	0.000	49.449	0.000	60.558
OQ08 01	17	1.000	0.000	0.069	0.090	0.449	0.481	0.031	0.472
OQ08 02	17	0.795	0.094	0.085	0.061	0.206	0.061	0.018	0.000
OQ08 03	17	1.000	0.000	0.117	0.098	0.290	0.103	0.034	0.031
OQ11 01	10	0.071	2.735	0.300	2.636	0.080	2.651	0.024	0.281
OQ11 02	20	0.779	0.153	0.015	0.113	0.406	0.245	0.006	0.217
OQ11 02S	18	0.555	0.168	0.025	0.120	0.240	0.248	0.006	0.217
OQ11 05	22	0.629	0.222	0.385	0.124	0.049	0.300	0.019	0.274
Mean	20	0.586	0.357	0.124	0.309	0.159	3.100	0.014	3.501
Median	20	0.629	0.168	0.085	0.120	0.141	0.296	0.010	0.223

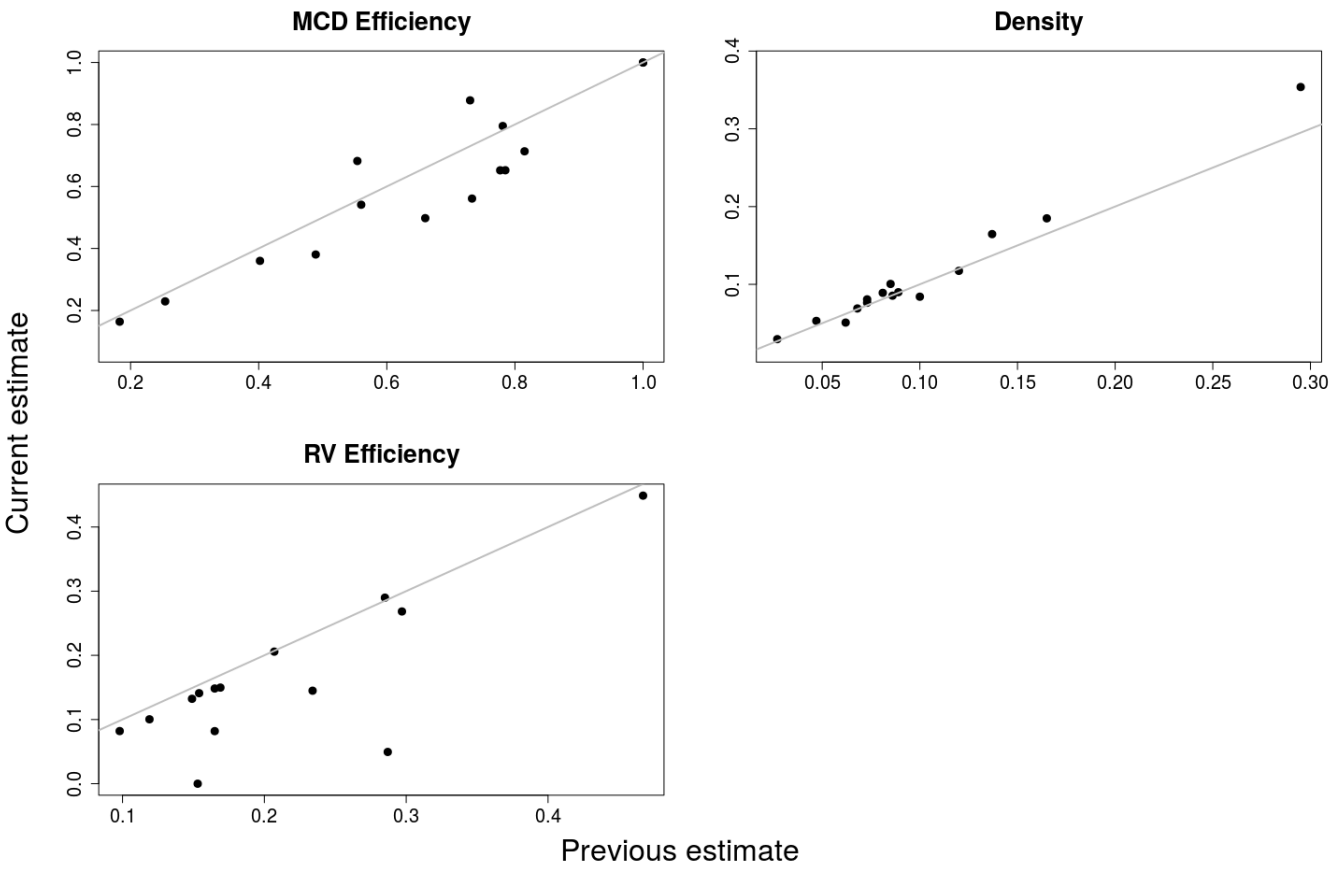

Figure 138: A comparison of patch model estimates made previously by Northeast Fisheries Science Center (2009) and in this assessment. In general the current estimates are lower in MCD efficiency and higher in density, resulting in higher estimates of RV efficiency. The gray lines in each plot represent perfect agreement.

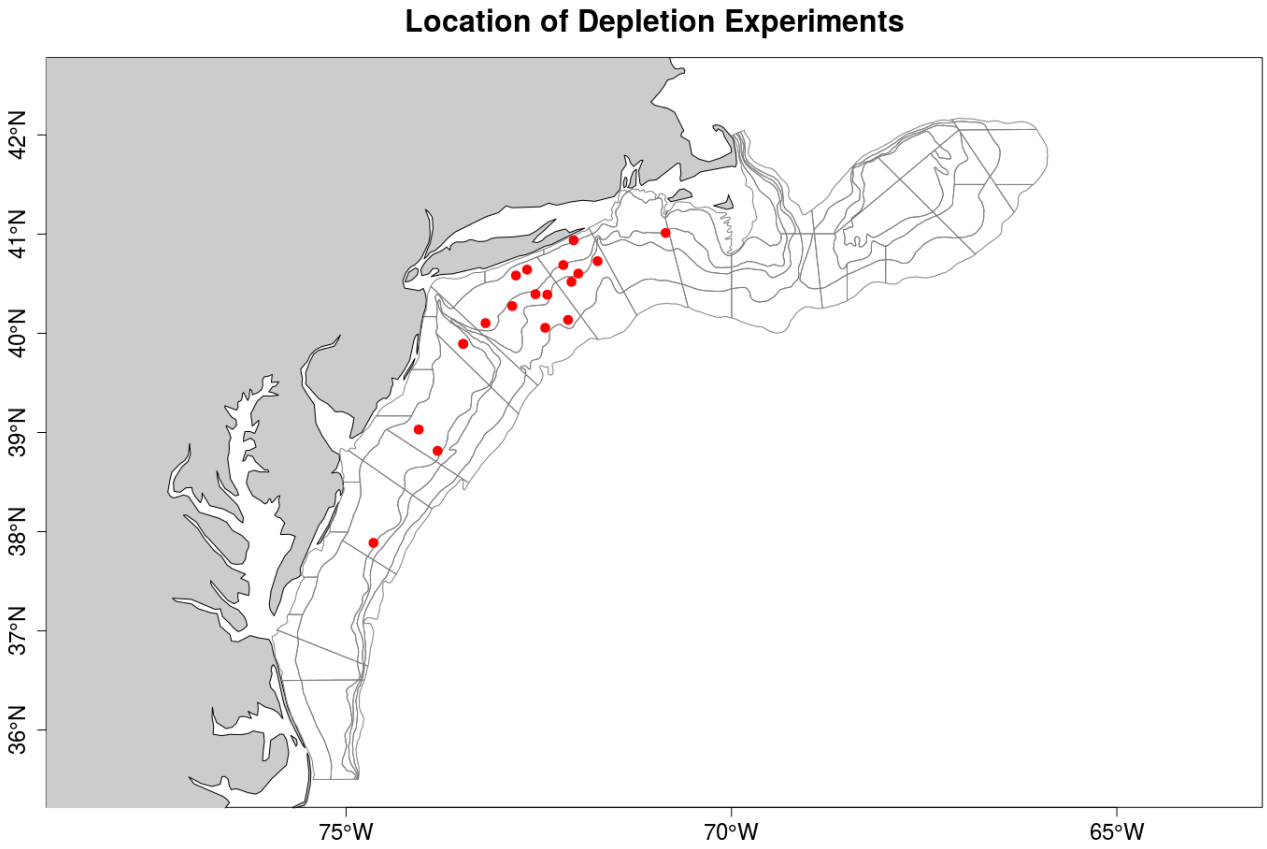

Figure 139: Location of all ocean quahog depletion experiments since 1999.

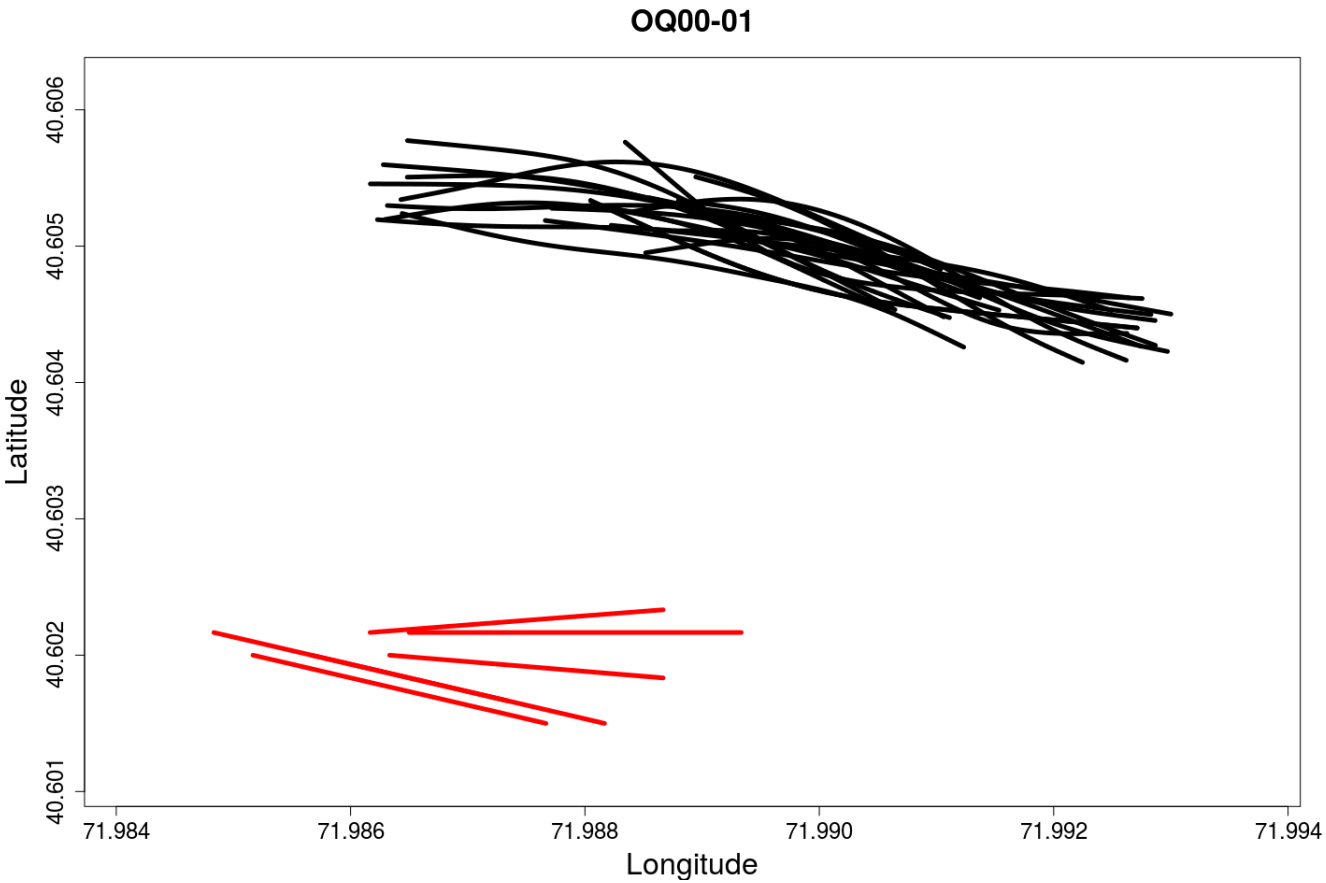

Figure 140: Relative positions of each tow in the set up (red lines) and depletion sequences (black) for depletion experiment OQ00-01.

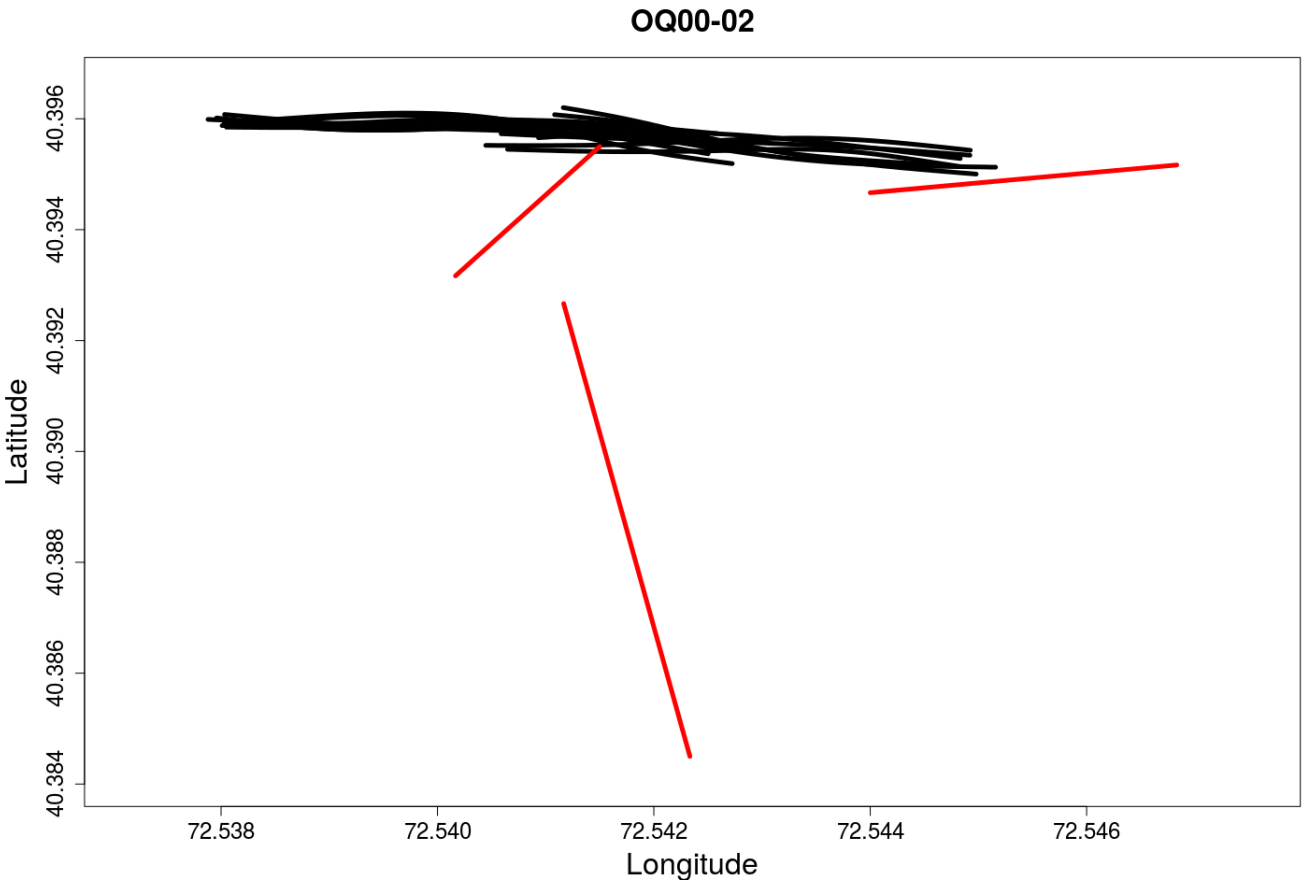

Figure 141: Relative positions of each tow in the set up (red lines) and depletion sequences (black) for depletion experiment OQ00-02.

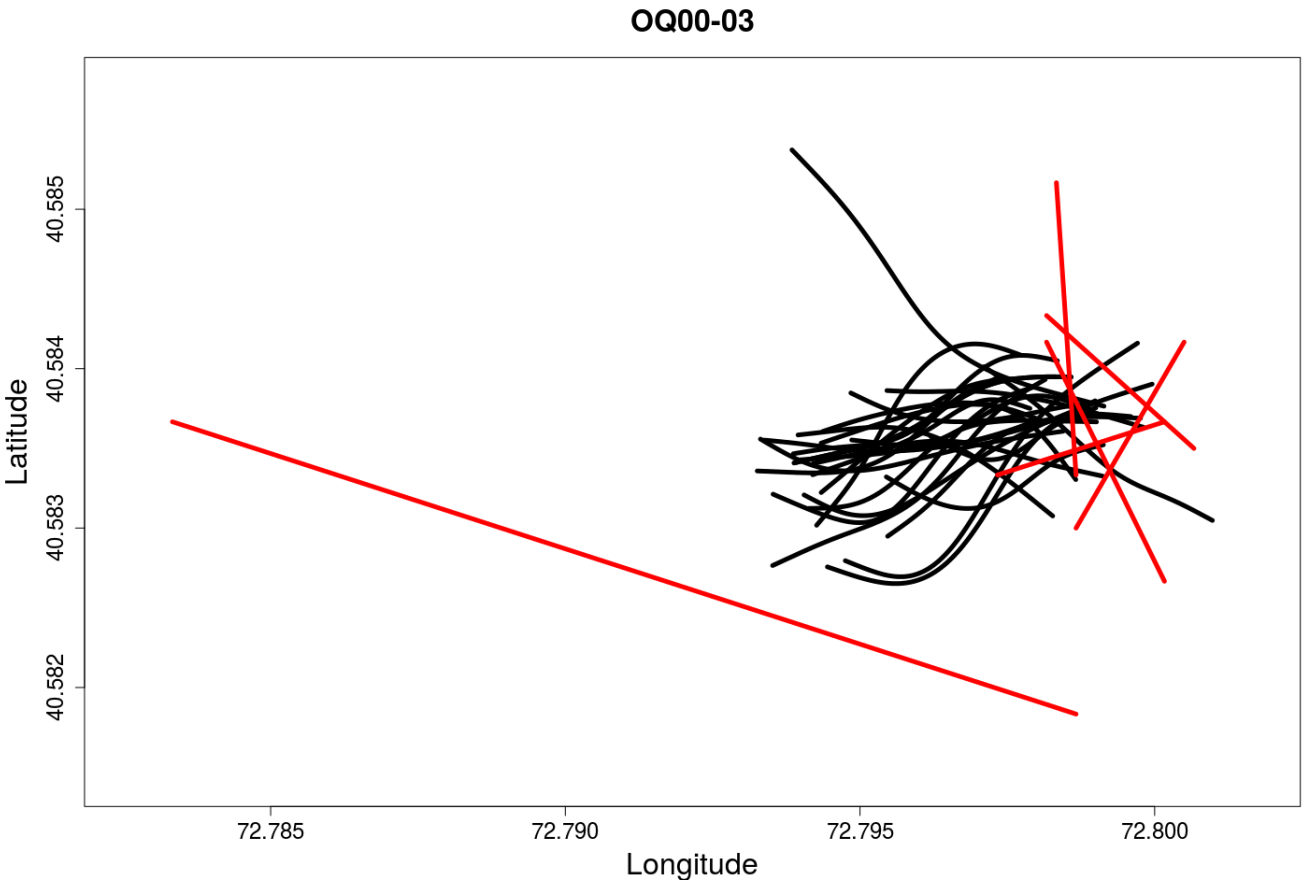

Figure 142: Relative positions of each tow in the set up (red lines) and depletion sequences (black) for depletion experiment OQ00-03.

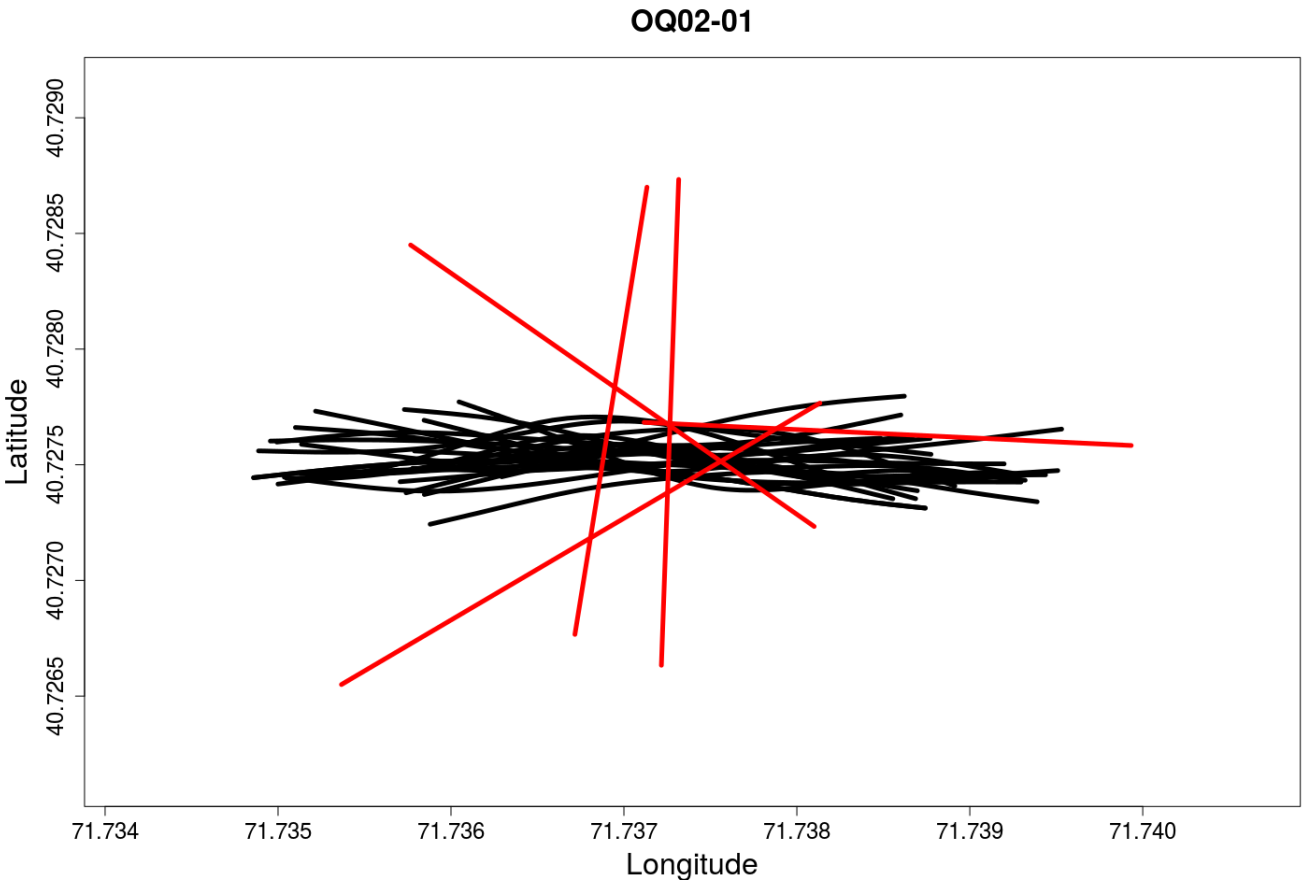

Figure 143: Relative positions of each tow in the set up (red lines) and depletion sequences (black) for depletion experiment OQ02-01.

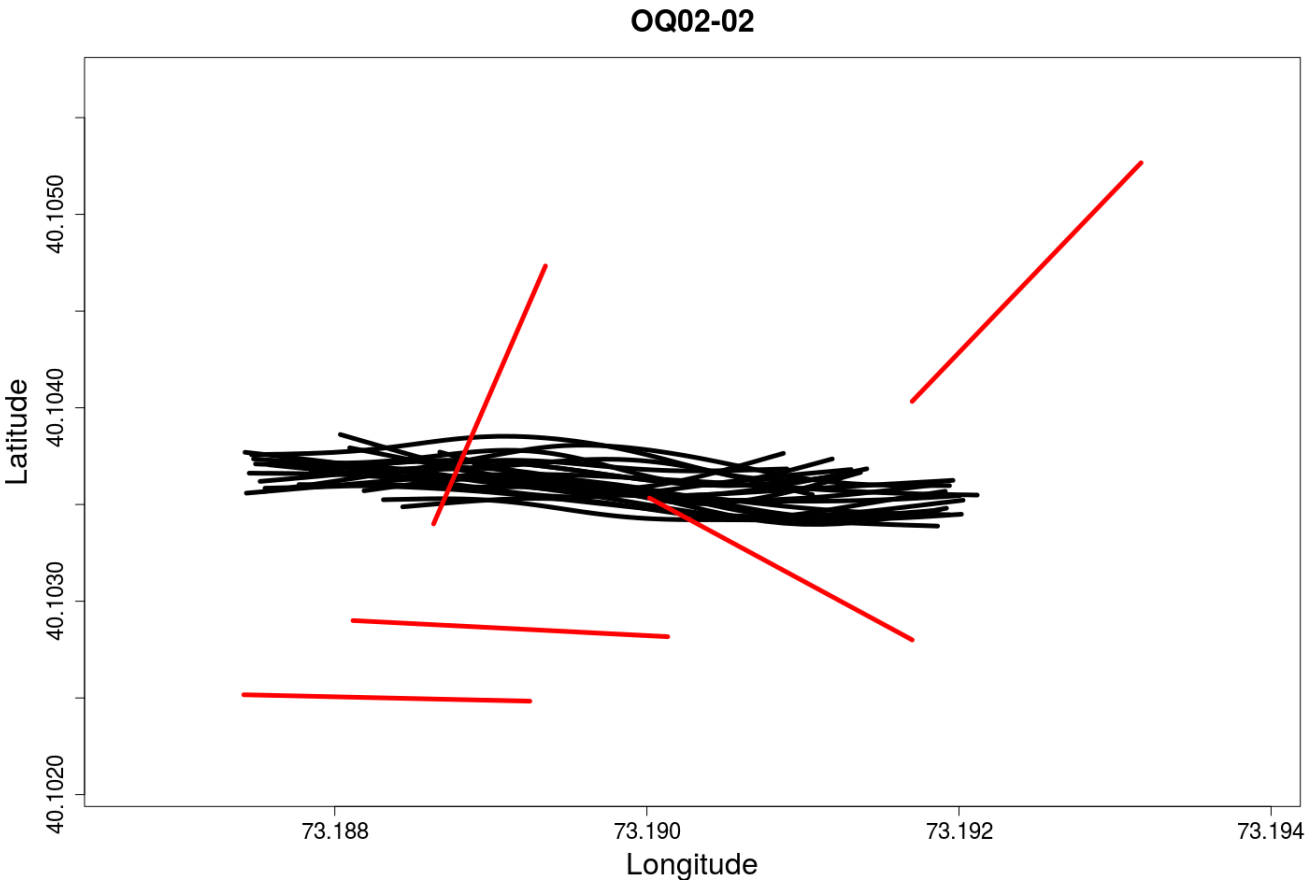

Figure 144: Relative positions of each tow in the set up (red lines) and depletion sequences (black) for depletion experiment OQ02-02.

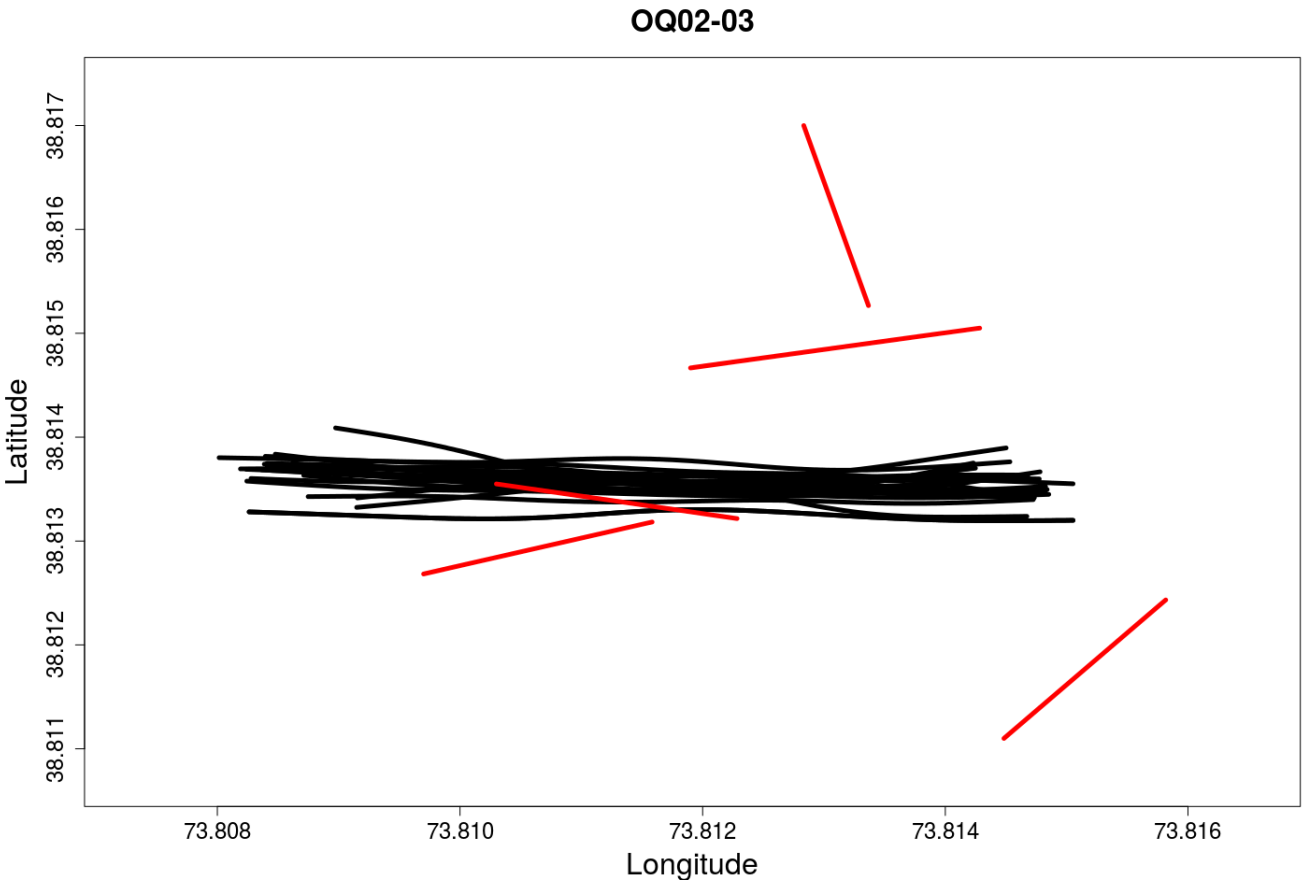

Figure 145: Relative positions of each tow in the set up (red lines) and depletion sequences (black) for depletion experiment OQ02-03.

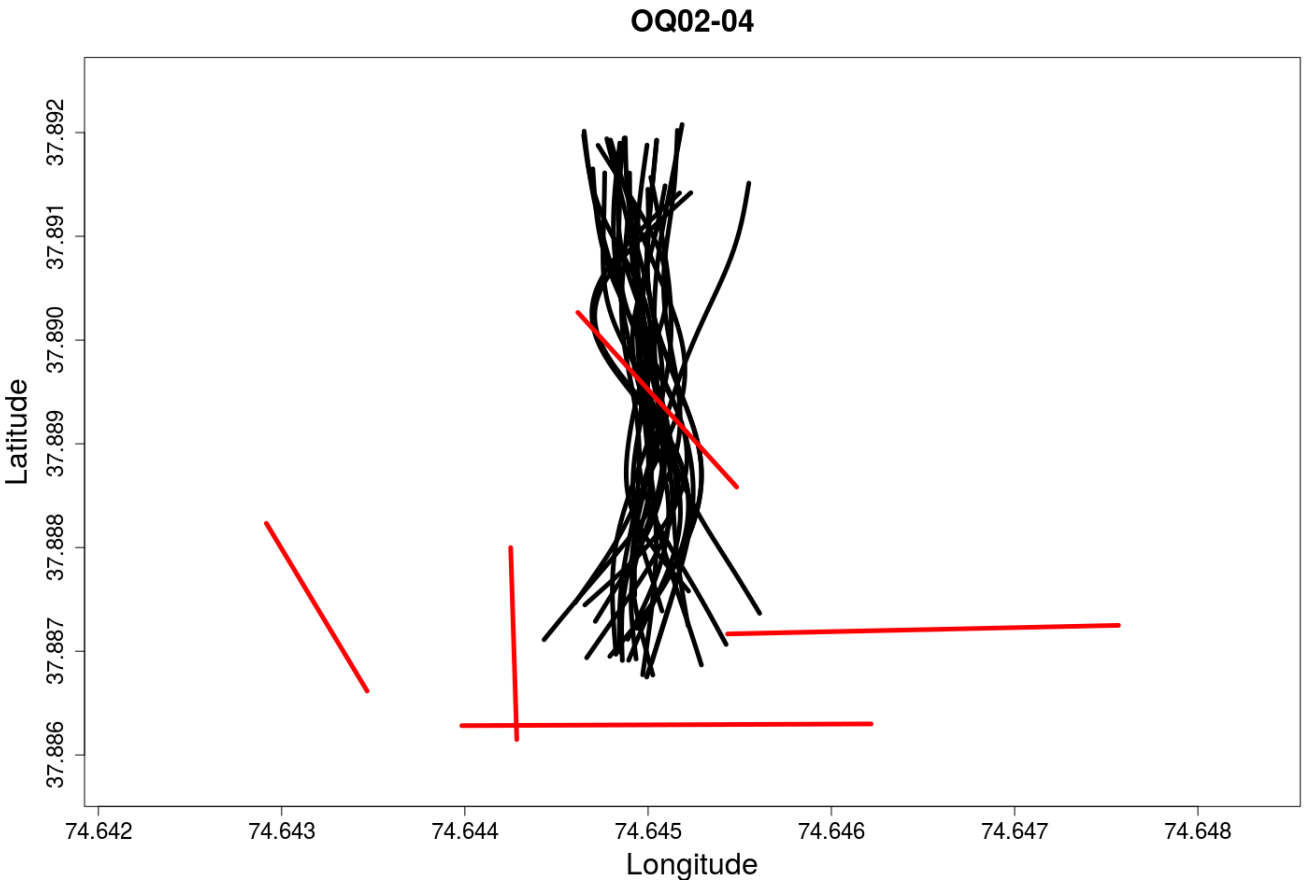

Figure 146: Relative positions of each tow in the set up (red lines) and depletion sequences (black) for depletion experiment OQ02-04.

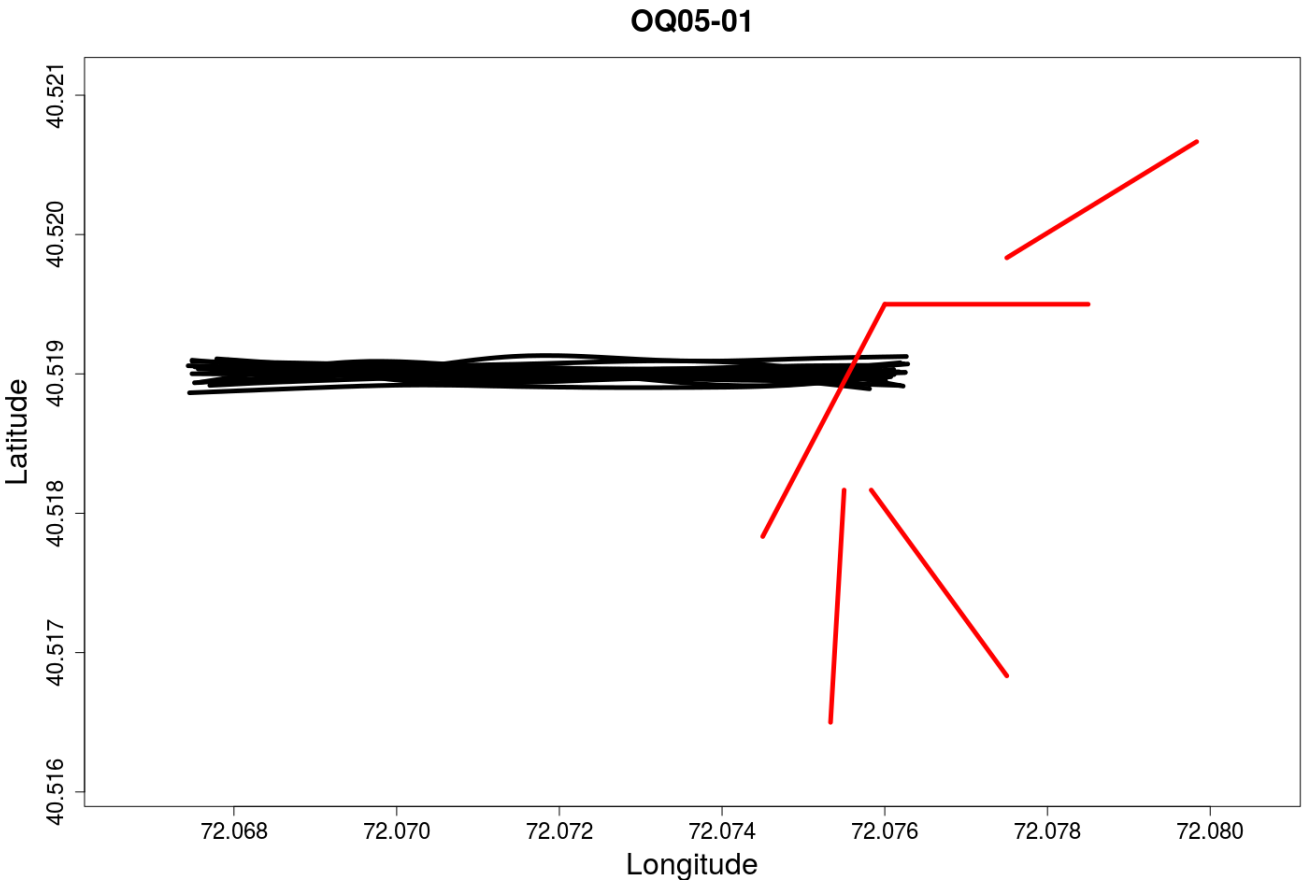

Figure 147: Relative positions of each tow in the set up (red lines) and depletion sequences (black) for depletion experiment OQ05-01.

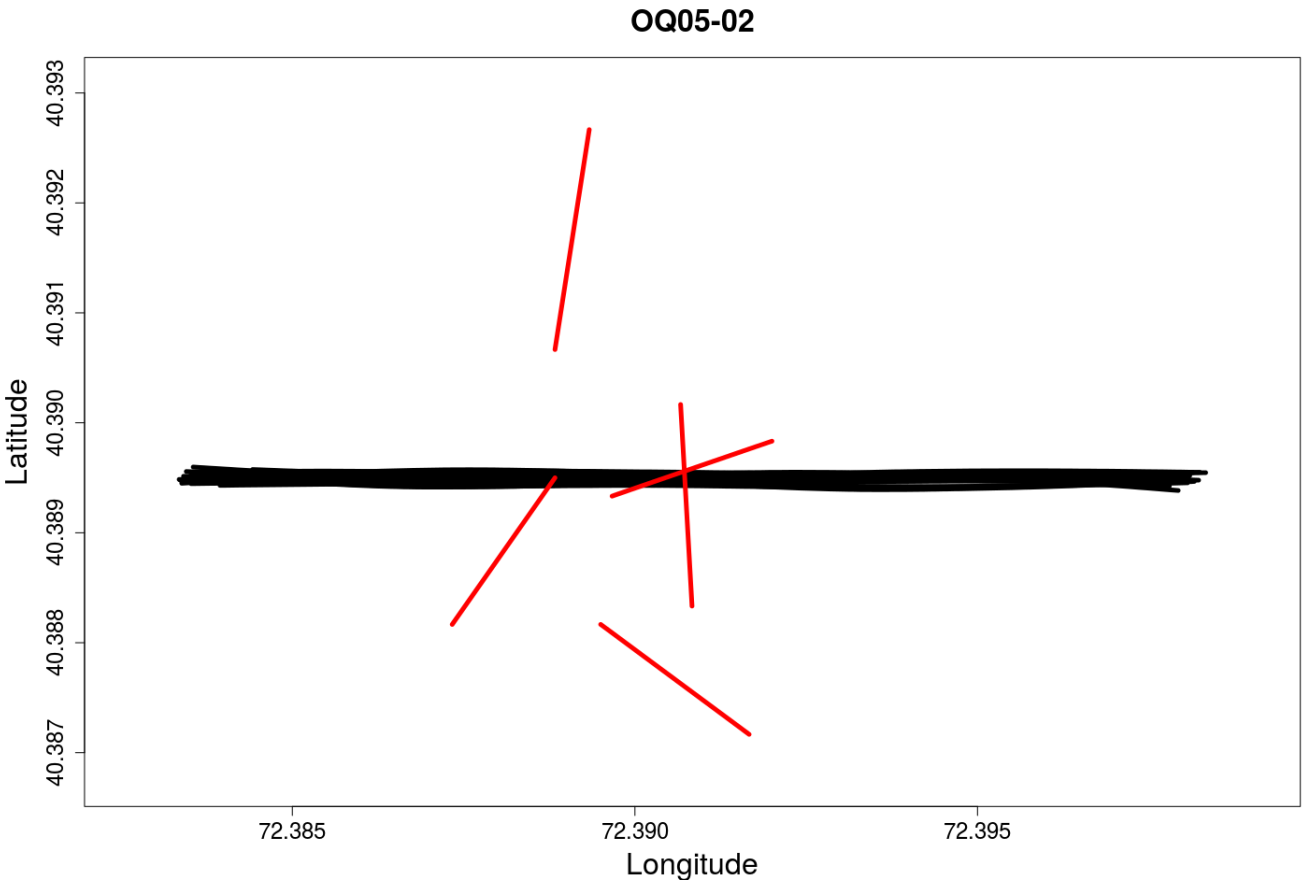

Figure 148: Relative positions of each tow in the set up (red lines) and depletion sequences (black) for depletion experiment OQ05-02.

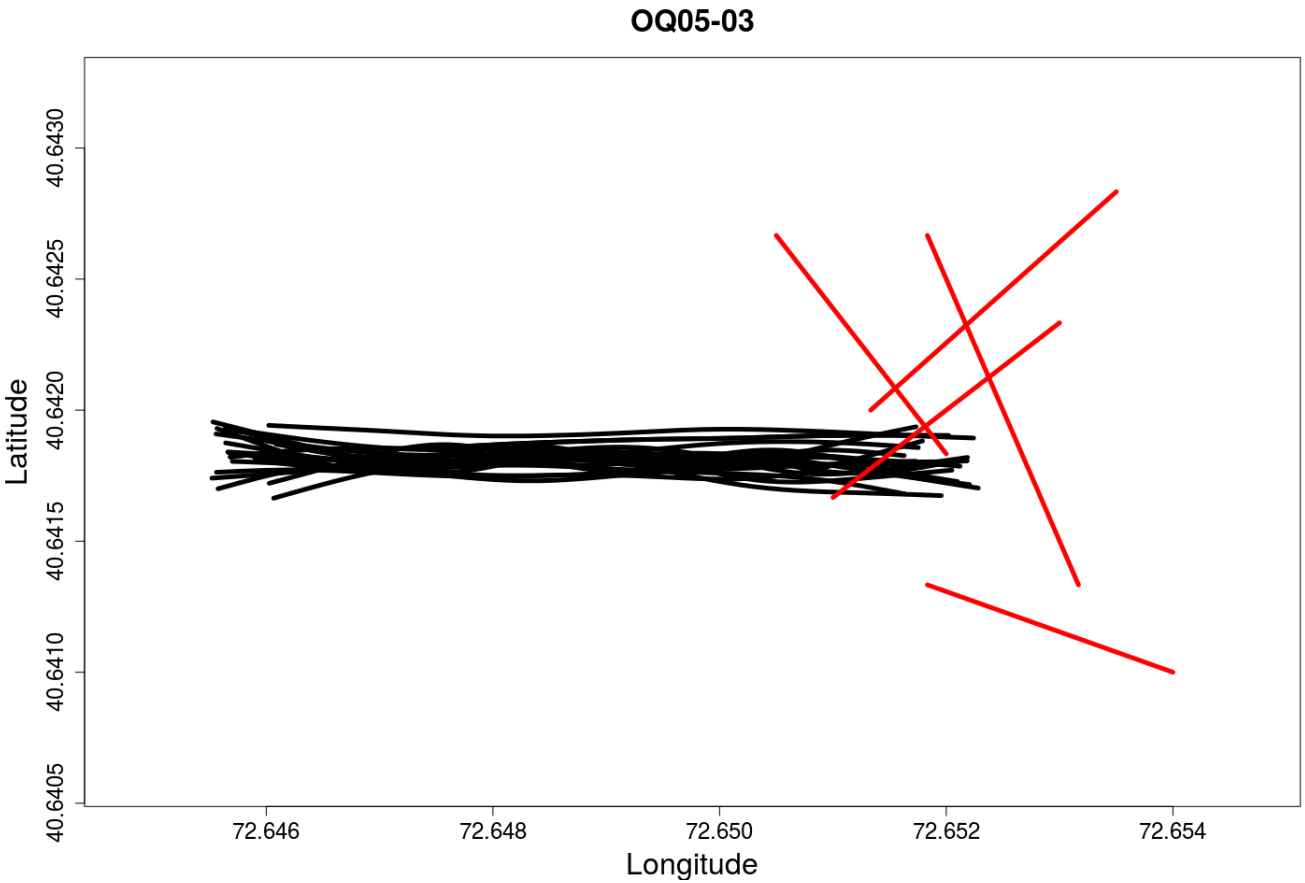

Figure 149: Relative positions of each tow in the set up (red lines) and depletion sequences (black) for depletion experiment OQ05-03.

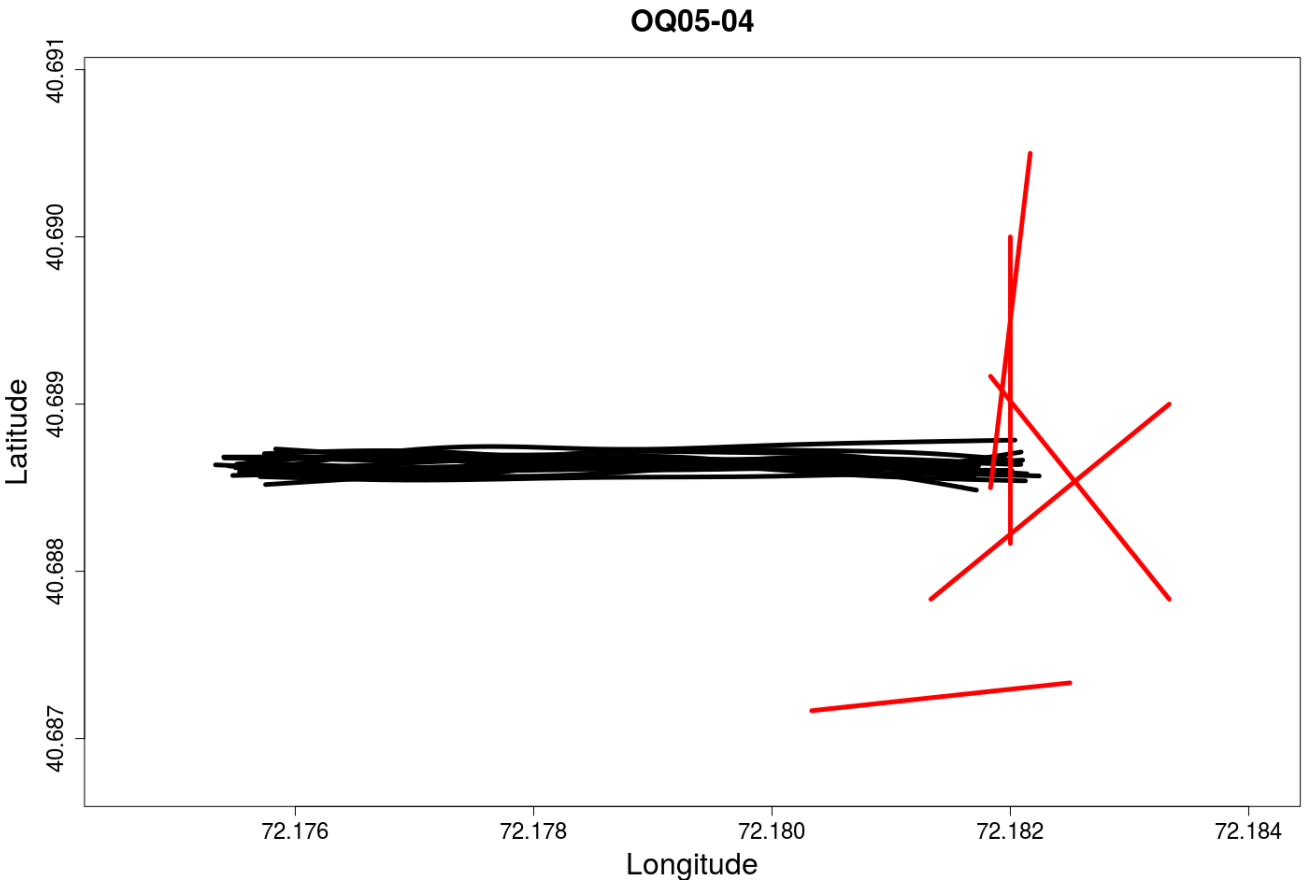

Figure 150: Relative positions of each tow in the set up (red lines) and depletion sequences (black) for depletion experiment OQ05-04.

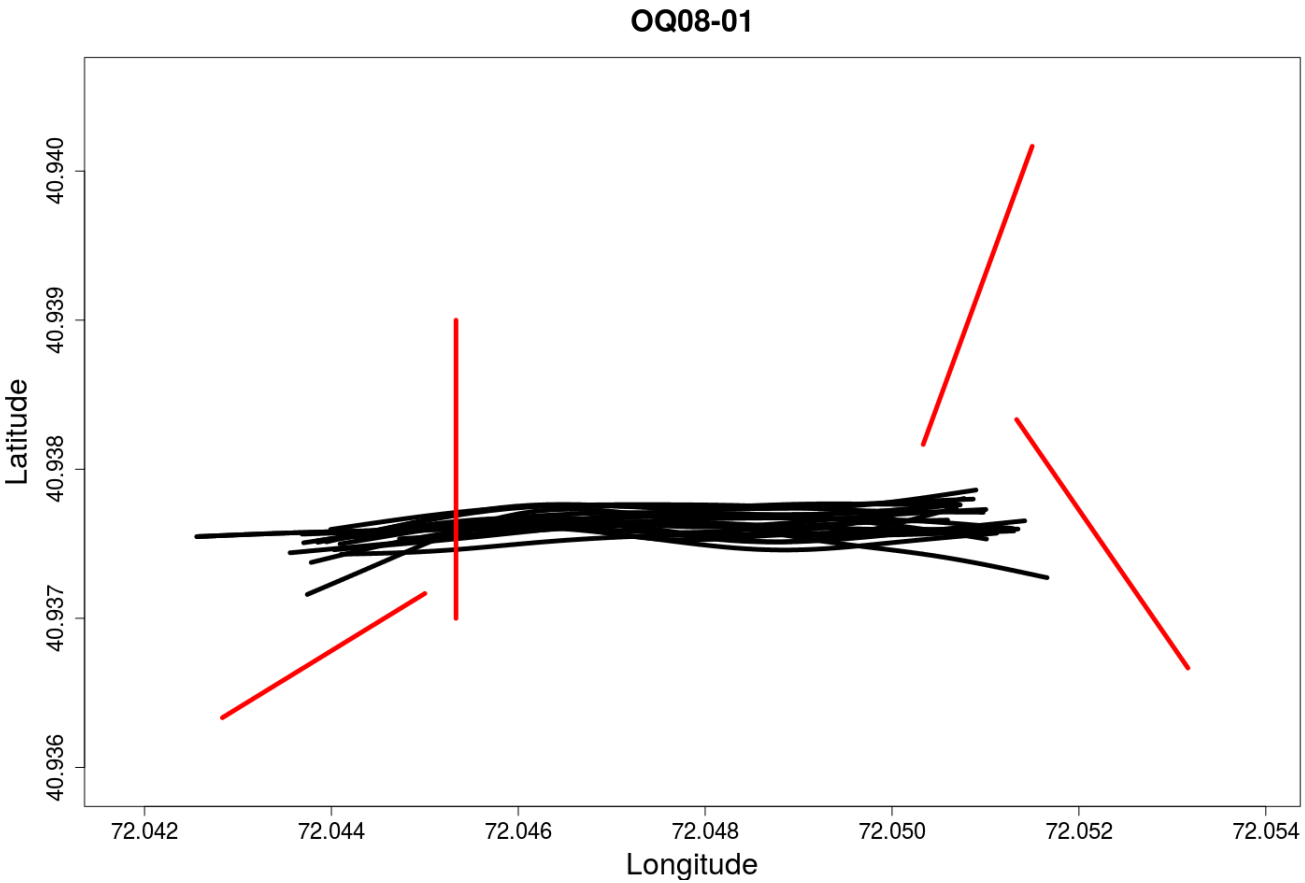

Figure 151: Relative positions of each tow in the set up (red lines) and depletion sequences (black) for depletion experiment OQ08-01.

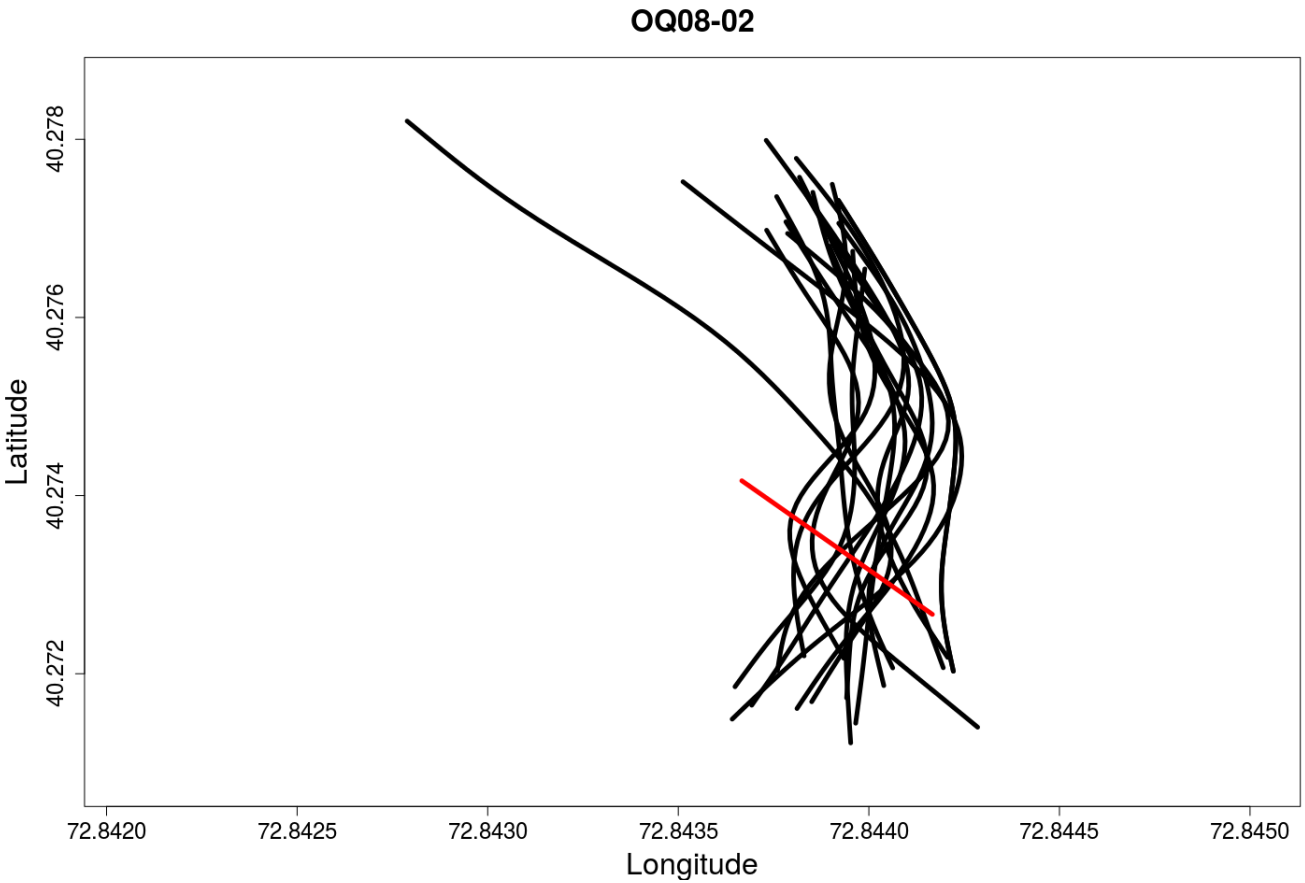

Figure 152: Relative positions of each tow in the set up (red lines) and depletion sequences (black) for depletion experiment OQ08-02.

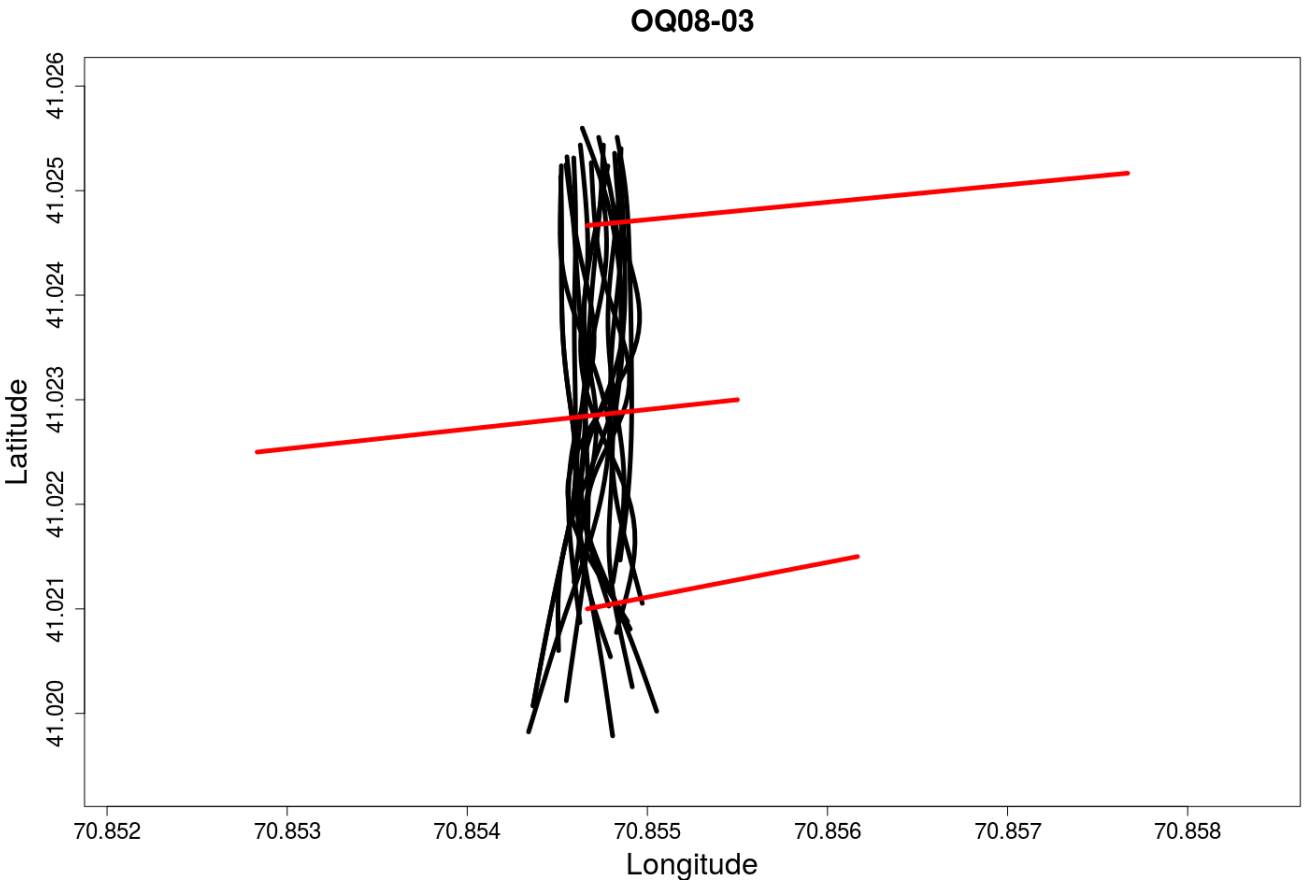

Figure 153: Relative positions of each tow in the set up (red lines) and depletion sequences (black) for depletion experiment OQ08-03.

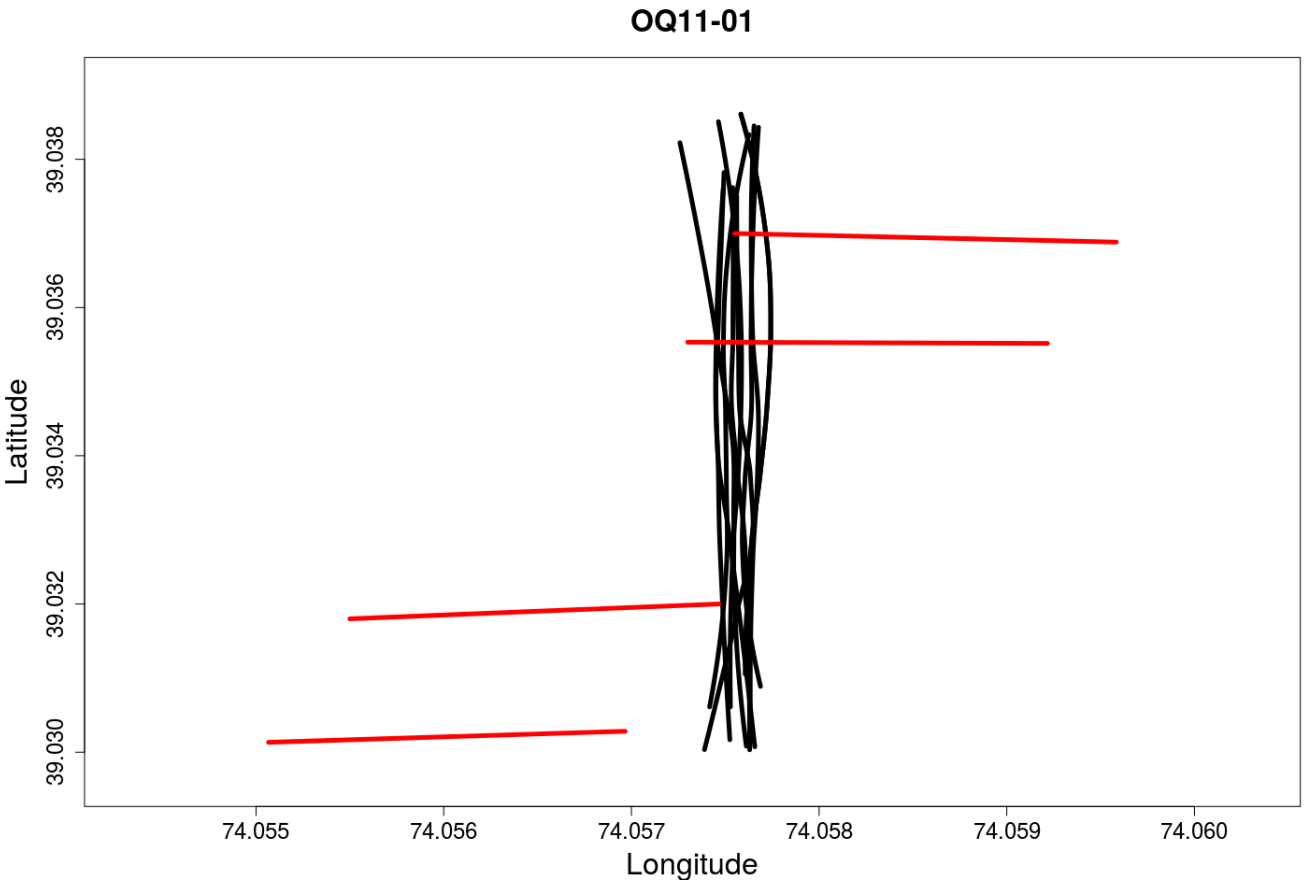

Figure 154: Relative positions of each tow in the set up (red lines) and depletion sequences (black) for depletion experiment OQ11-01.

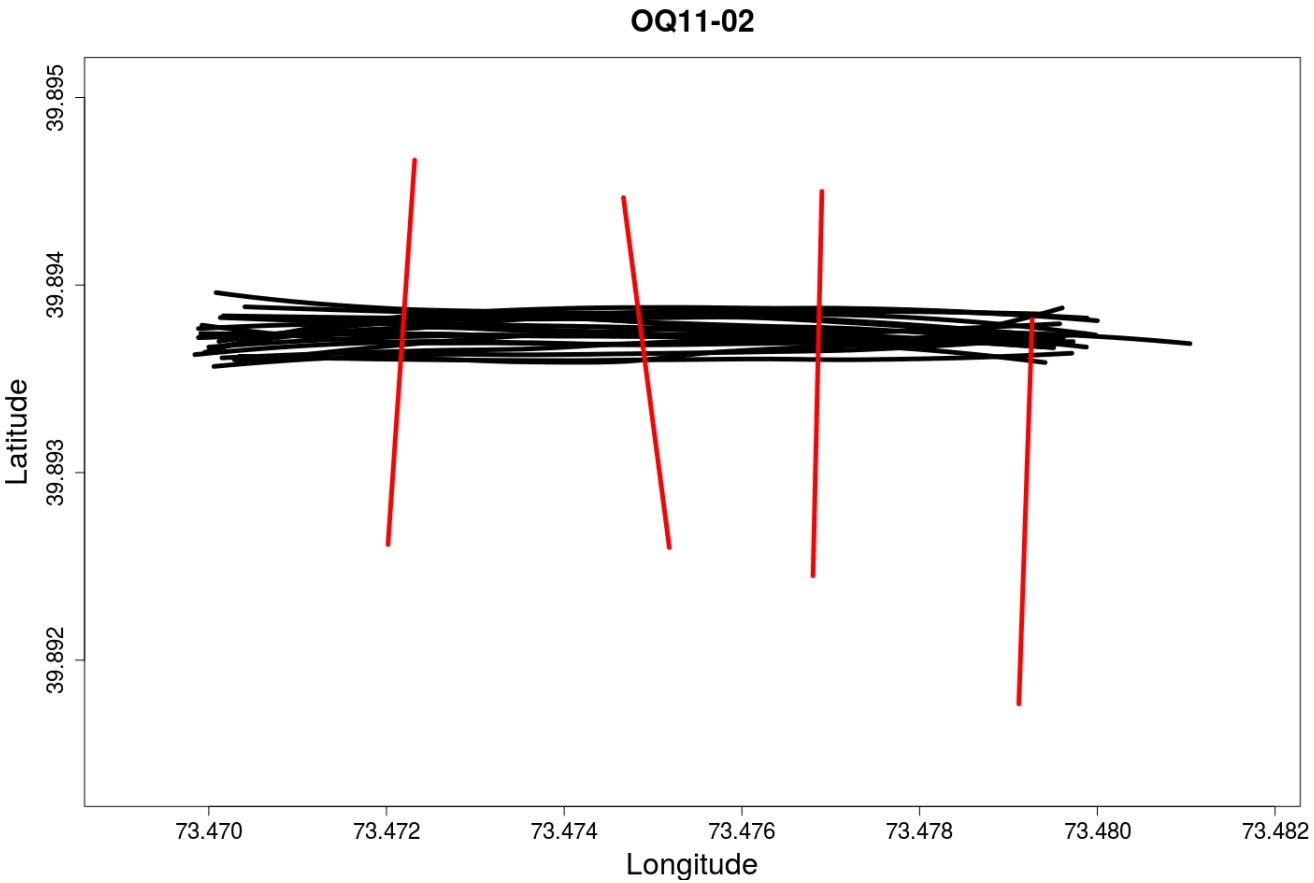

Figure 155: Relative positions of each tow in the set up (red lines) and depletion sequences (black) for depletion experiment OQ11-02.

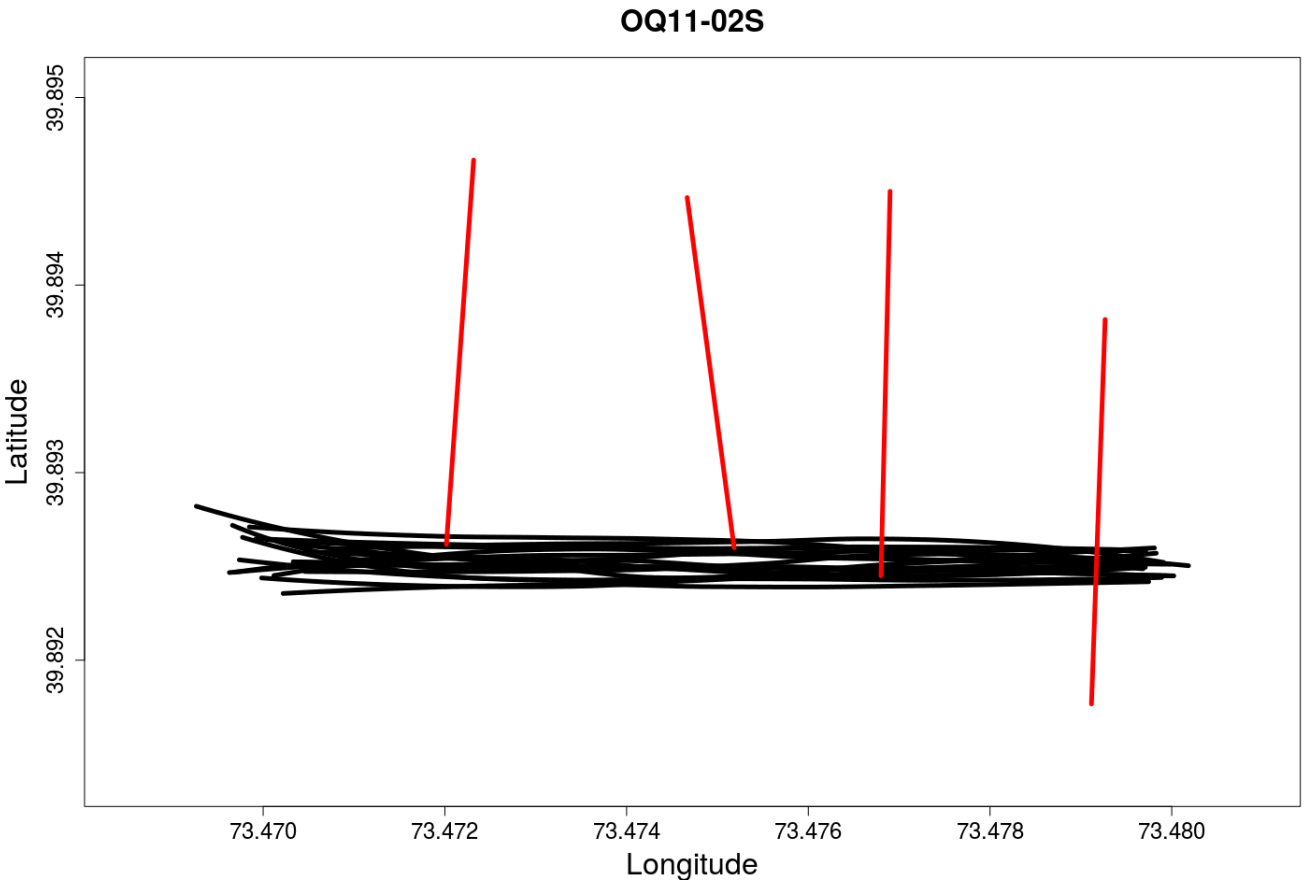

Figure 156: Relative positions of each tow in the set up (red lines) and depletion sequences (black) for depletion experiment OQ11-02S.

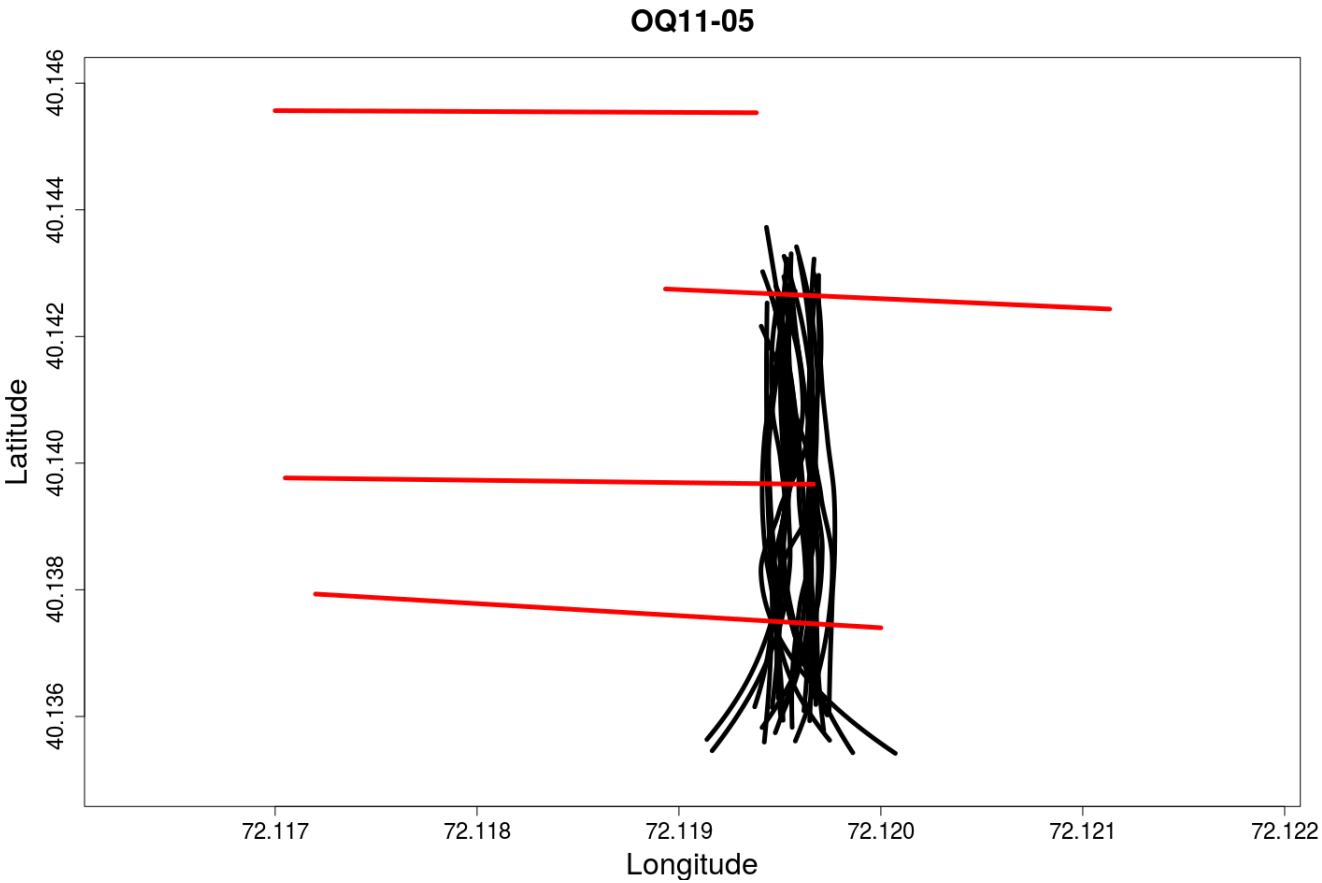

Figure 157: Relative positions of each tow in the set up (red lines) and depletion sequences (black) for depletion experiment OQ11-05.

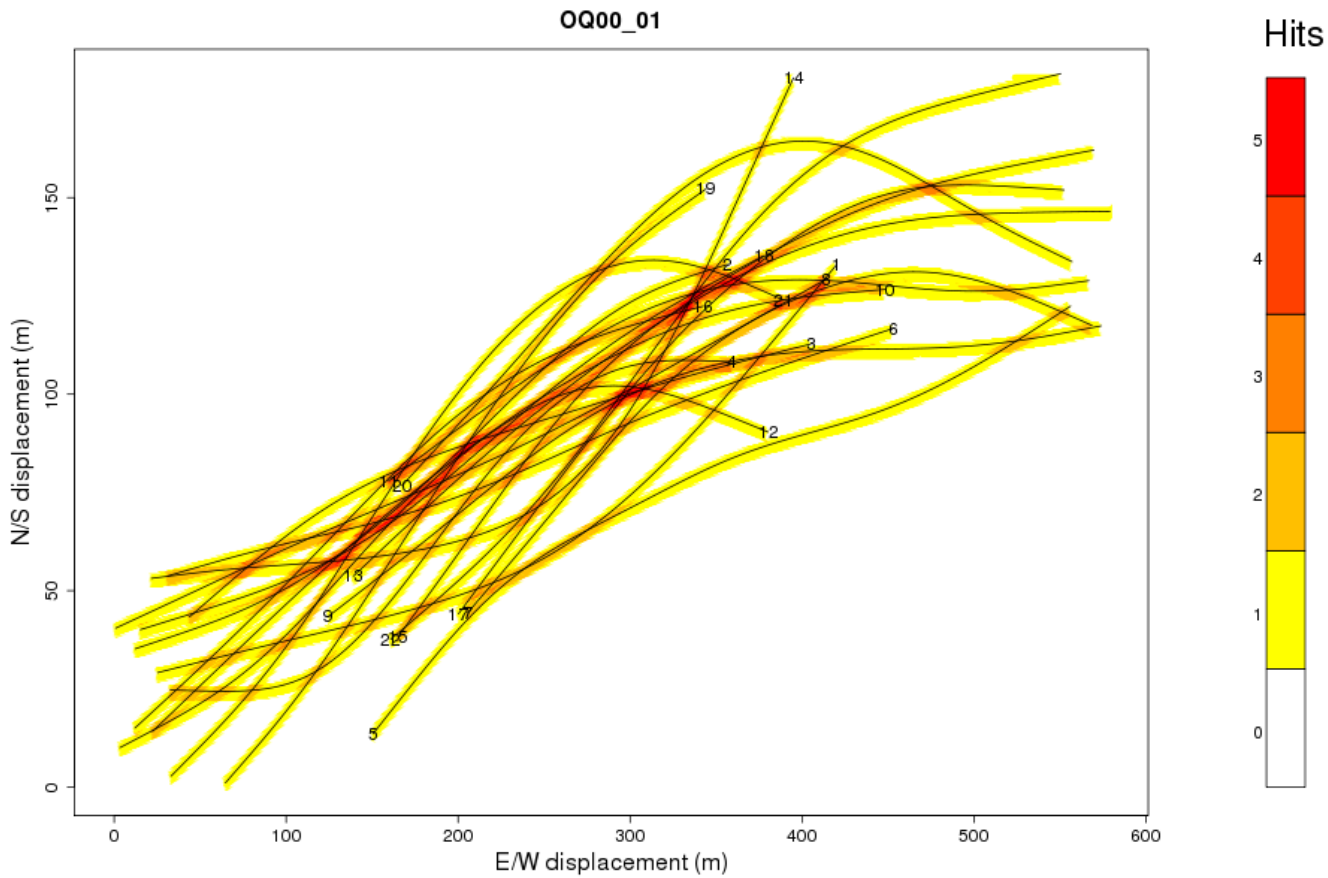

Figure 158: Depletion sequence for experiment OQ00-01, showing the number of passes made by the dredge over each cm^2 of the experimental area.

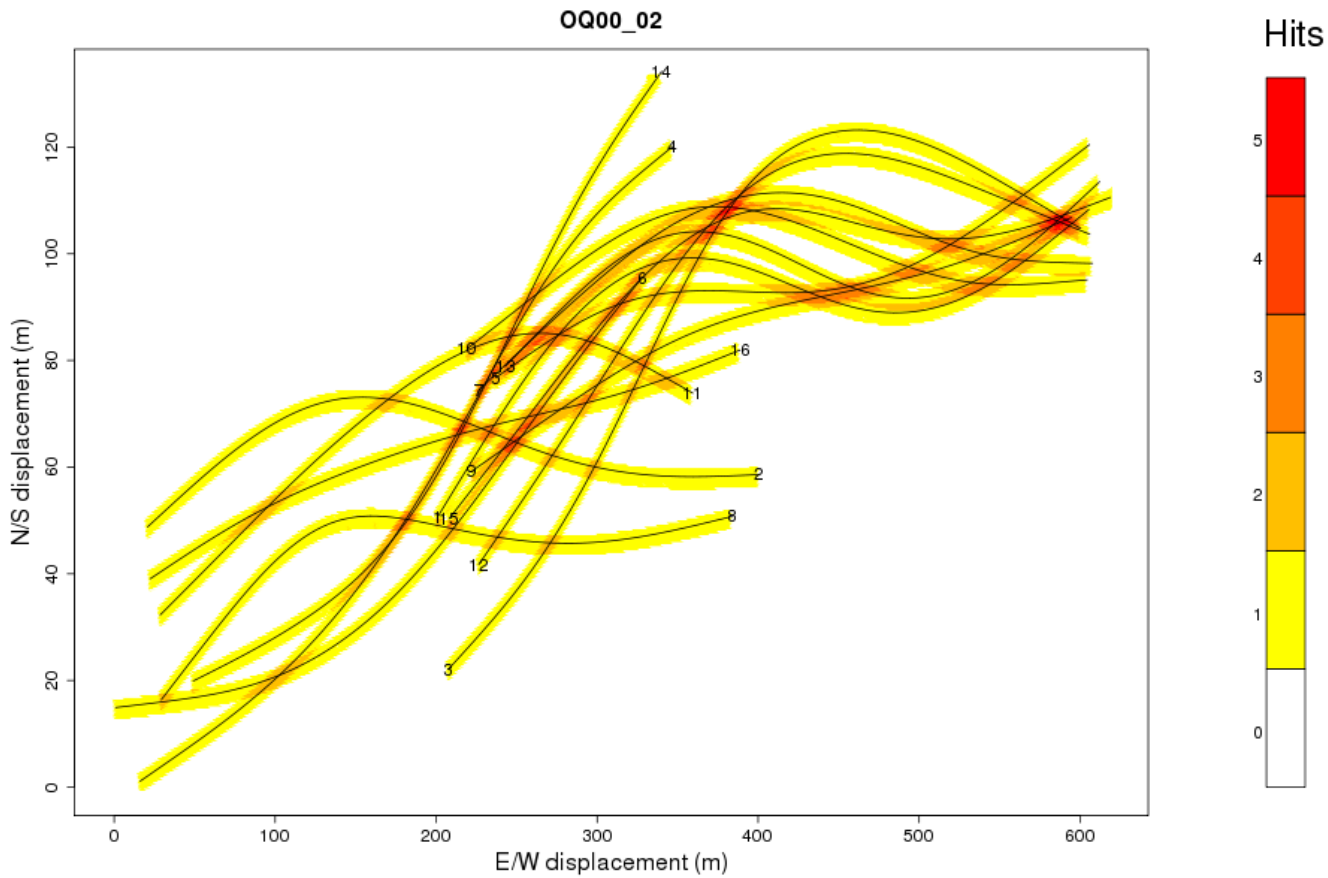

Figure 159: Depletion sequence for experiment OQ00-02, showing the number of passes made by the dredge over each cm^2 of the experimental area.

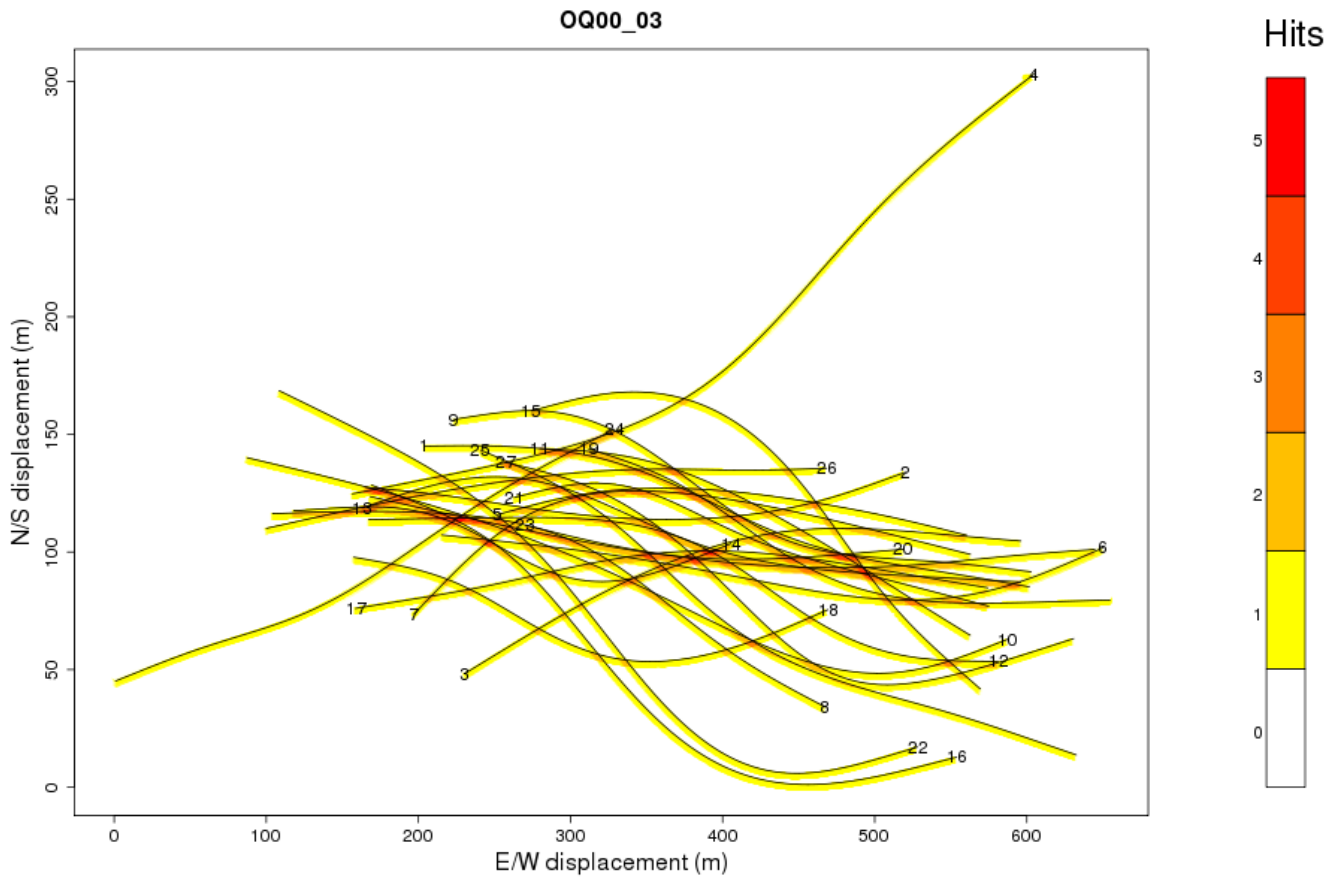

Figure 160: Depletion sequence for experiment OQ00-03, showing the number of passes made by the dredge over each cm^2 of the experimental area.

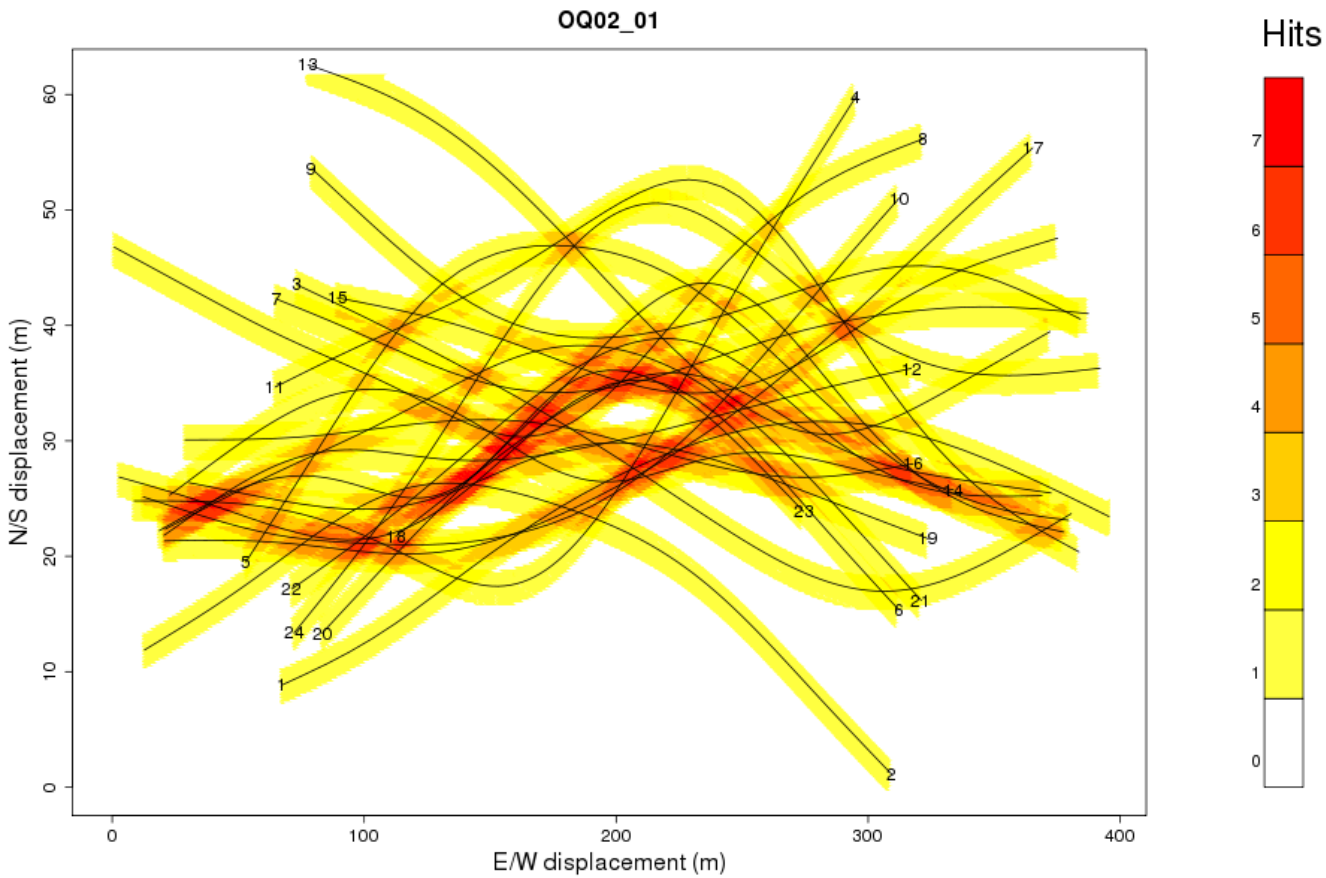

Figure 161: Depletion sequence for experiment OQ02-01, showing the number of passes made by the dredge over each cm^2 of the experimental area.

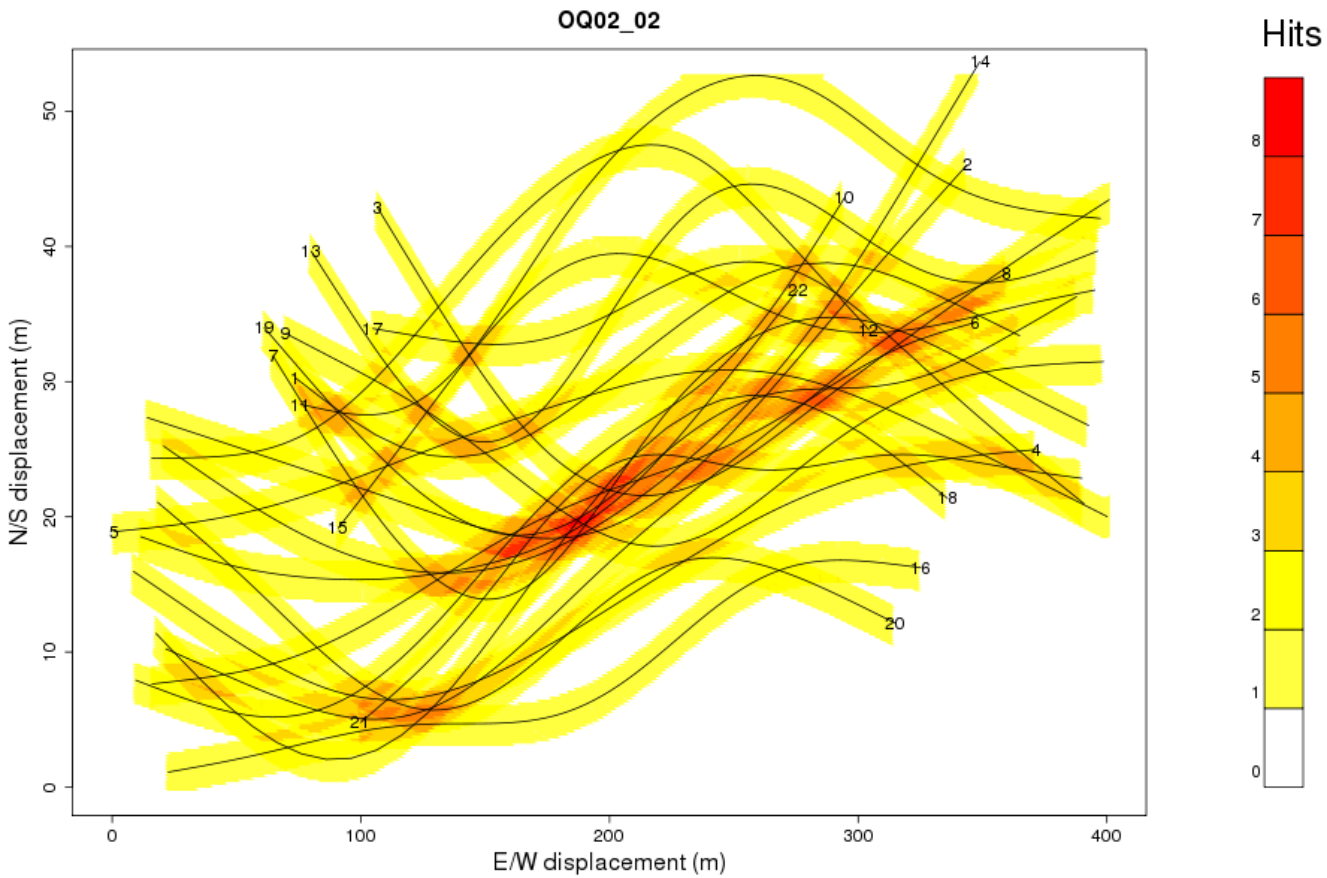

Figure 162: Depletion sequence for experiment OQ02-02, showing the number of passes made by the dredge over each cm^2 of the experimental area.

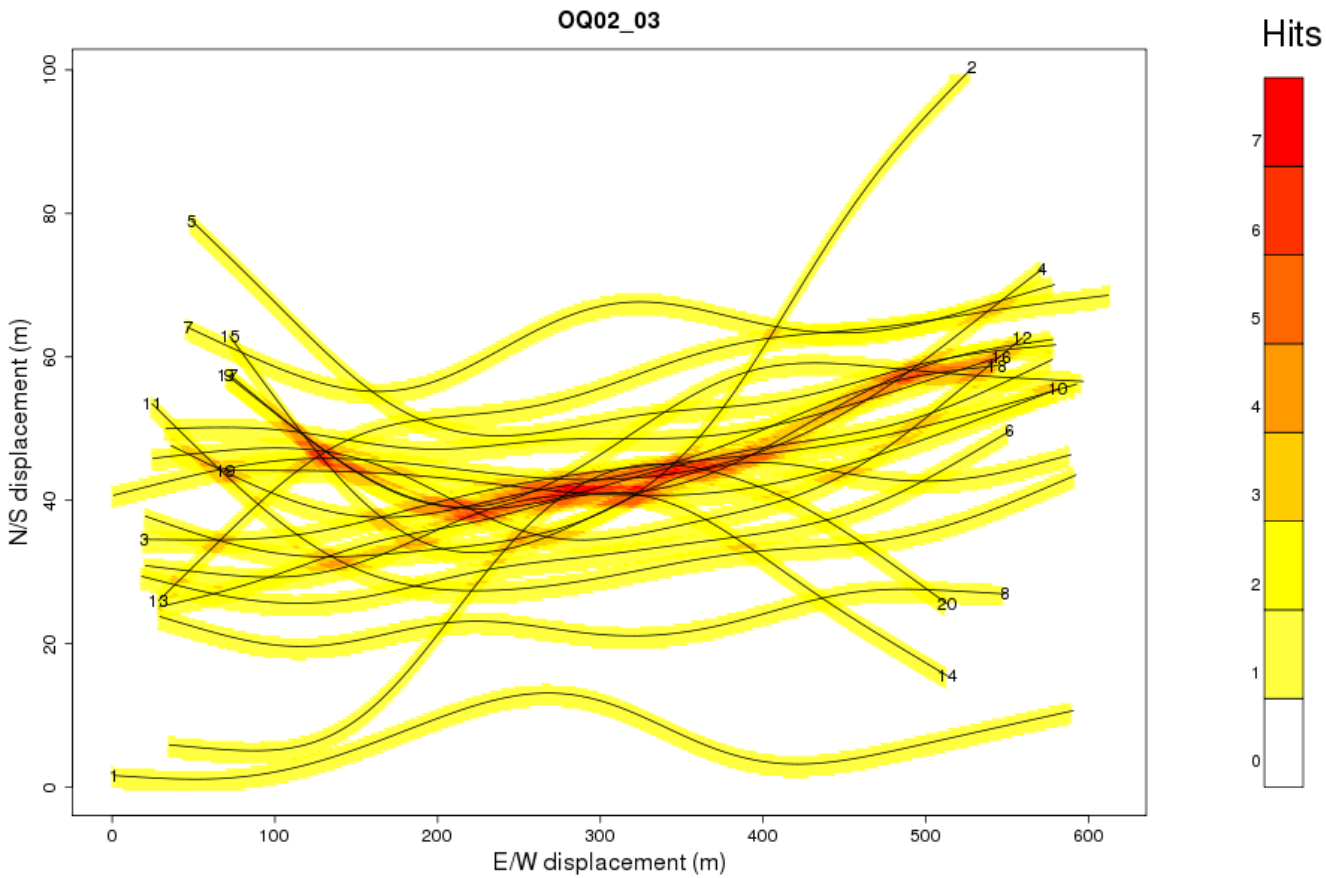

Figure 163: Depletion sequence for experiment OQ02-03, showing the number of passes made by the dredge over each cm^2 of the experimental area.

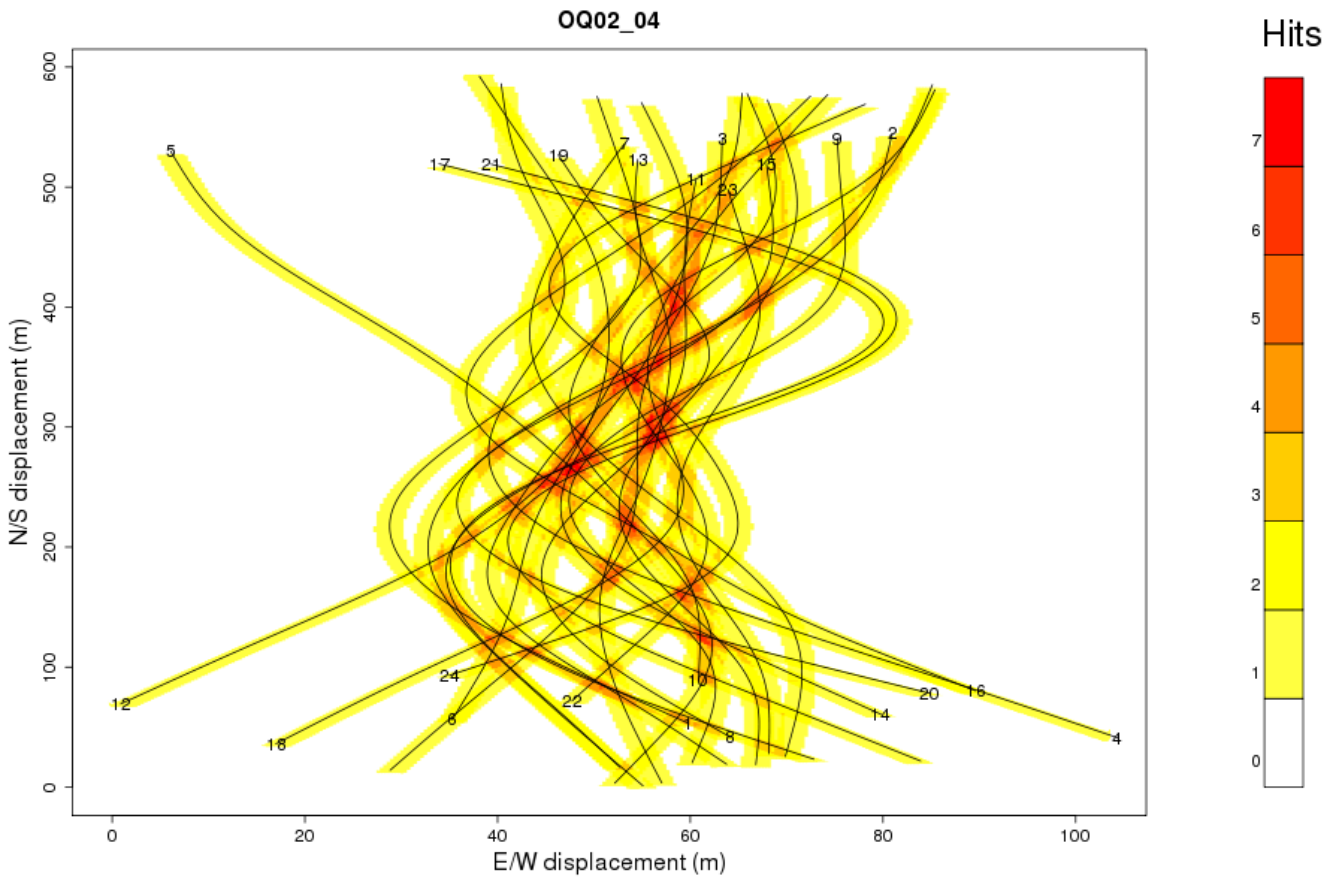

Figure 164: Depletion sequence for experiment OQ02-04, showing the number of passes made by the dredge over each cm^2 of the experimental area.

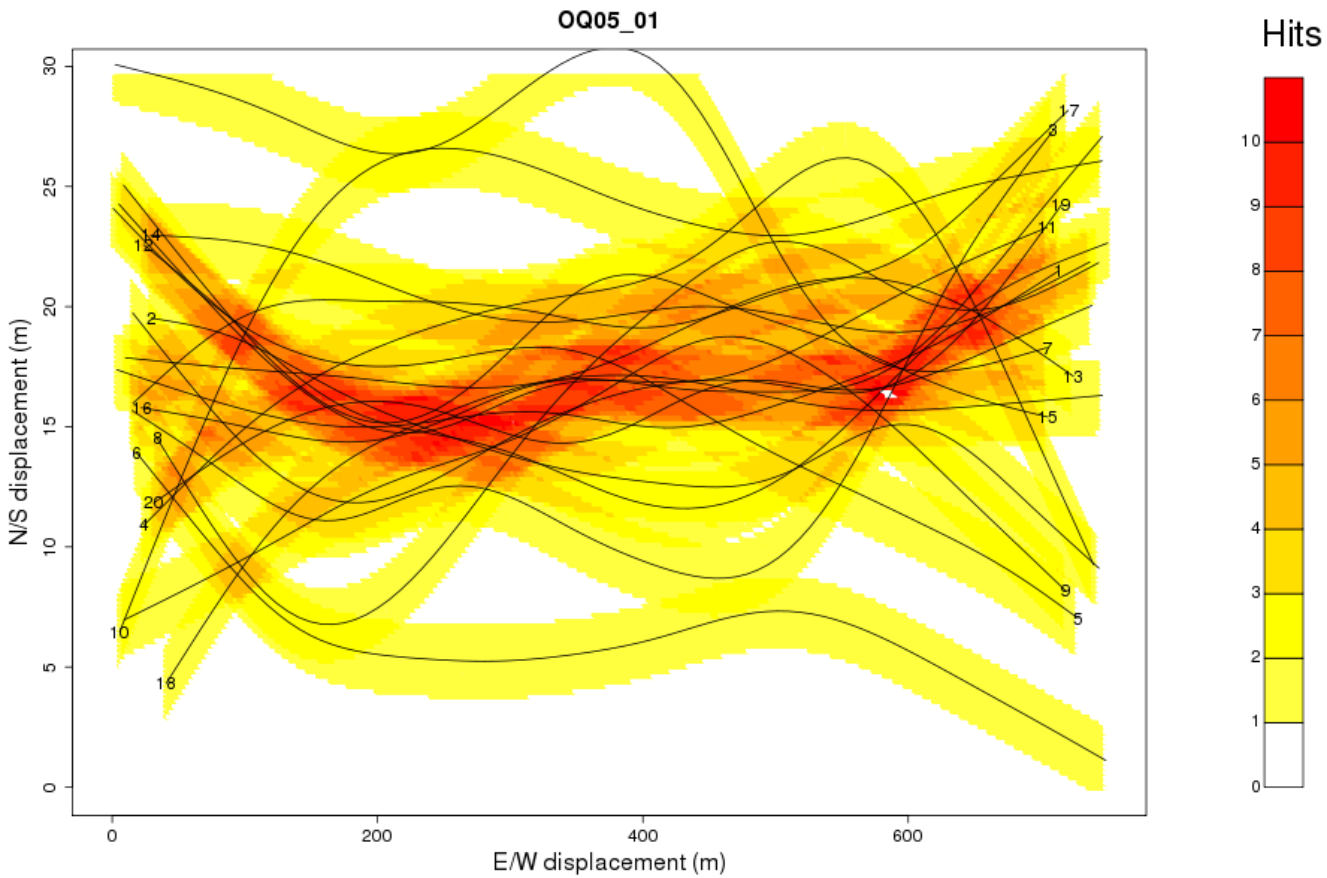

Figure 165: Depletion sequence for experiment OQ05-01, showing the number of passes made by the dredge over each cm^2 of the experimental area.

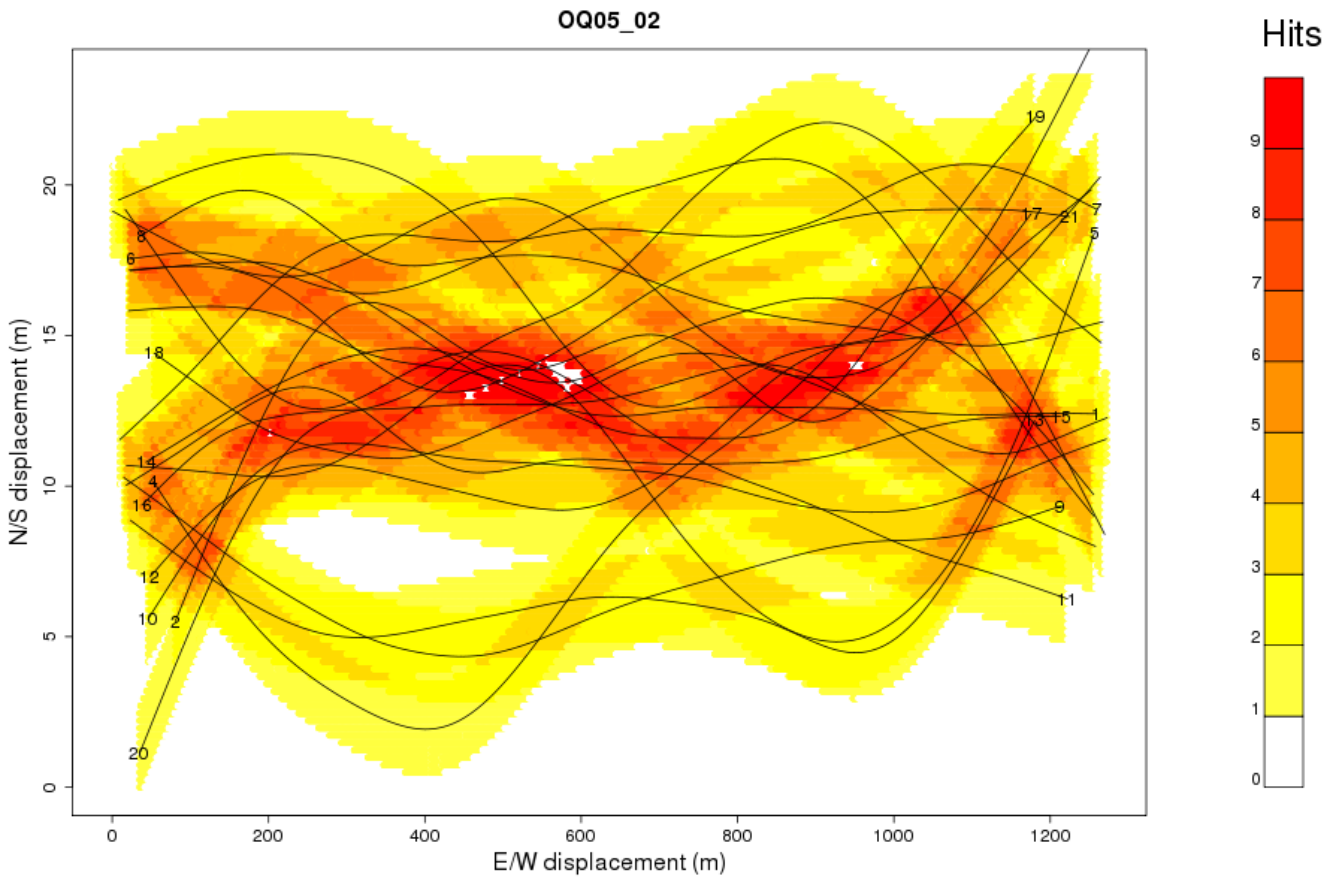

Figure 166: Depletion sequence for experiment OQ05-02, showing the number of passes made by the dredge over each cm^2 of the experimental area.

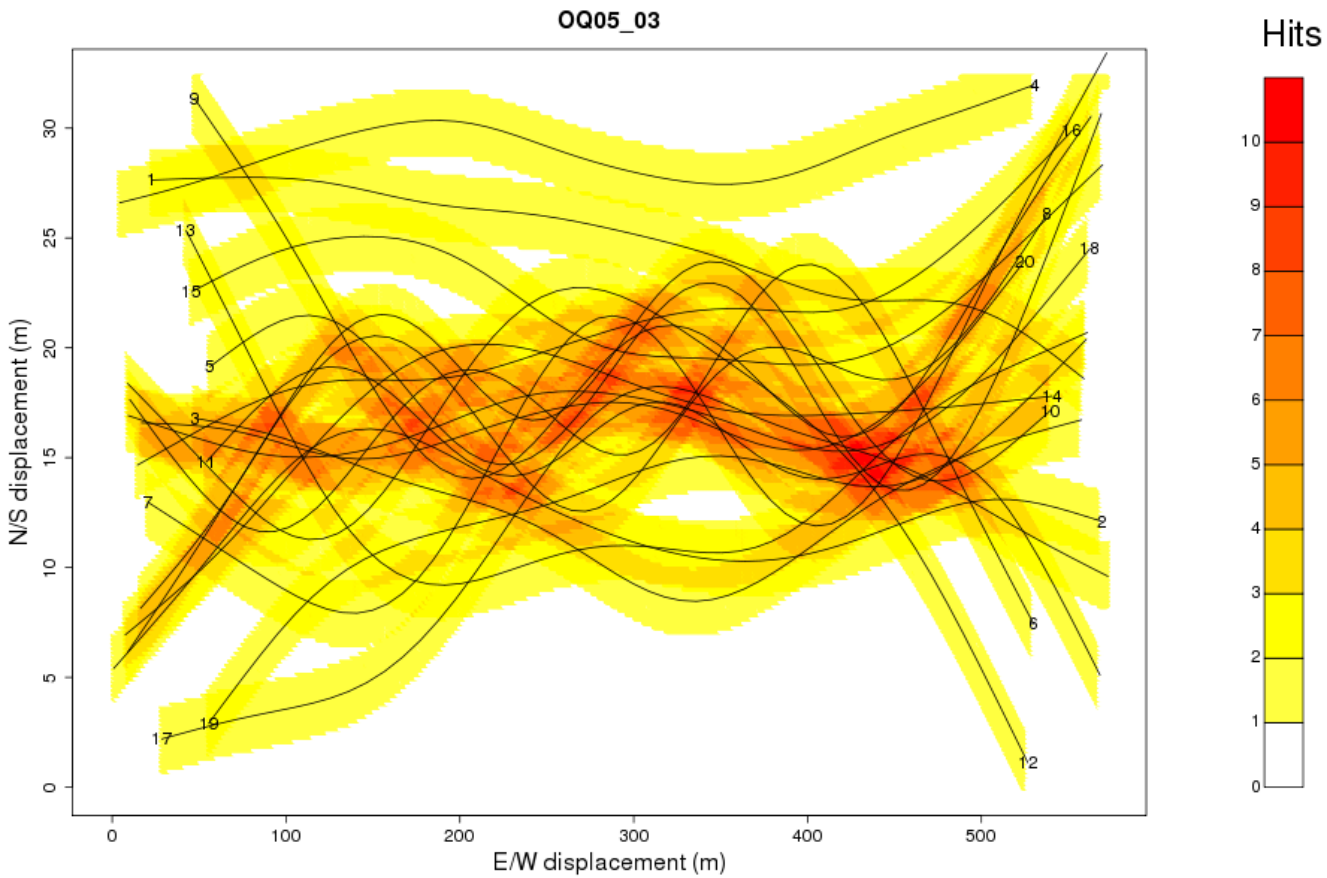

Figure 167: Depletion sequence for experiment OQ05-03, showing the number of passes made by the dredge over each cm^2 of the experimental area.

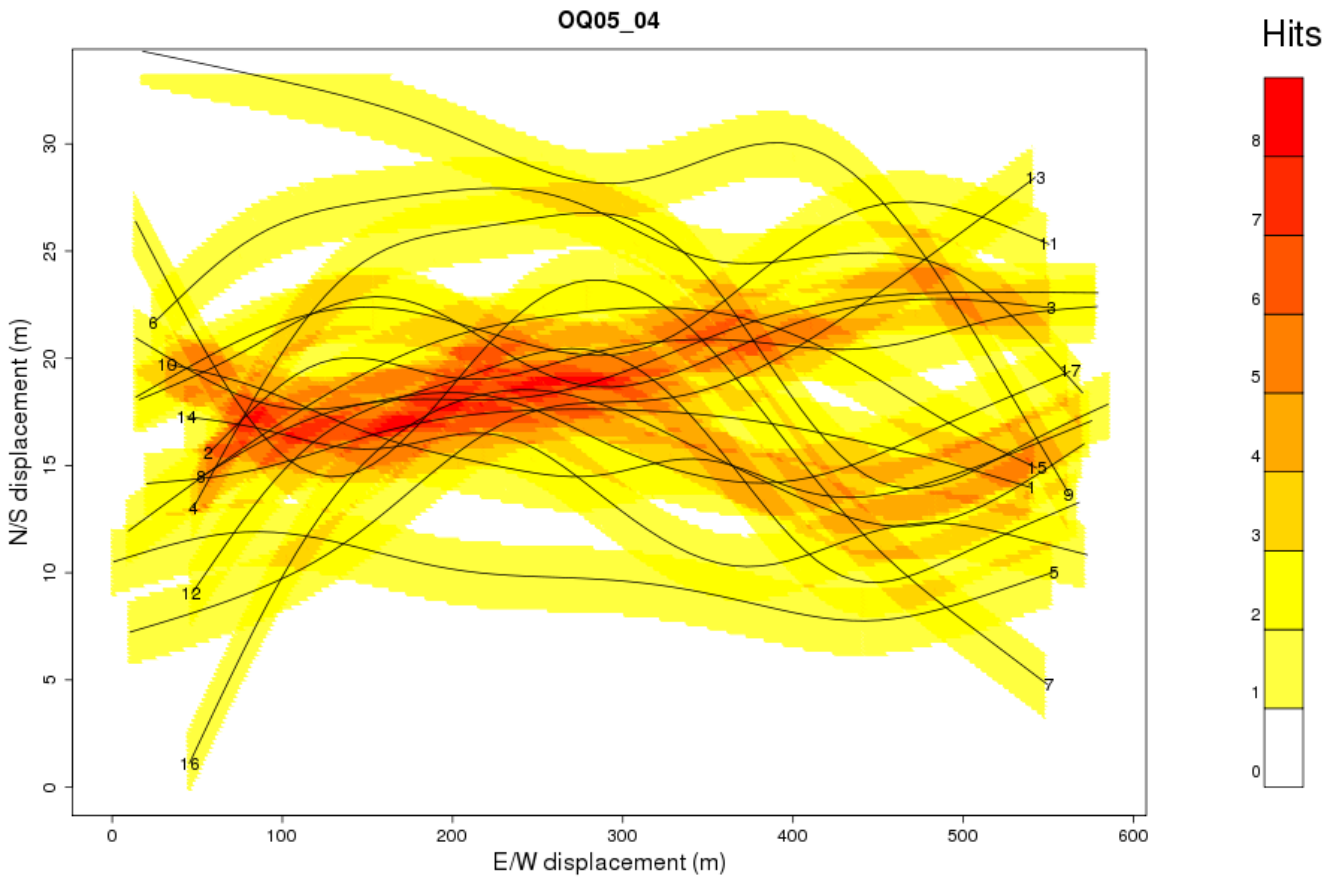

Figure 168: Depletion sequence for experiment OQ05-04, showing the number of passes made by the dredge over each cm^2 of the experimental area.

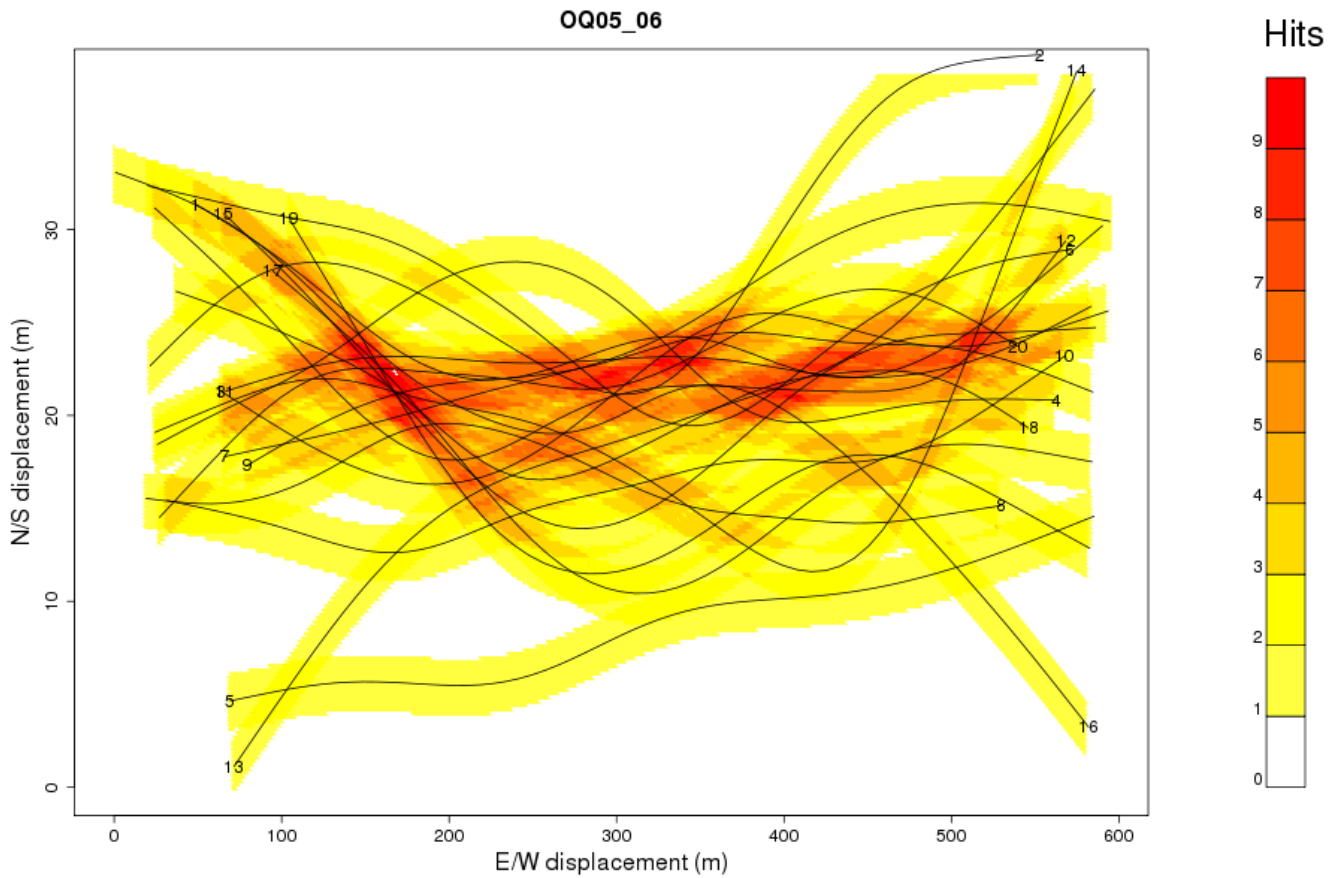

Figure 169: Depletion sequence for experiment OQ05-06, showing the number of passes made by the dredge over each cm^2 of the experimental area.

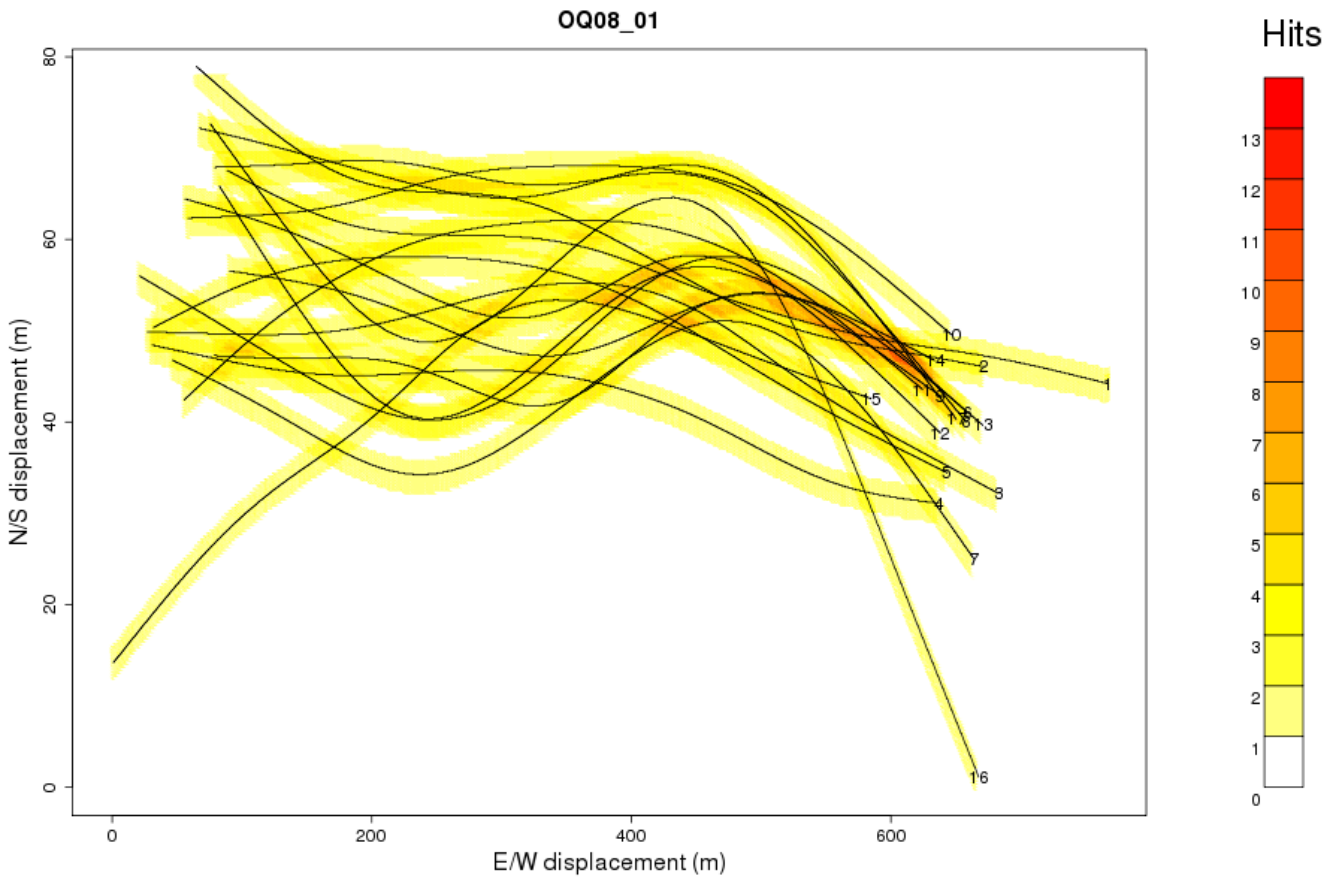

Figure 170: Depletion sequence for experiment OQ08-01, showing the number of passes made by the dredge over each cm^2 of the experimental area.

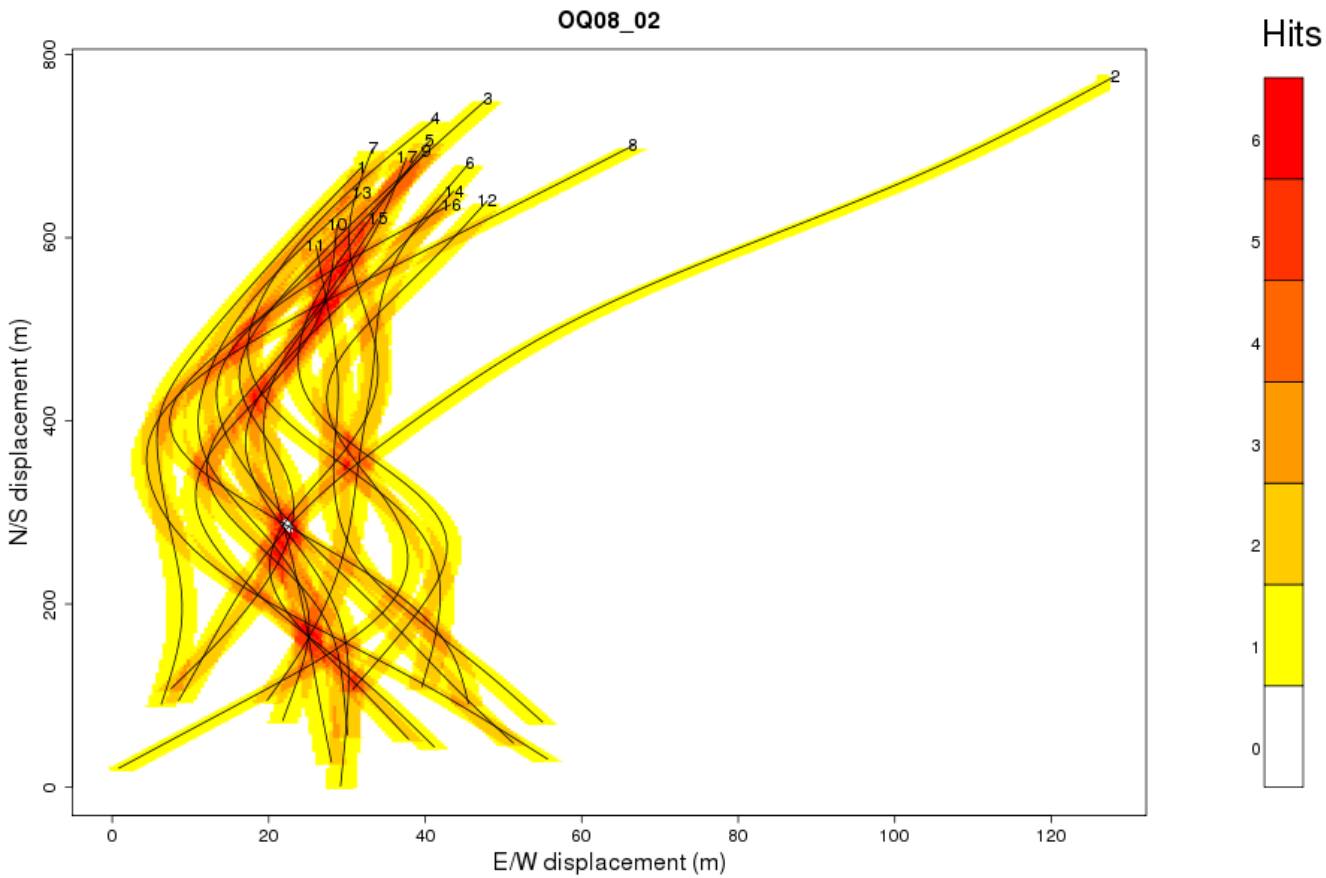

Figure 171: Depletion sequence for experiment OQ08-02, showing the number of passes made by the dredge over each cm^2 of the experimental area.

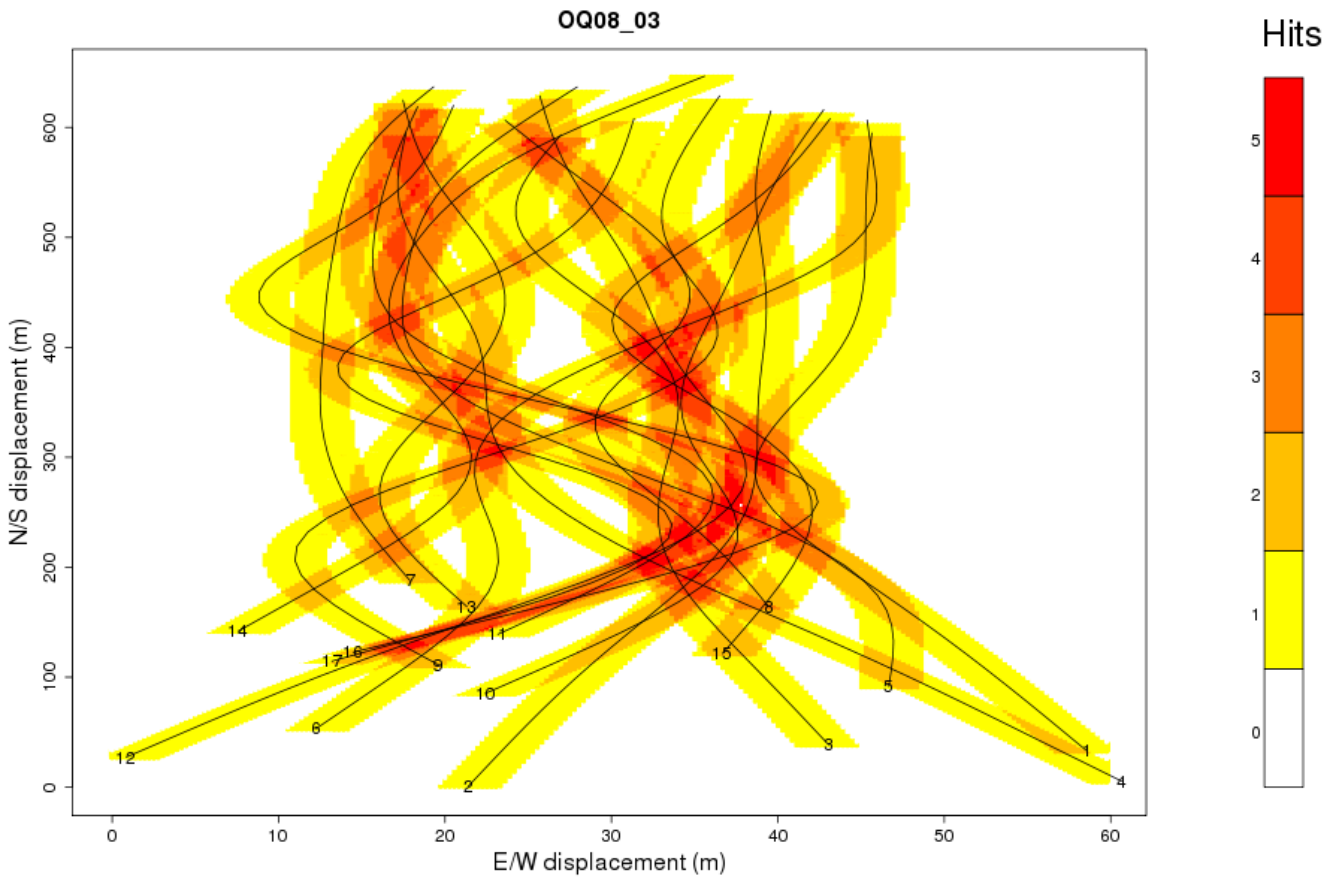

Figure 172: Depletion sequence for experiment OQ08-03, showing the number of passes made by the dredge over each cm^2 of the experimental area.

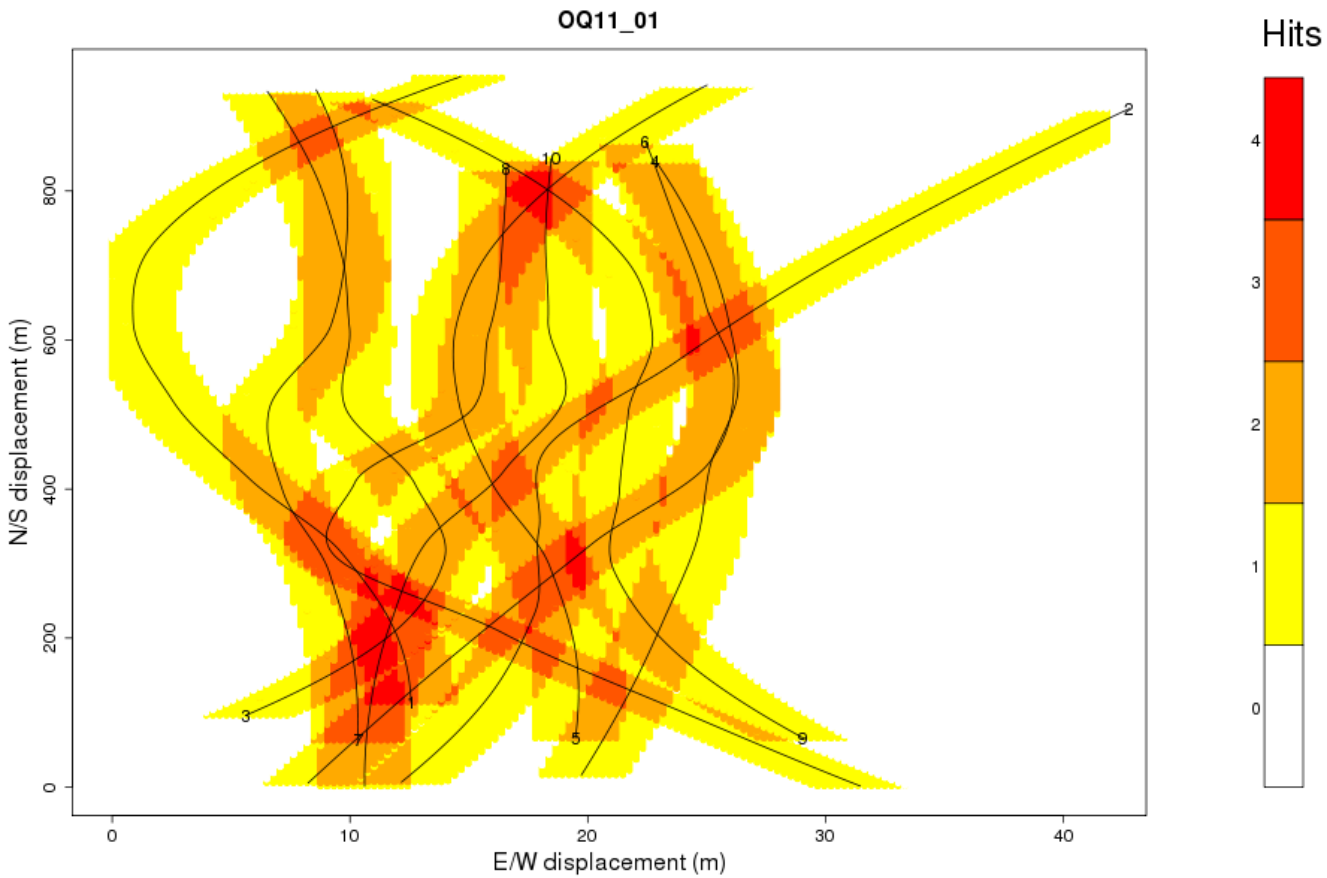

Figure 173: Depletion sequence for experiment OQ11-01, showing the number of passes made by the dredge over each cm^2 of the experimental area.

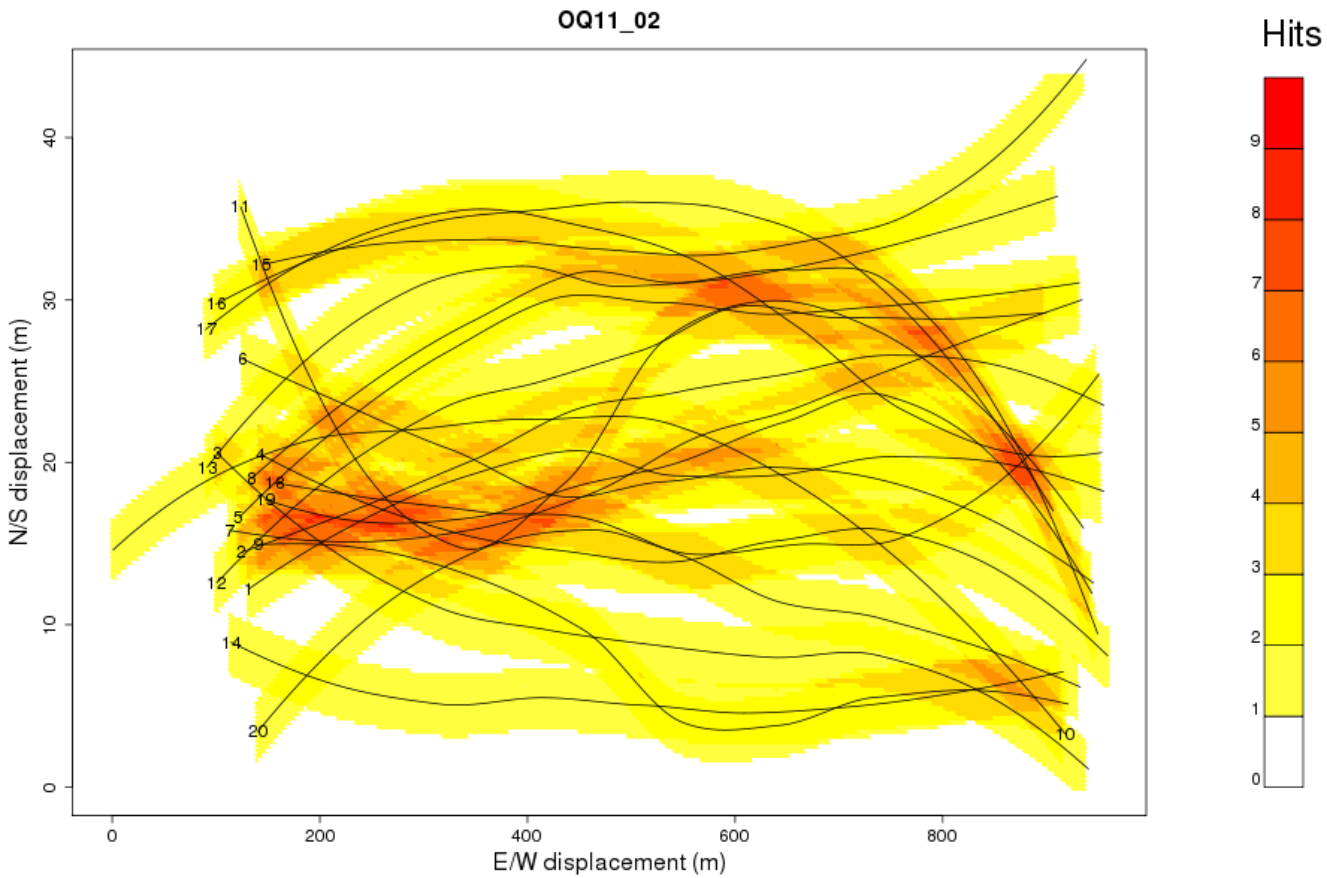

Figure 174: Depletion sequence for experiment OQ11-02, showing the number of passes made by the dredge over each cm^2 of the experimental area.

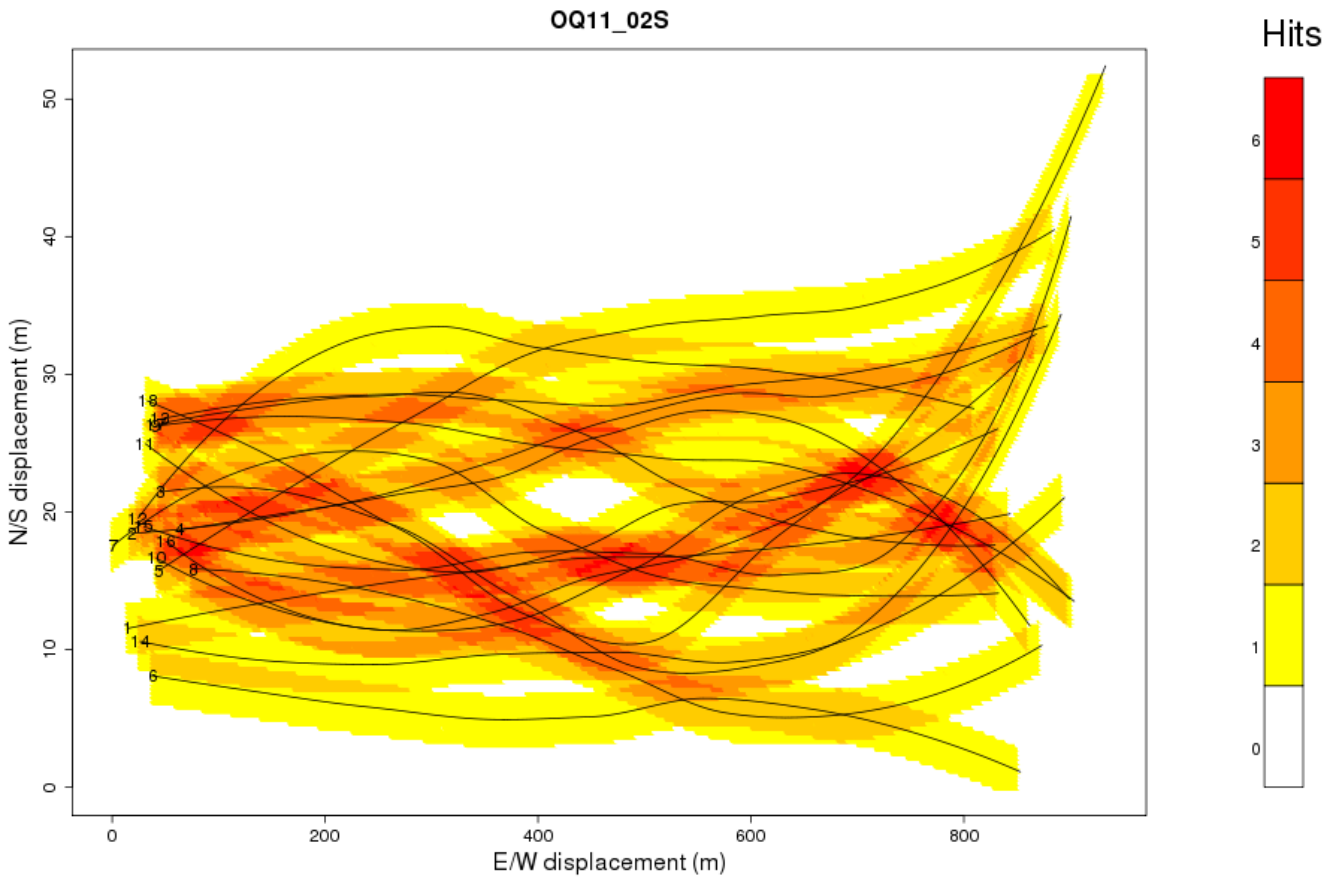

Figure 175: Depletion sequence for experiment OQ11-02S, showing the number of passes made by the dredge over each cm^2 of the experimental area.

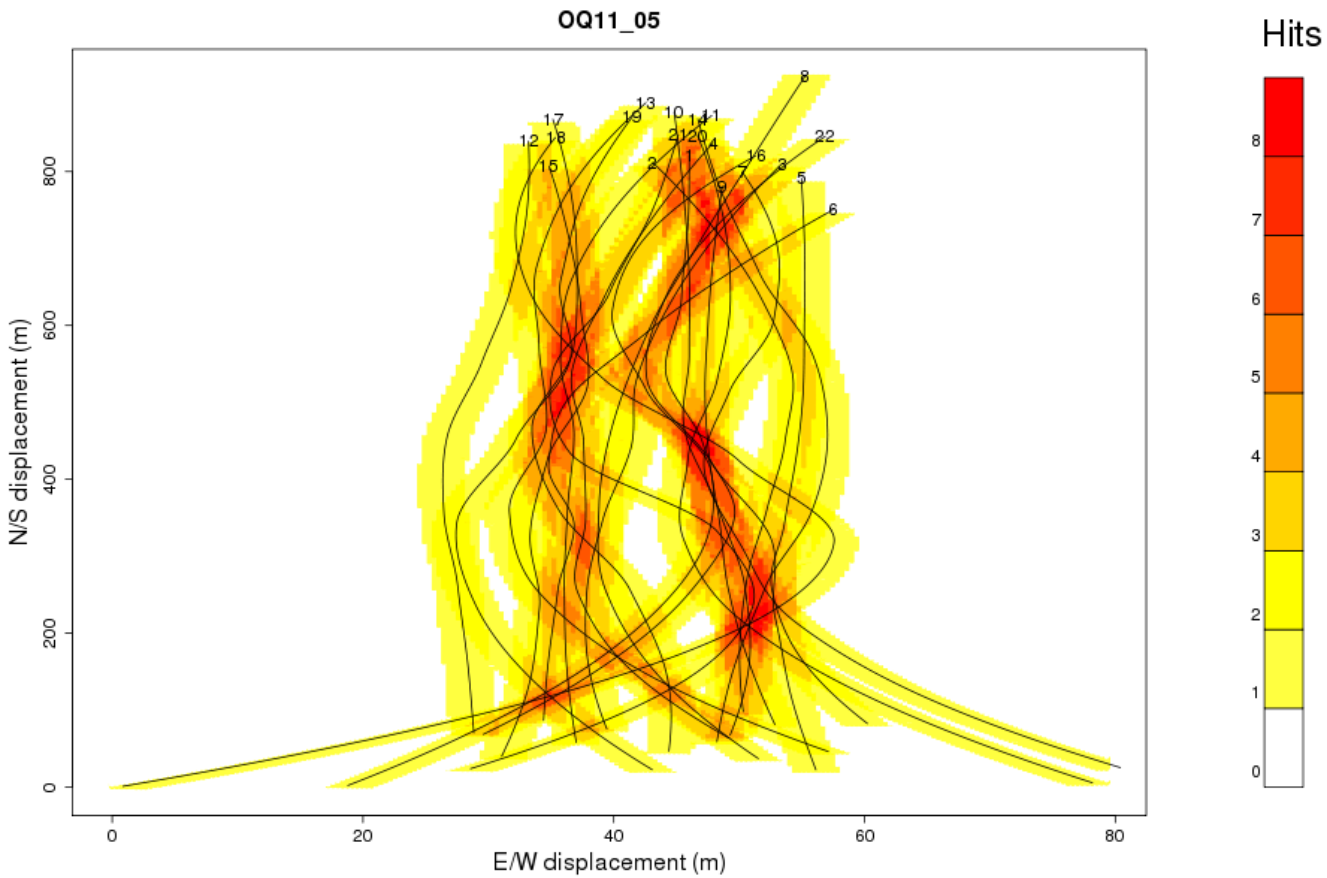

Figure 176: Depletion sequence for experiment OQ11-05, showing the number of passes made by the dredge over each cm^2 of the experimental area.

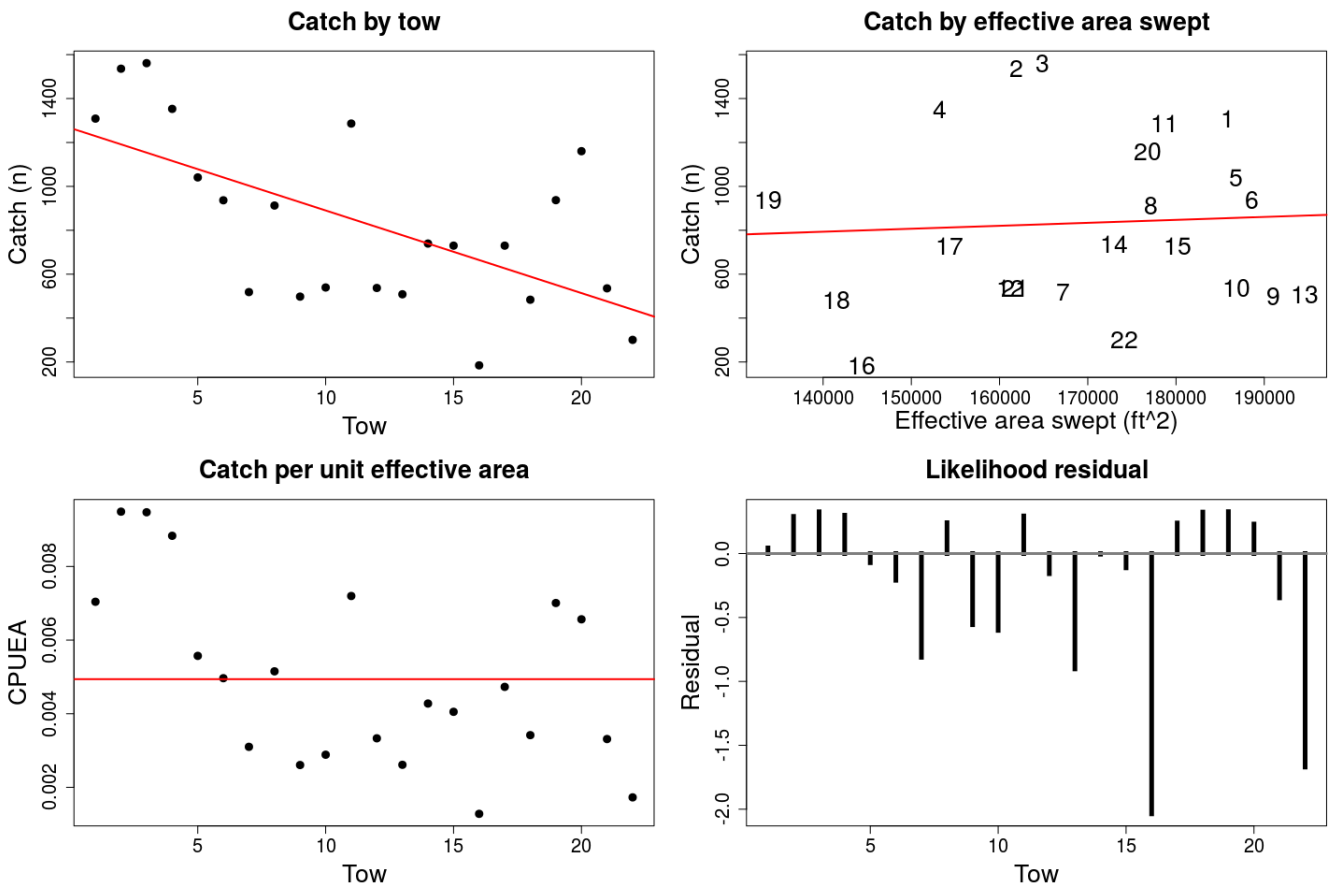

Figure 177: Diagnostic plots for ocean quahog depletion experiment OQ00-01. Catch by tow shows the catch recorded in each tow. This plot should show a declining trend over time. Catch vs. effective area swept shows the catch by the area swept by each tow, while accounting for the area in each tow that has already been fished. The numbers indicate the order of tows. This plot should show an increasing trend. CPUEA vs. tow shows the catch per unit of effective area by tow. This plot should not show a trend. Likelihood residual shows the fit of the model to each tow and should not indicate any patterns if the model has worked well.

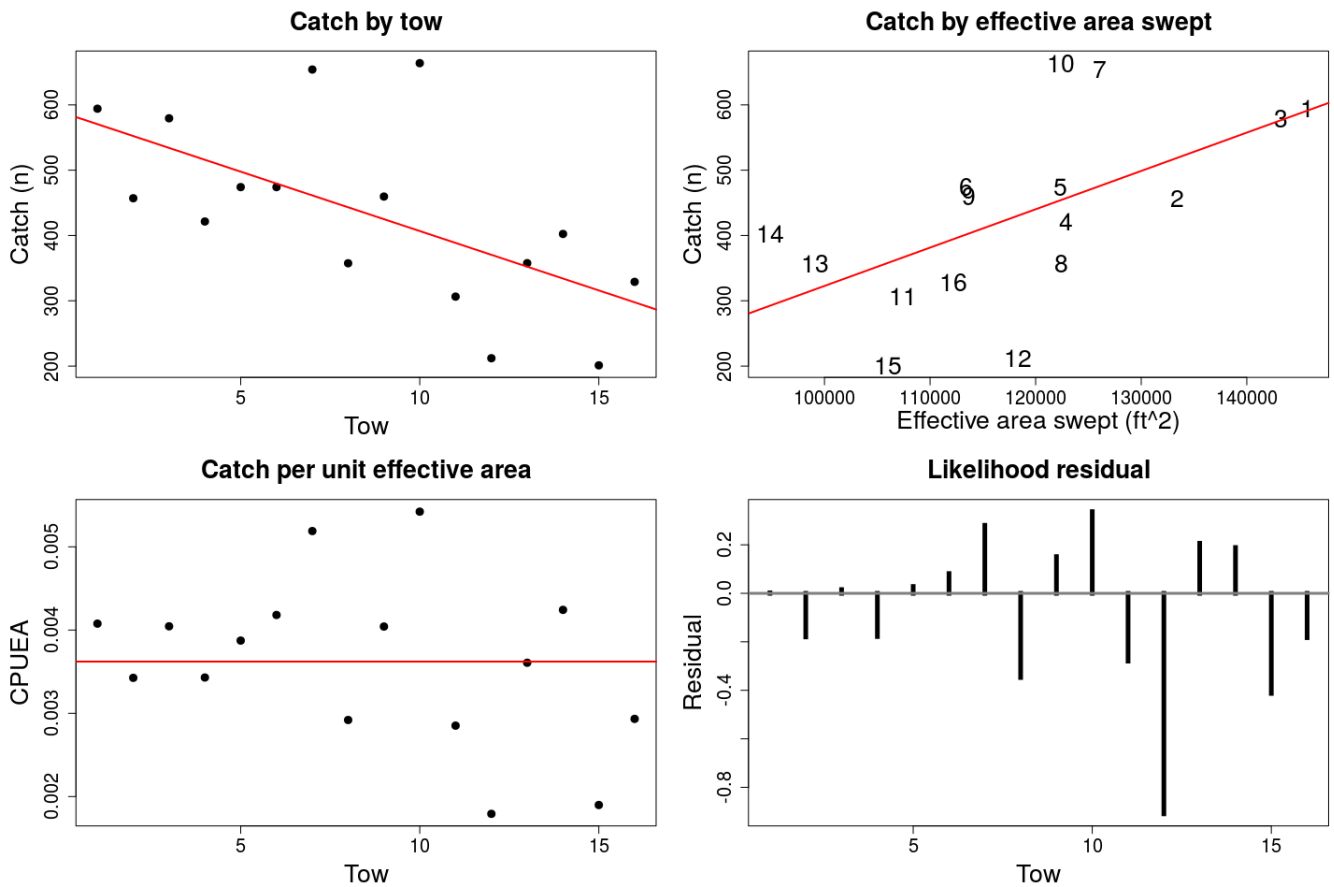

Figure 178: Diagnostic plots for ocean quahog depletion experiment OQ00-02. Catch by tow shows the catch recorded in each tow. This plot should show a declining trend over time. Catch vs. effective area swept shows the catch by the area swept by each tow, while accounting for the area in each tow that has already been fished. The numbers indicate the order of tows. This plot should show an increasing trend. CPUEA vs. tow shows the catch per unit of effective area by tow. This plot should not show a trend. Likelihood residual shows the fit of the model to each tow and should not indicate any patterns if the model has worked well.

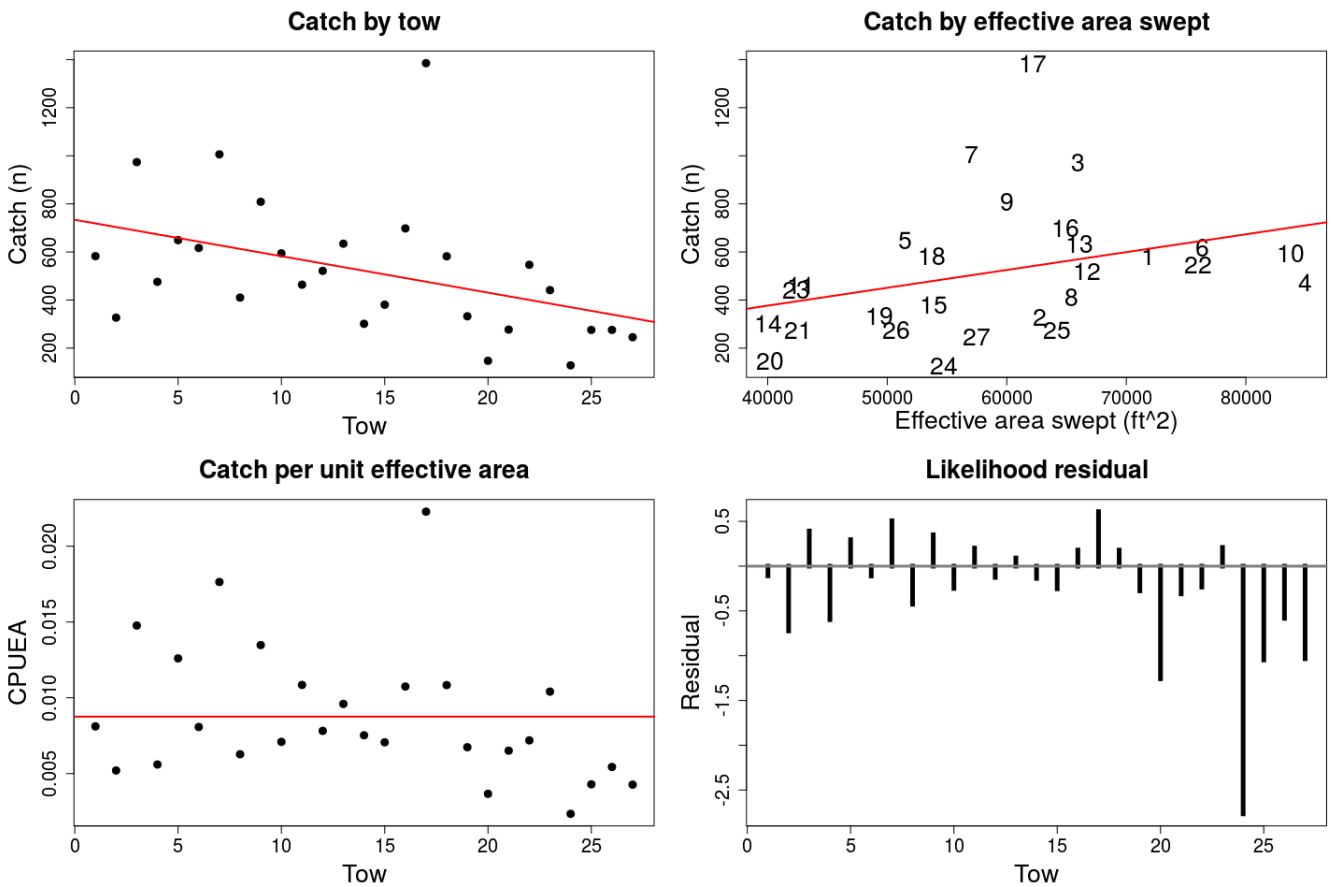

Figure 179: Diagnostic plots for ocean quahog depletion experiment OQ00-03. Catch by tow shows the catch recorded in each tow. This plot should show a declining trend over time. Catch vs. effective area swept shows the catch by the area swept by each tow, while accounting for the area in each tow that has already been fished. The numbers indicate the order of tows. This plot should show an increasing trend. CPUEA vs. tow shows the catch per unit of effective area by tow. This plot should not show a trend. Likelihood residual shows the fit of the model to each tow and should not indicate any patterns if the model has worked well.

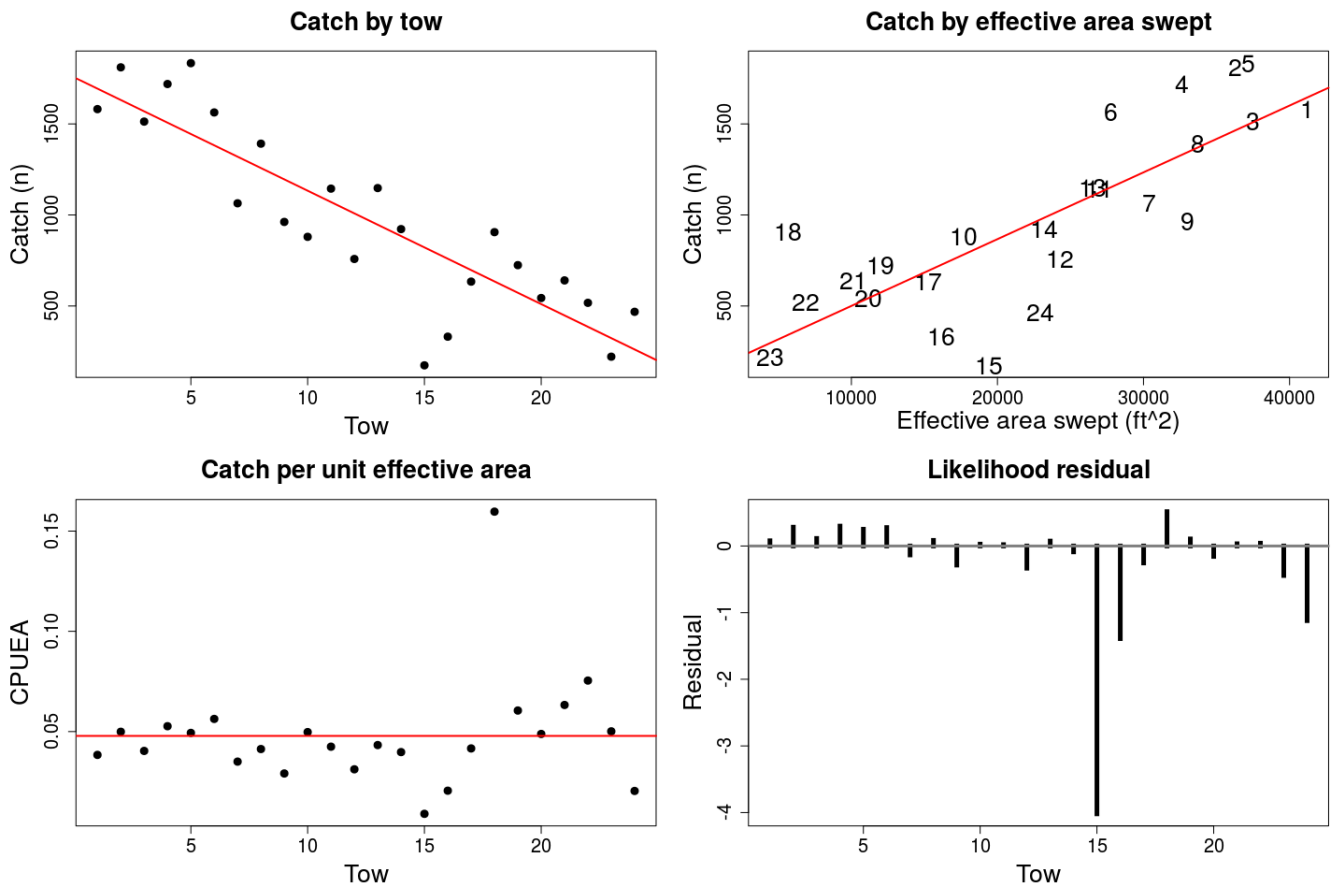

Figure 180: Diagnostic plots for ocean quahog depletion experiment OQ02-01. Catch by tow shows the catch recorded in each tow. This plot should show a declining trend over time. Catch vs. effective area swept shows the catch by the area swept by each tow, while accounting for the area in each tow that has already been fished. The numbers indicate the order of tows. This plot should show an increasing trend. CPUEA vs. tow shows the catch per unit of effective area by tow. This plot should not show a trend. Likelihood residual shows the fit of the model to each tow and should not indicate any patterns if the model has worked well.

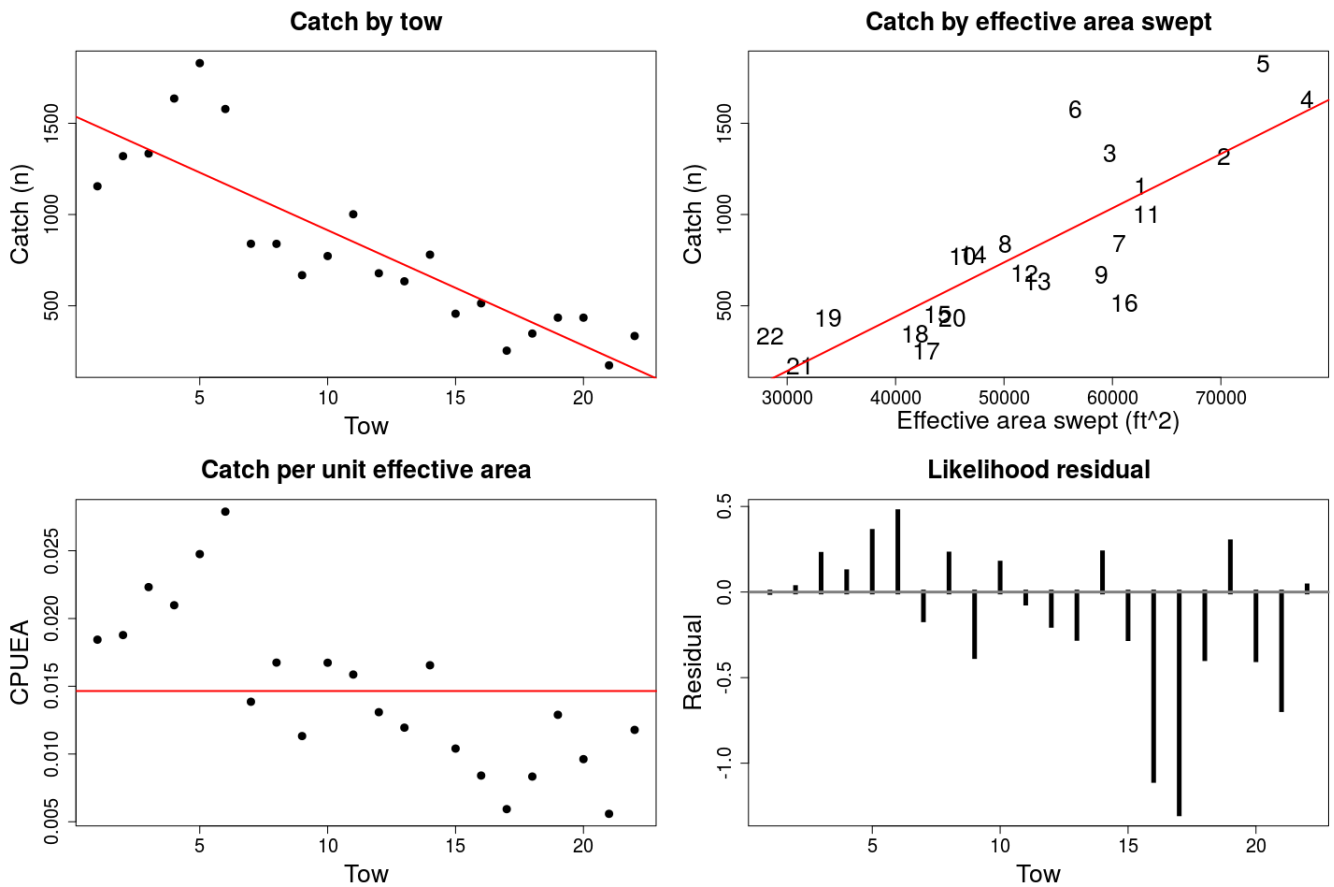

Figure 181: Diagnostic plots for ocean quahog depletion experiment OQ02-02. Catch by tow shows the catch recorded in each tow. This plot should show a declining trend over time. Catch vs. effective area swept shows the catch by the area swept by each tow, while accounting for the area in each tow that has already been fished. The numbers indicate the order of tows. This plot should show an increasing trend. CPUEA vs. tow shows the catch per unit of effective area by tow. This plot should not show a trend. Likelihood residual shows the fit of the model to each tow and should not indicate any patterns if the model has worked well.

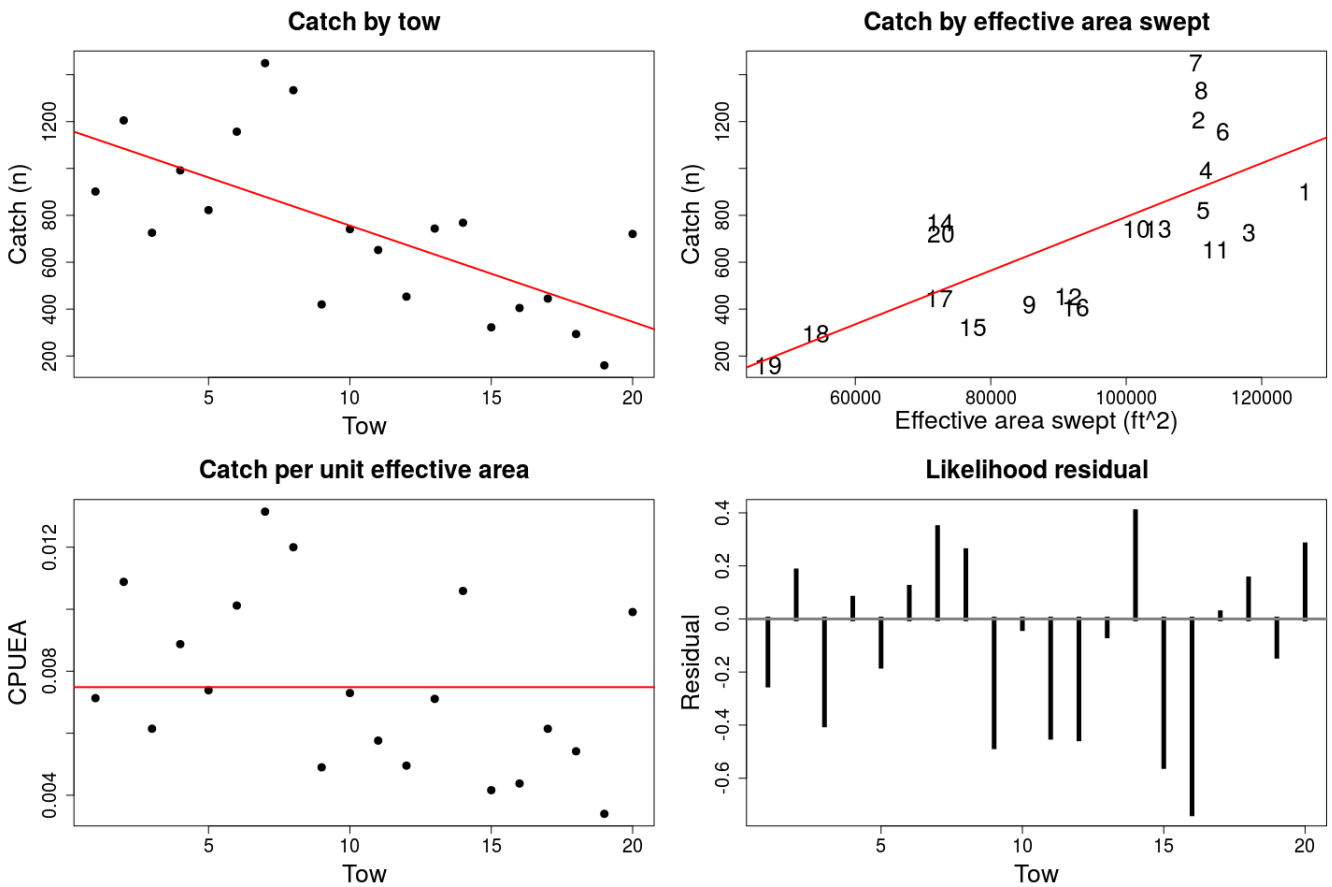

Figure 182: Diagnostic plots for ocean quahog depletion experiment OQ02-03. Catch by tow shows the catch recorded in each tow. This plot should show a declining trend over time. Catch vs. effective area swept shows the catch by the area swept by each tow, while accounting for the area in each tow that has already been fished. The numbers indicate the order of tows. This plot should show an increasing trend. CPUEA vs. tow shows the catch per unit of effective area by tow. This plot should not show a trend. Likelihood residual shows the fit of the model to each tow and should not indicate any patterns if the model has worked well.

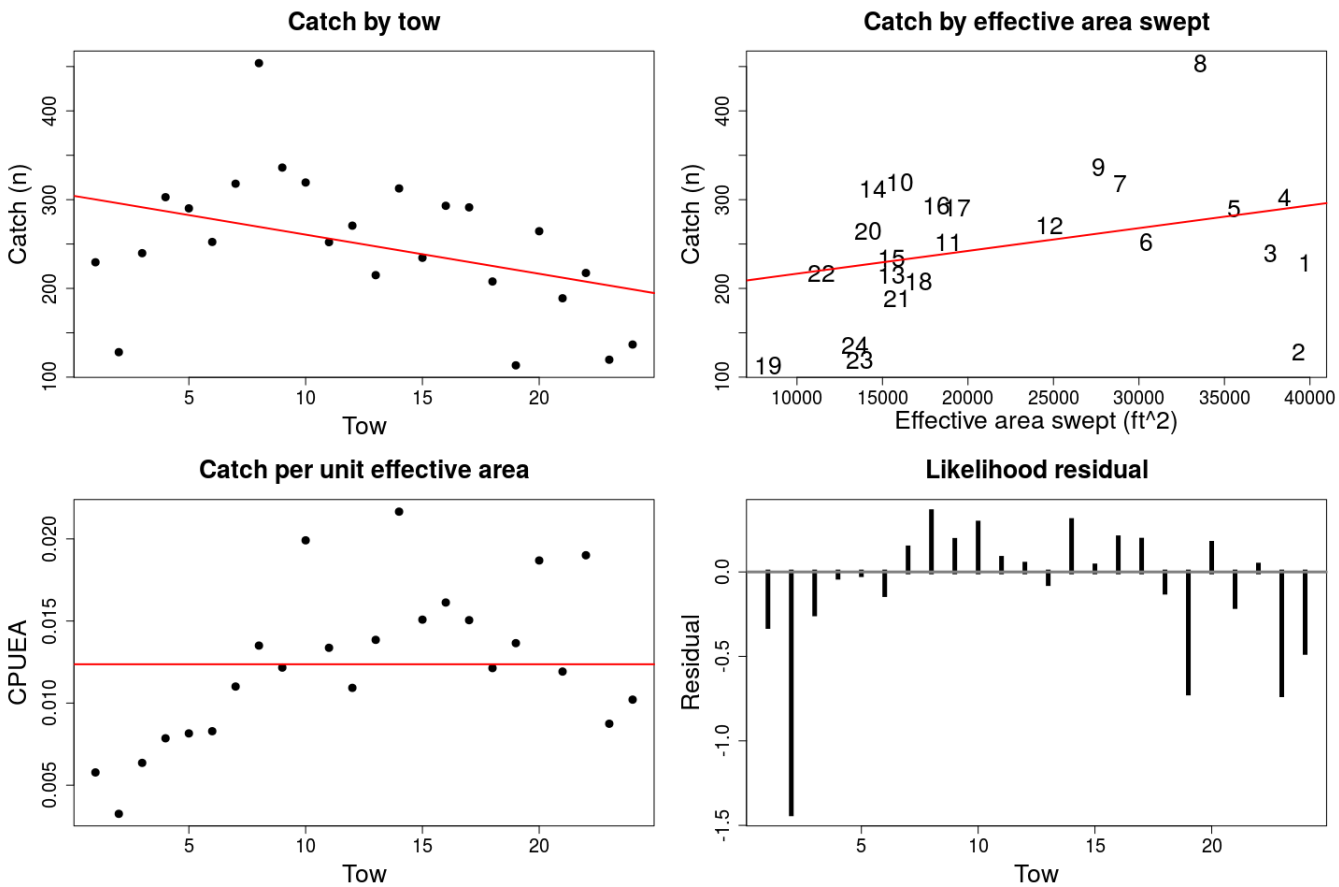

Figure 183: Diagnostic plots for ocean quahog depletion experiment OQ02-04. Catch by tow shows the catch recorded in each tow. This plot should show a declining trend over time. Catch vs. effective area swept shows the catch by the area swept by each tow, while accounting for the area in each tow that has already been fished. The numbers indicate the order of tows. This plot should show an increasing trend. CPUEA vs. tow shows the catch per unit of effective area by tow. This plot should not show a trend. Likelihood residual shows the fit of the model to each tow and should not indicate any patterns if the model has worked well.

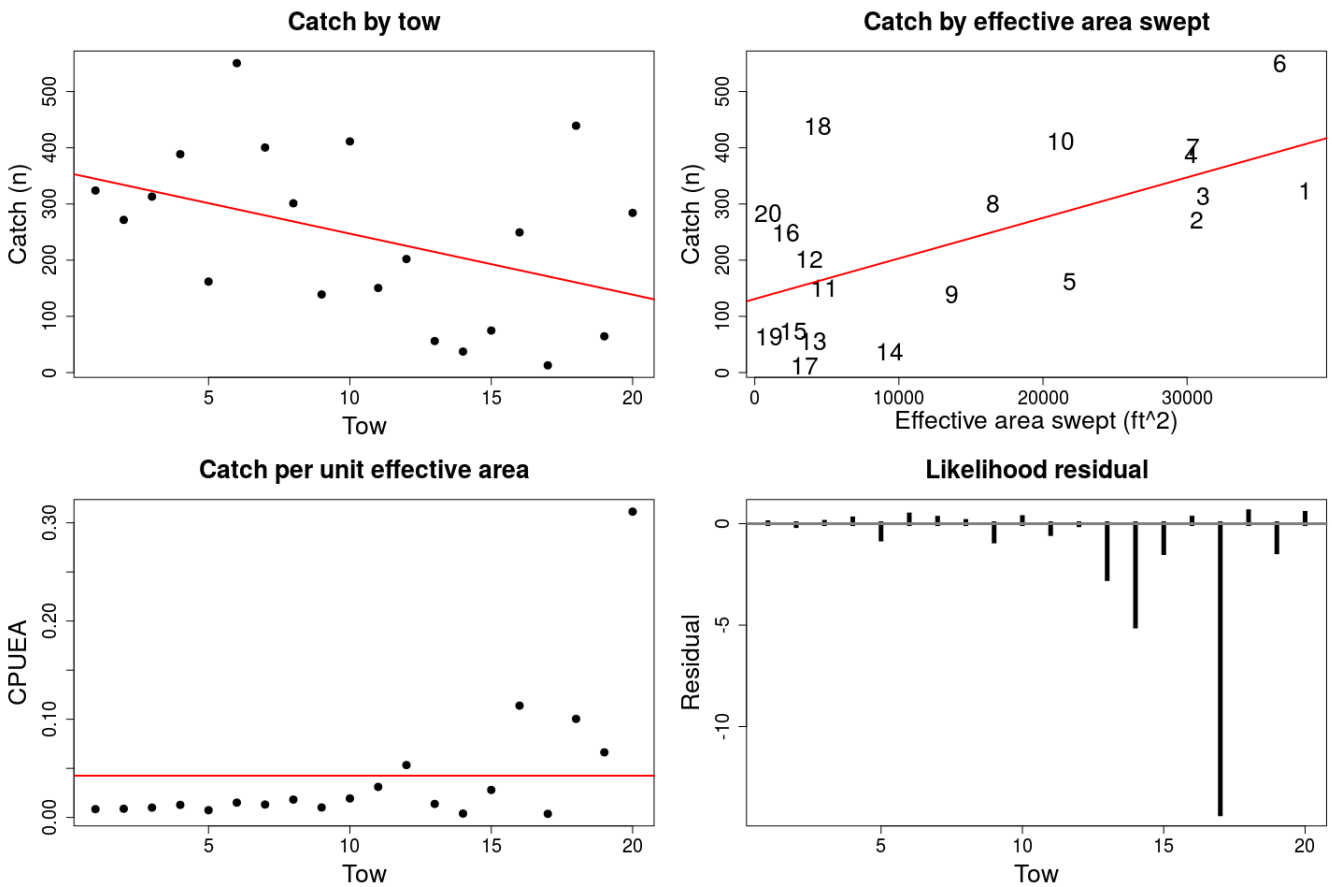

Figure 184: Diagnostic plots for ocean quahog depletion experiment OQ05-01. Catch by tow shows the catch recorded in each tow. This plot should show a declining trend over time. Catch vs. effective area swept shows the catch by the area swept by each tow, while accounting for the area in each tow that has already been fished. The numbers indicate the order of tows. This plot should show an increasing trend. CPUEA vs. tow shows the catch per unit of effective area by tow. This plot should not show a trend. Likelihood residual shows the fit of the model to each tow and should not indicate any patterns if the model has worked well.

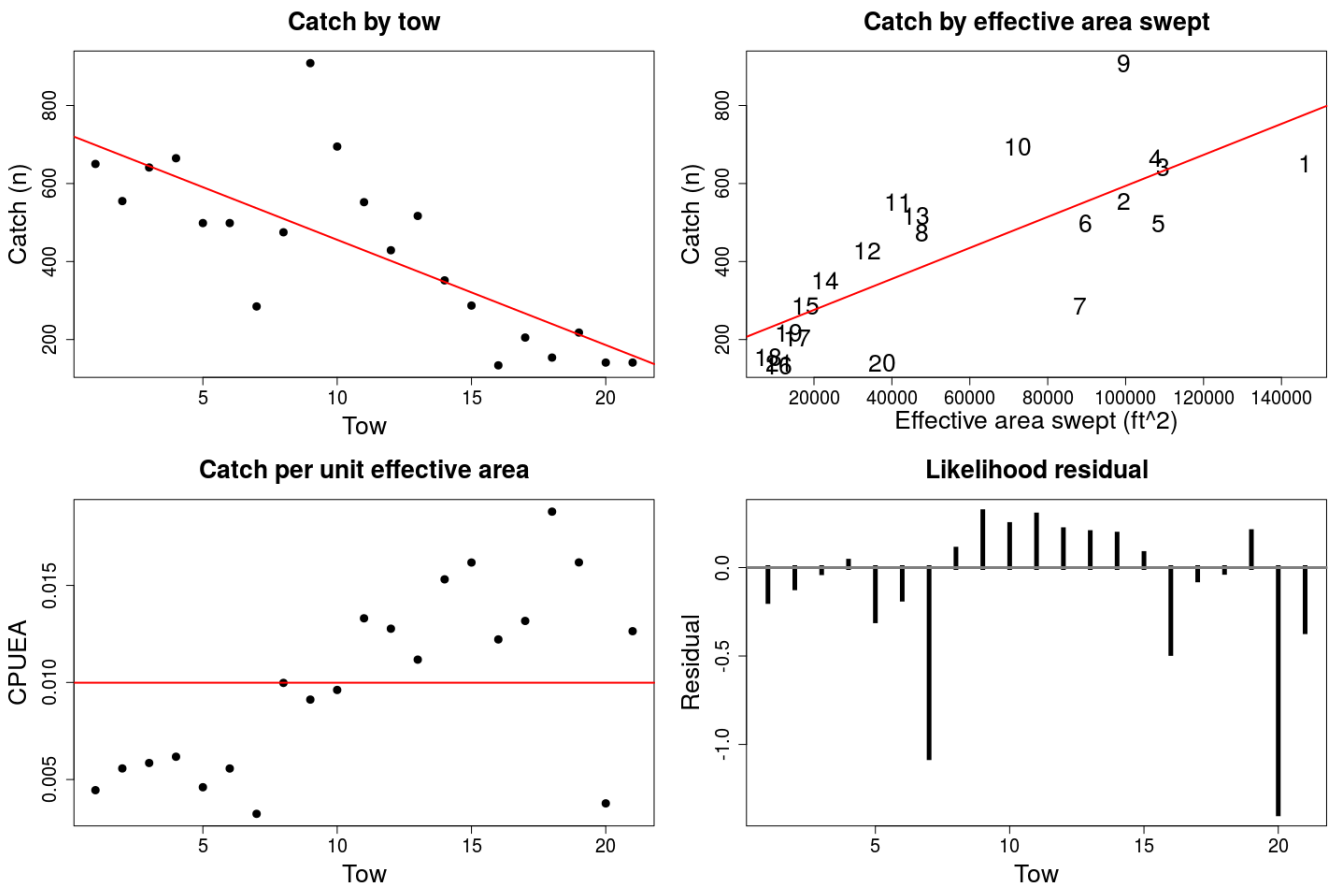

Figure 185: Diagnostic plots for ocean quahog depletion experiment OQ05-02. Catch by tow shows the catch recorded in each tow. This plot should show a declining trend over time. Catch vs. effective area swept shows the catch by the area swept by each tow, while accounting for the area in each tow that has already been fished. The numbers indicate the order of tows. This plot should show an increasing trend. CPUEA vs. tow shows the catch per unit of effective area by tow. This plot should not show a trend. Likelihood residual shows the fit of the model to each tow and should not indicate any patterns if the model has worked well.

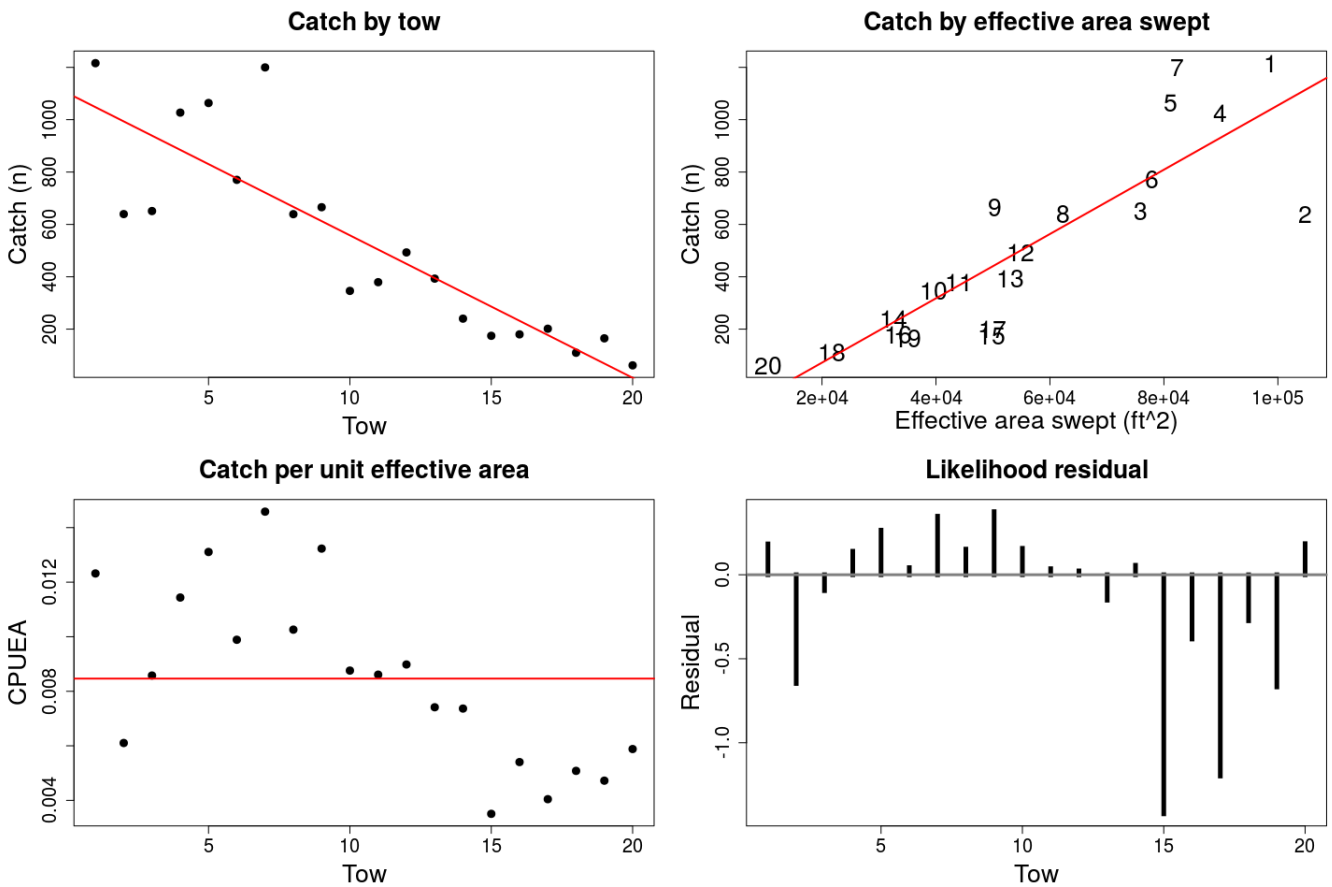

Figure 186: Diagnostic plots for ocean quahog depletion experiment OQ05-03. Catch by tow shows the catch recorded in each tow. This plot should show a declining trend over time. Catch vs. effective area swept shows the catch by the area swept by each tow, while accounting for the area in each tow that has already been fished. The numbers indicate the order of tows. This plot should show an increasing trend. CPUEA vs. tow shows the catch per unit of effective area by tow. This plot should not show a trend. Likelihood residual shows the fit of the model to each tow and should not indicate any patterns if the model has worked well.

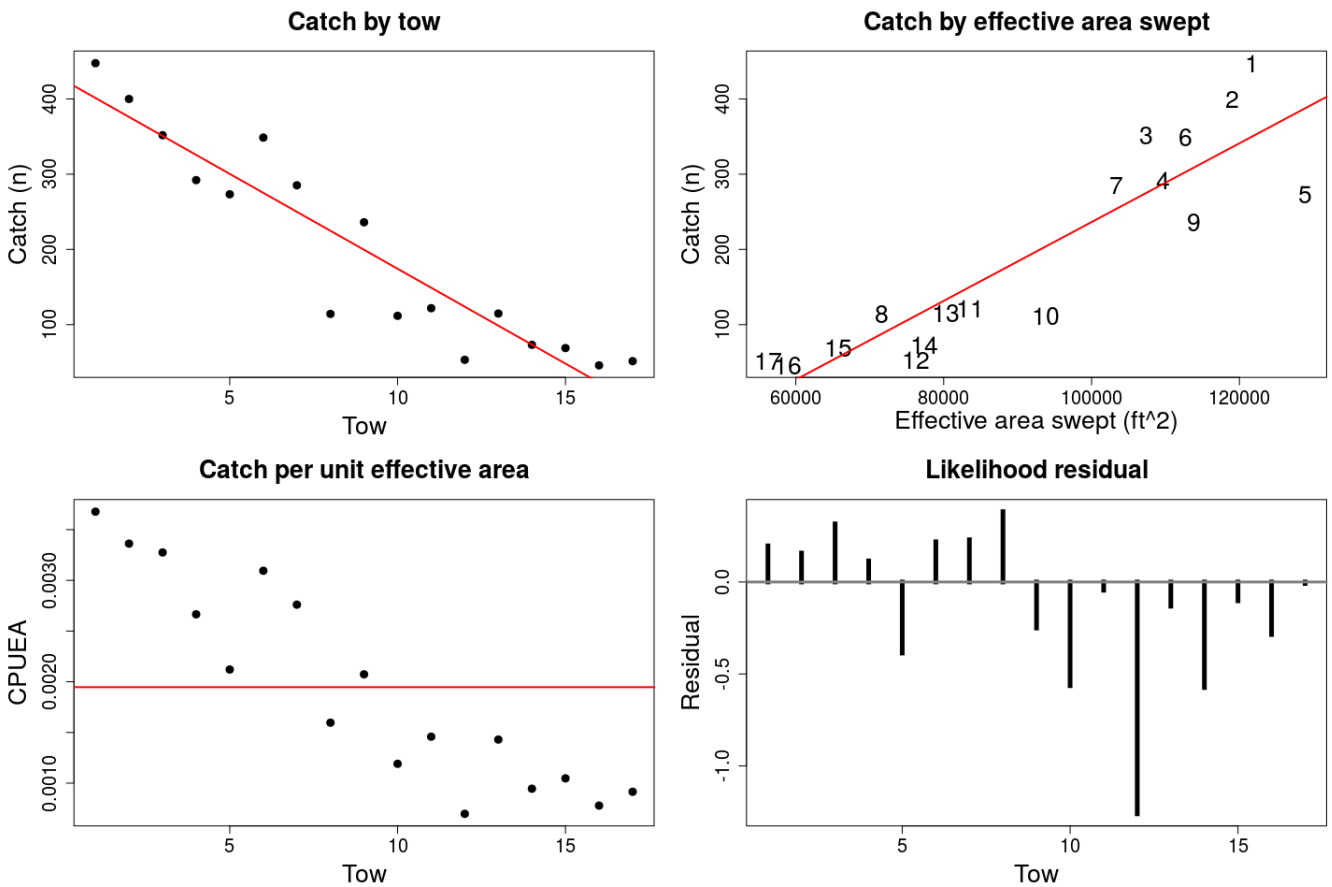

Figure 187: Diagnostic plots for ocean quahog depletion experiment OQ05-04. Catch by tow shows the catch recorded in each tow. This plot should show a declining trend over time. Catch vs. effective area swept shows the catch by the area swept by each tow, while accounting for the area in each tow that has already been fished. The numbers indicate the order of tows. This plot should show an increasing trend. CPUEA vs. tow shows the catch per unit of effective area by tow. This plot should not show a trend. Likelihood residual shows the fit of the model to each tow and should not indicate any patterns if the model has worked well.

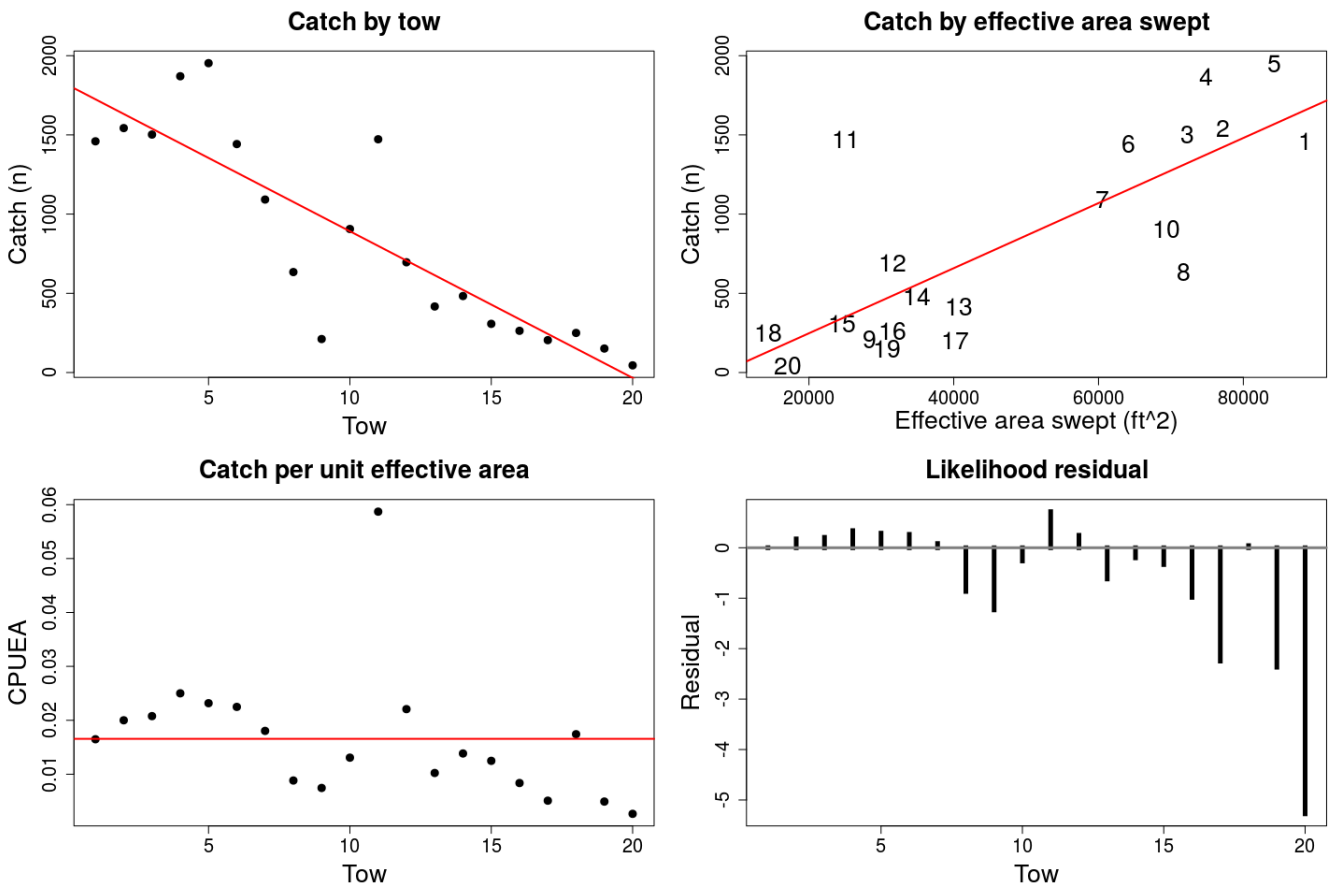

Figure 188: Diagnostic plots for ocean quahog depletion experiment OQ05-06. Catch by tow shows the catch recorded in each tow. This plot should show a declining trend over time. Catch vs. effective area swept shows the catch by the area swept by each tow, while accounting for the area in each tow that has already been fished. The numbers indicate the order of tows. This plot should show an increasing trend. CPUEA vs. tow shows the catch per unit of effective area by tow. This plot should not show a trend. Likelihood residual shows the fit of the model to each tow and should not indicate any patterns if the model has worked well.

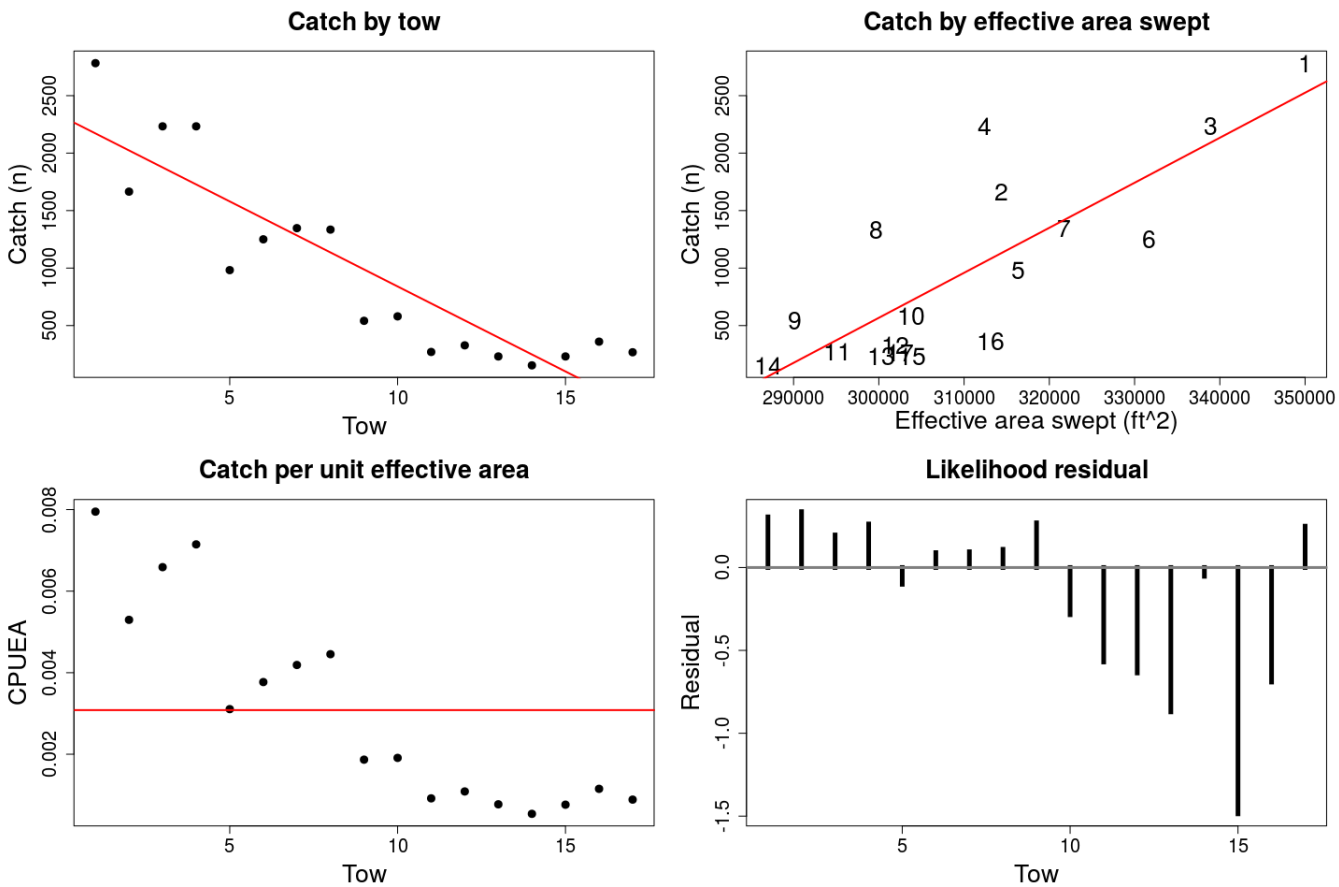

Figure 189: Diagnostic plots for ocean quahog depletion experiment OQ08-01. Catch by tow shows the catch recorded in each tow. This plot should show a declining trend over time. Catch vs. effective area swept shows the catch by the area swept by each tow, while accounting for the area in each tow that has already been fished. The numbers indicate the order of tows. This plot should show an increasing trend. CPUEA vs. tow shows the catch per unit of effective area by tow. This plot should not show a trend. Likelihood residual shows the fit of the model to each tow and should not indicate any patterns if the model has worked well.

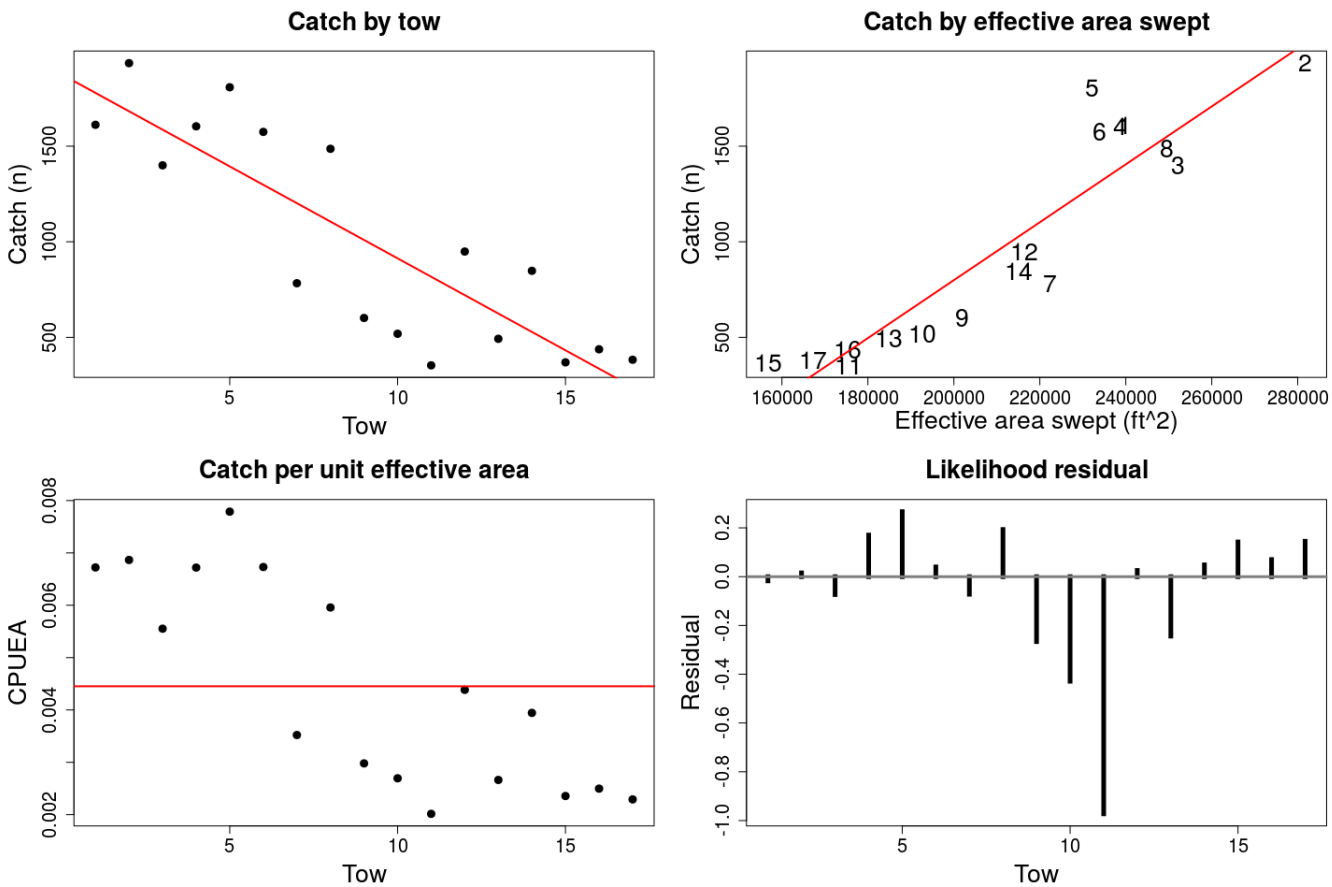

Figure 190: Diagnostic plots for ocean quahog depletion experiment OQ08-02. Catch by tow shows the catch recorded in each tow. This plot should show a declining trend over time. Catch vs. effective area swept shows the catch by the area swept by each tow, while accounting for the area in each tow that has already been fished. The numbers indicate the order of tows. This plot should show an increasing trend. CPUEA vs. tow shows the catch per unit of effective area by tow. This plot should not show a trend. Likelihood residual shows the fit of the model to each tow and should not indicate any patterns if the model has worked well.

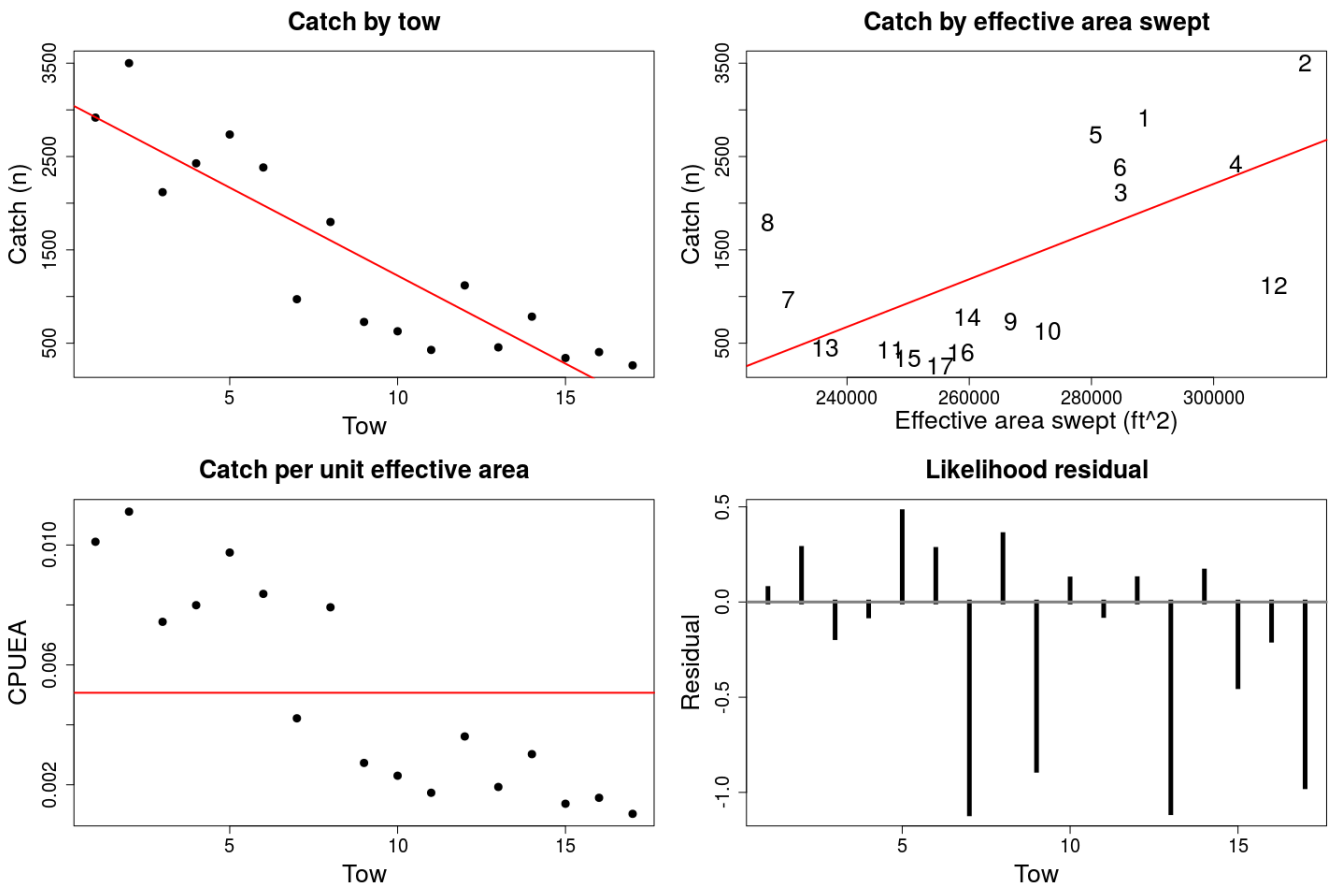

Figure 191: Diagnostic plots for ocean quahog depletion experiment OQ08-03. Catch by tow shows the catch recorded in each tow. This plot should show a declining trend over time. Catch vs. effective area swept shows the catch by the area swept by each tow, while accounting for the area in each tow that has already been fished. The numbers indicate the order of tows. This plot should show an increasing trend. CPUEA vs. tow shows the catch per unit of effective area by tow. This plot should not show a trend. Likelihood residual shows the fit of the model to each tow and should not indicate any patterns if the model has worked well.

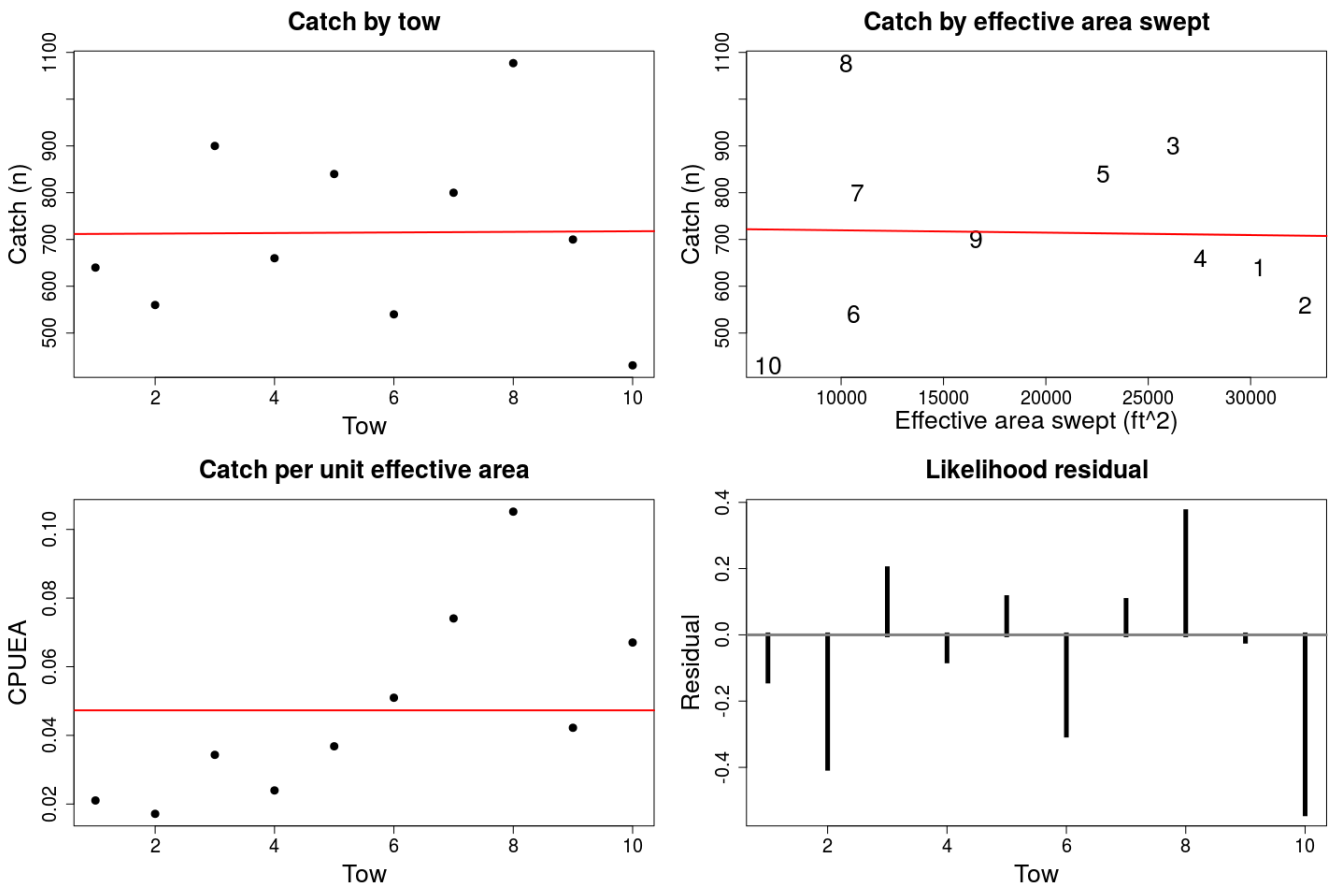

Figure 192: Diagnostic plots for ocean quahog depletion experiment OQ11-01. Catch by tow shows the catch recorded in each tow. This plot should show a declining trend over time. Catch vs. effective area swept shows the catch by the area swept by each tow, while accounting for the area in each tow that has already been fished. The numbers indicate the order of tows. This plot should show an increasing trend. CPUEA vs. tow shows the catch per unit of effective area by tow. This plot should not show a trend. Likelihood residual shows the fit of the model to each tow and should not indicate any patterns if the model has worked well.

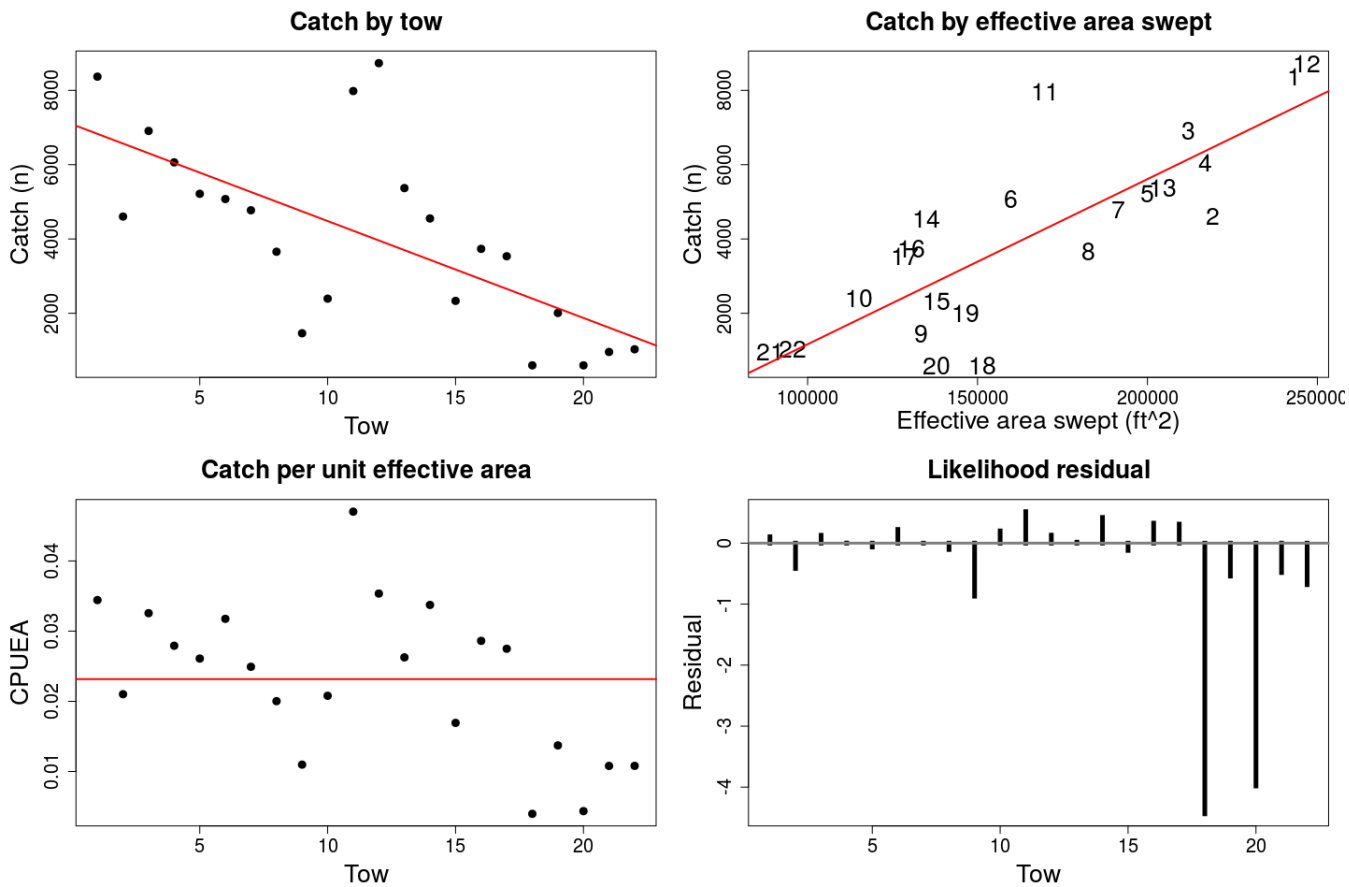

Figure 193: Diagnostic plots for ocean quahog depletion experiment OQ11-05. Catch by tow shows the catch recorded in each tow. This plot should show a declining trend over time. Catch vs. effective area swept shows the catch by the area swept by each tow, while accounting for the area in each tow that has already been fished. The numbers indicate the order of tows. This plot should show an increasing trend. CPUEA vs. tow shows the catch per unit of effective area by tow. This plot should not show a trend. Likelihood residual shows the fit of the model to each tow and should not indicate any patterns if the model has worked well.

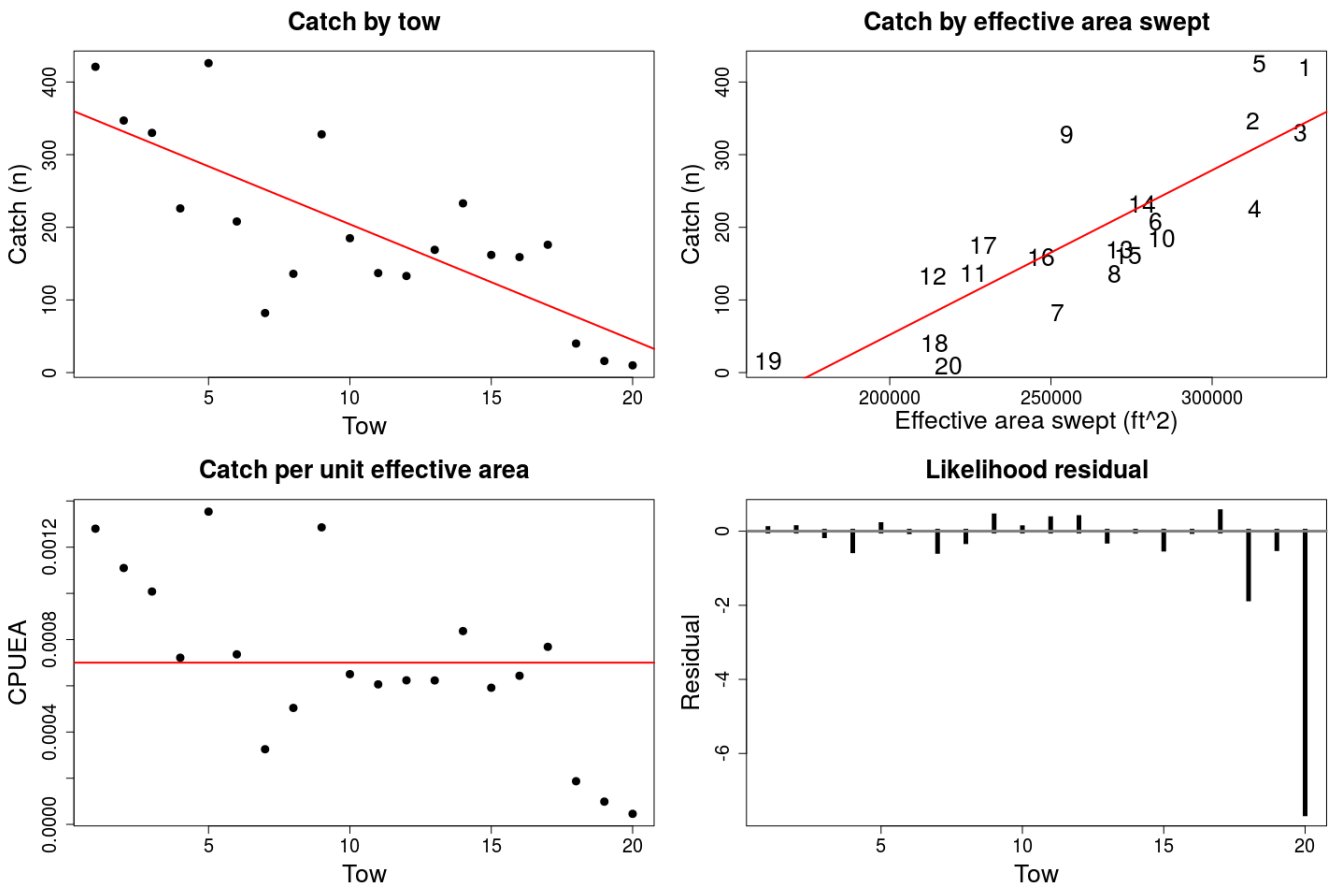

Figure 194: Diagnostic plots for ocean quahog depletion experiment OQSC11-02. Catch by tow shows the catch recorded in each tow. This plot should show a declining trend over time. Catch vs. effective area swept shows the catch by the area swept by each tow, while accounting for the area in each tow that has already been fished. The numbers indicate the order of tows. This plot should show an increasing trend. CPUEA vs. tow shows the catch per unit of effective area by tow. This plot should not show a trend. Likelihood residual shows the fit of the model to each tow and should not indicate any patterns if the model has worked well.

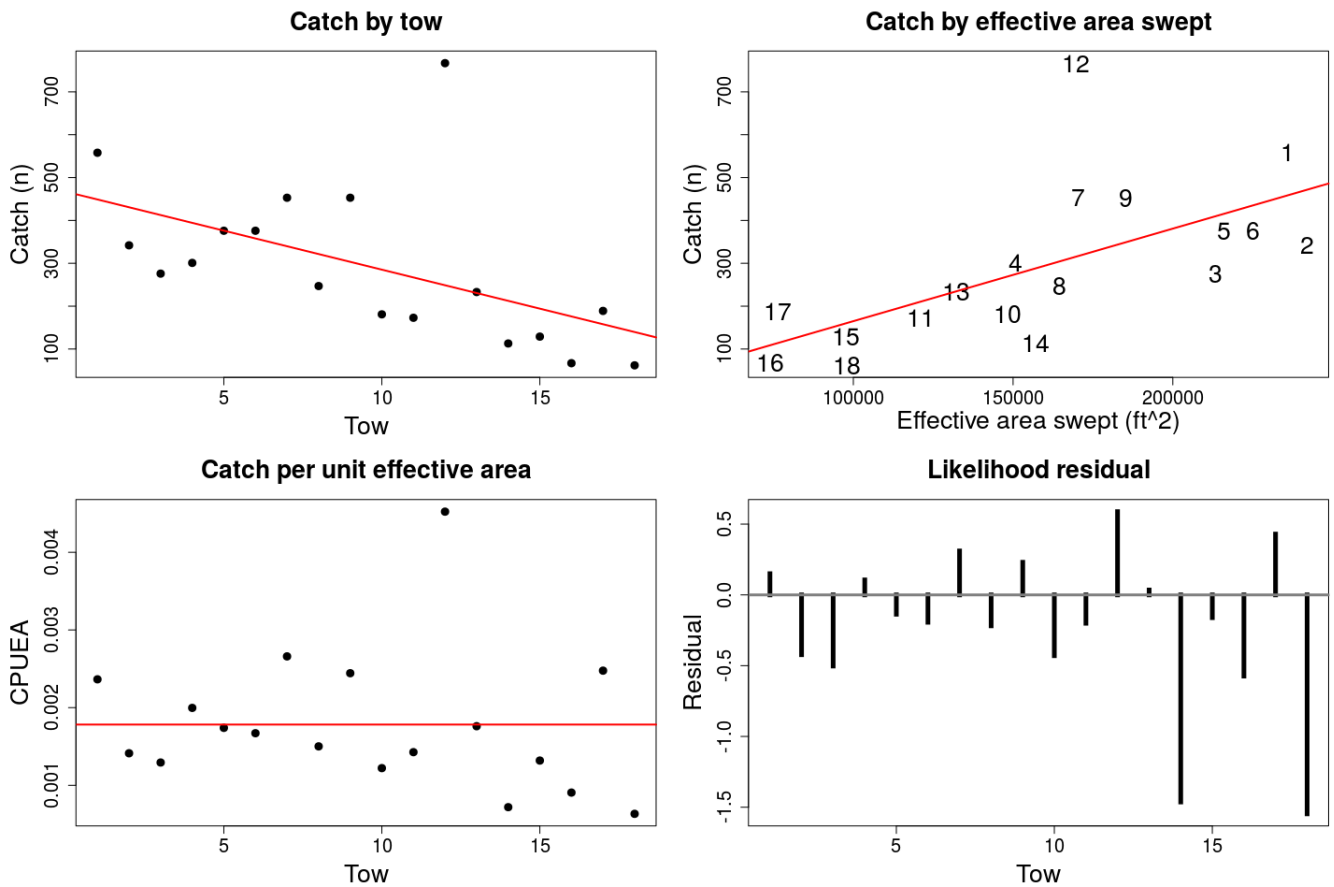

Figure 195: Diagnostic plots for ocean quahog depletion experiment OQSC11-02S. Catch by tow shows the catch recorded in each tow. This plot should show a declining trend over time. Catch vs. effective area swept shows the catch by the area swept by each tow, while accounting for the area in each tow that has already been fished. The numbers indicate the order of tows. This plot should show an increasing trend. CPUEA vs. tow shows the catch per unit of effective area by tow. This plot should not show a trend. Likelihood residual shows the fit of the model to each tow and should not indicate any patterns if the model has worked well.

Appendix 4 Prior distributions for survey catchability

Depletion experiments formed the basis for developing prior distributions for catchability in surveys. The Patch model (Rago et al. 2006; Hennen et al. 2012) estimates capture efficiency for a standard industry dredge similar to the MCD. The estimates of capture efficiencies that were judged to be well estimated (estimated efficiency < 1.0 and cv < 2.0; Figure 196) were combined to form a sample of capture efficiencies from which the prior distribution for survey catchability was generated. To smooth the distributions and weight estimates properly, the sample of capture efficiencies was resampled using a weighted bootstrap procedure, in which the weights were proportional to the inverse of the cv of each estimate (Figure 197). A beta distribution was fit to the resampled efficiency estimates and the mean and cv from this fit were used as the mean and cv for the prior distribution of capture efficiency in the assessment ($e_{MCD} = 0.608$, $cv_{MCD} = 0.262$; Figure 197).

Previous assessments (Northeast Fisheries Science Center 2009) used an estimator for RV survey dredge capture efficiency that was based on the ratio of observed density in the "set up tows" and the density estimate derived from depletion experiments conducted at the same site. Set up tows were conducted aboard the *RV Delaware II* using the survey dredge described above. They were 1-5 parallel tows evenly spaced over 1 km at the sites selected for depletion experiments. The set up tows were oriented perpendicularly to the expected direction of depletion tows in recent years. The estimator was:

$$e = \frac{d}{D} \tag{4}$$

where e is estimated survey efficiency, d is the observed density in set up tows and D is the estimated depletion experiment density. The implicit assumption of this analysis is that d and D reflect densities on the same ground and that the estimates of d and D are unbiased.

The estimates of capture efficiency from eq. 4 were subjected to the same resampling procedure as the estimates of capture efficiency for the MCD. Seventeen of the 19 depletion experiments resulted in useable RV efficiency estimates (Figure 198). The weighted frequency distribution of RV efficiencies was lower than that of MCD efficiency estimates (Figure 199) and the beta fit to that sample produced a lower mean and cv ($e_{RV} = 0.194\, cv_{RV} = 0.546$; Figure 199).

Figures

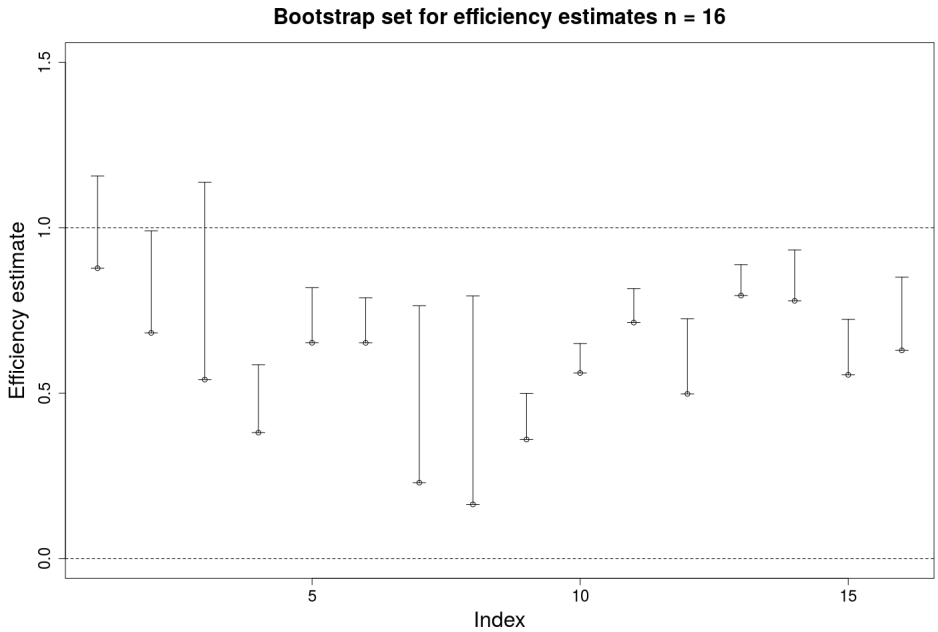

Figure 196: Efficiency estimates for each of the MCD depletion experiments for ocean quahog that resulted in estimated capture efficiencies < 1.0 and cv < 2.0. The cv associated with each estimate is shown as a vertical error bar, where the distance from the point estimate is the cv.

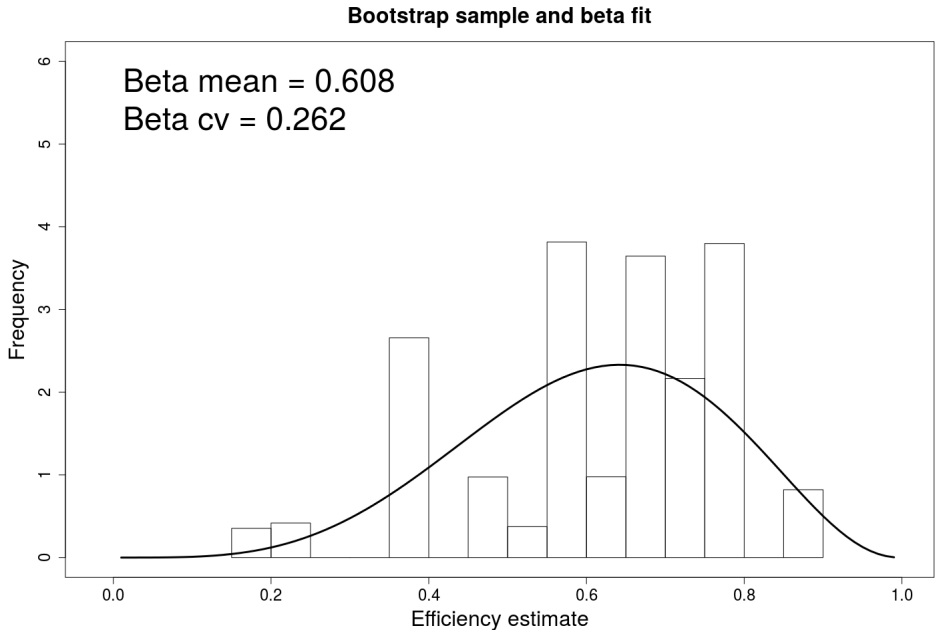

Figure 197: A beta distribution fit to the bootstrap sample of efficiency estimates for the MCD. The bootstrap sample was composed of those patch model estimates for ocean quahog that resulted in capture efficiencies < 1.0 and cv < 2.0. The weights for the bootstrap procedure were proportional to the inverse of the cv of each efficiency estimate.

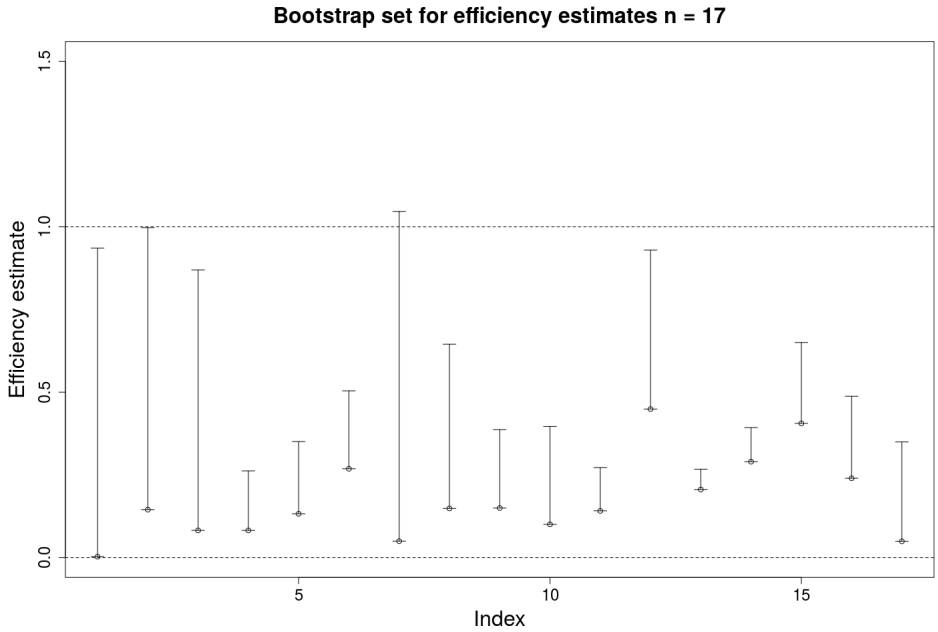

Figure 198: Efficiency estimates for each of the RD depletion experiments for ocean quahog that resulted in estimated capture efficiencies < 1.0 and cv < 2.0. The cv associated with each estimate is shown as a vertical error bar, where the distance from the point estimate is the cv.

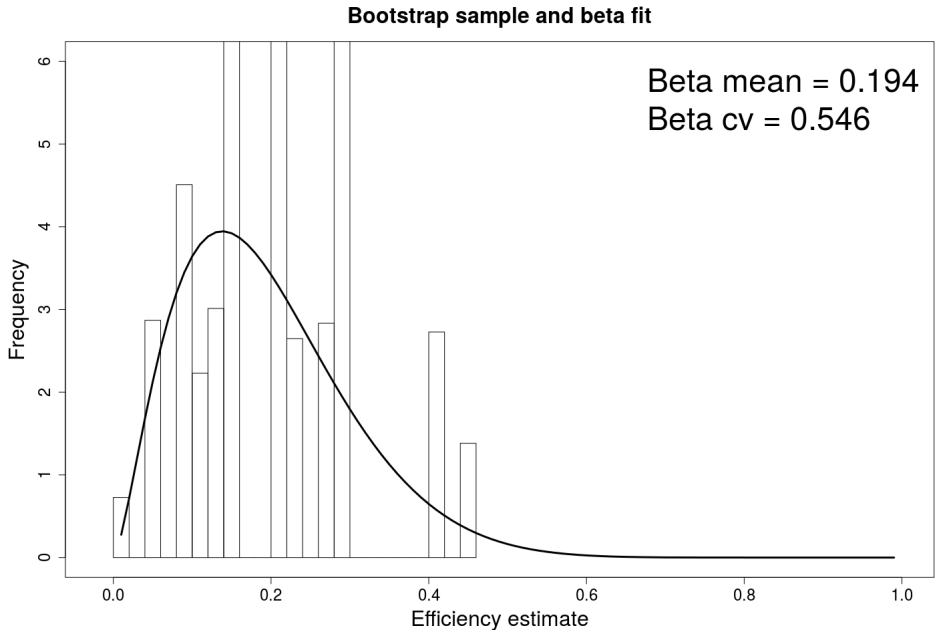

Figure 199: A beta distribution fit to the bootstrap sample of efficiency estimates for the RV. The bootstrap sample was composed of patch model estimates for ocean quahog that resulted in capture efficiencies < 1.0 and cv < 2.0. The weights for the bootstrap procedure were proportional to the inverse of the cv of each efficiency estimate.

Appendix 5 Depth and temperature changes

The distribution and biology of ocean quahog are potentially changing with potential effects on fishery productivity as ocean temperature changes. For example, increasing water temperature may result in changes to Atlantic surfclam growth (Munroe et al. 2016). Increasing water temperature may also be driving a shift in Atlantic surfclam distribution, to deeper water in the southern area (Weinberg et al. 2002). It is reasonable to assume that any responses to temperature would be strongest in the southern-most regions (SVA, DMV and NJ), and shallow habitat depth boundary, where ocean temperatures are warmest and probably nearest the warm water tolerance for ocean quahog.

Depth and temperature

Survey stations are distributed randomly relative to depth within a stratum and the same strata tend to be sampled over time within a region (Table 10). Therefore, if the depth distribution of ocean quahog were trending over time, the depth at which most of the animals were caught within a region might be expected to increase. Plots of the depth at which the median cumulative catch within each region occurs over time show this relationship in NJ (Figures 200 – 205). SVA does not have enough positive tows to draw conclusions. It should be noted that fishery behavior might contribute to these trends as well, as the shallower areas are preferred due to proximity to processors, if fishing is in relatively shallow water.

Temperature was recorded as part of the survey station data (beginning in 2002), and may be a useful indicator of habitat preference for ocean quahog. Plots of the temperature and depth recorded at each survey station over time, against the total number of ocean quahog caught are provided here (Figures 206 – 211). The results indicate that temperature and depth preferences vary by region, but appear to be relatively consistent over (recent) time. This may be indicative of local adaptation, or there may be other local factors, potentially correlated with temperature and depth, that influence habitat preference in each region.

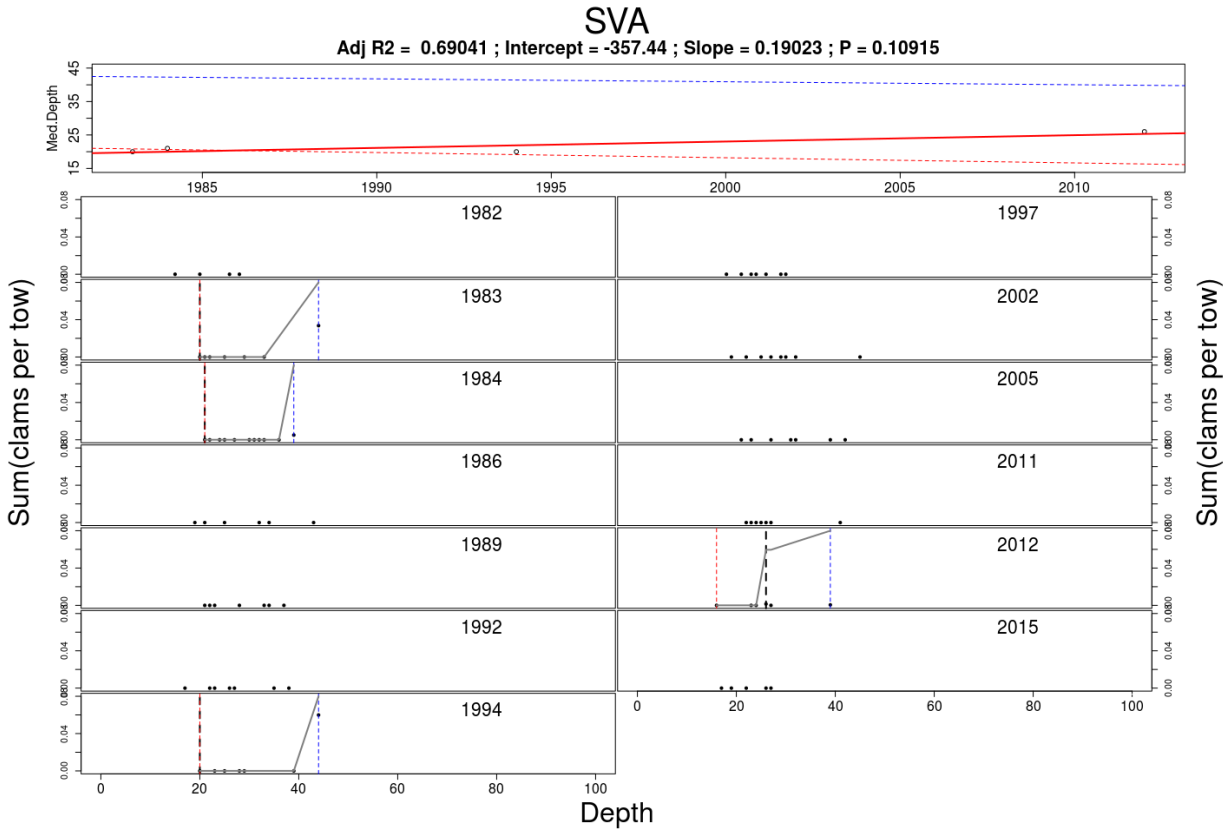

Figure 200: Total ocean quahog caught at depth by year in SVA. The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The top panel is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years. Inshore (shallow) strata were not well sampled in recent years and were excluded from this analysis.

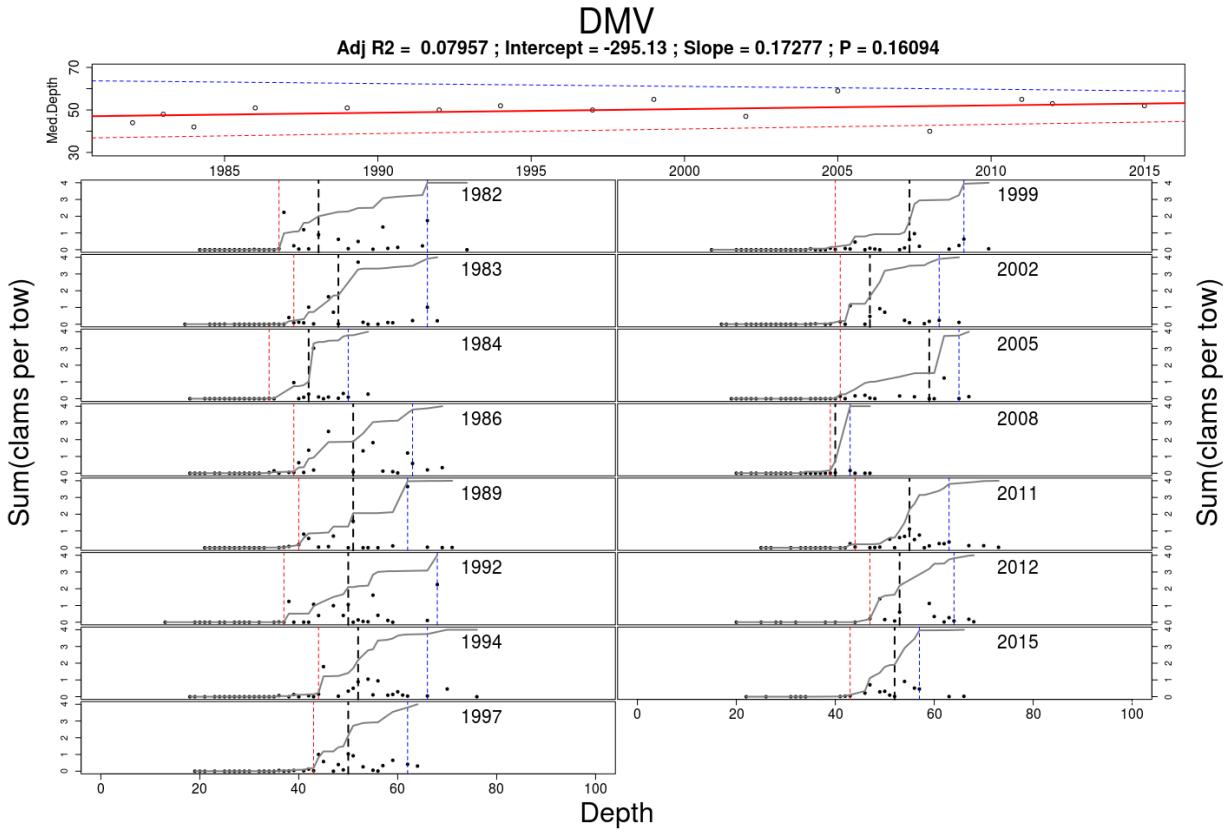

Figure 201: Total ocean quahog caught at depth by year in DMV. The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The top panel is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years. Inshore (shallow) strata were not well sampled in recent years and were excluded from this analysis.

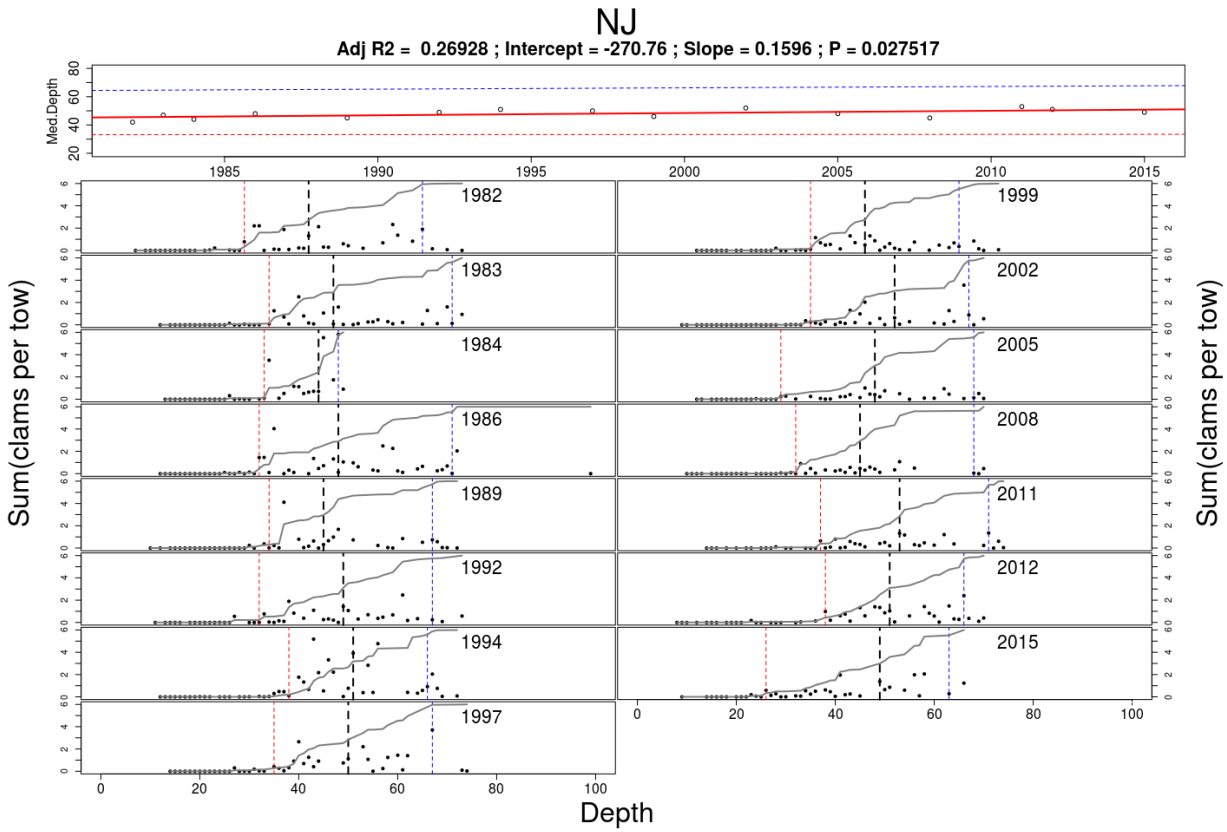

Figure 202: Total ocean quahog caught at depth by year in NJ. The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The top panel is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years.

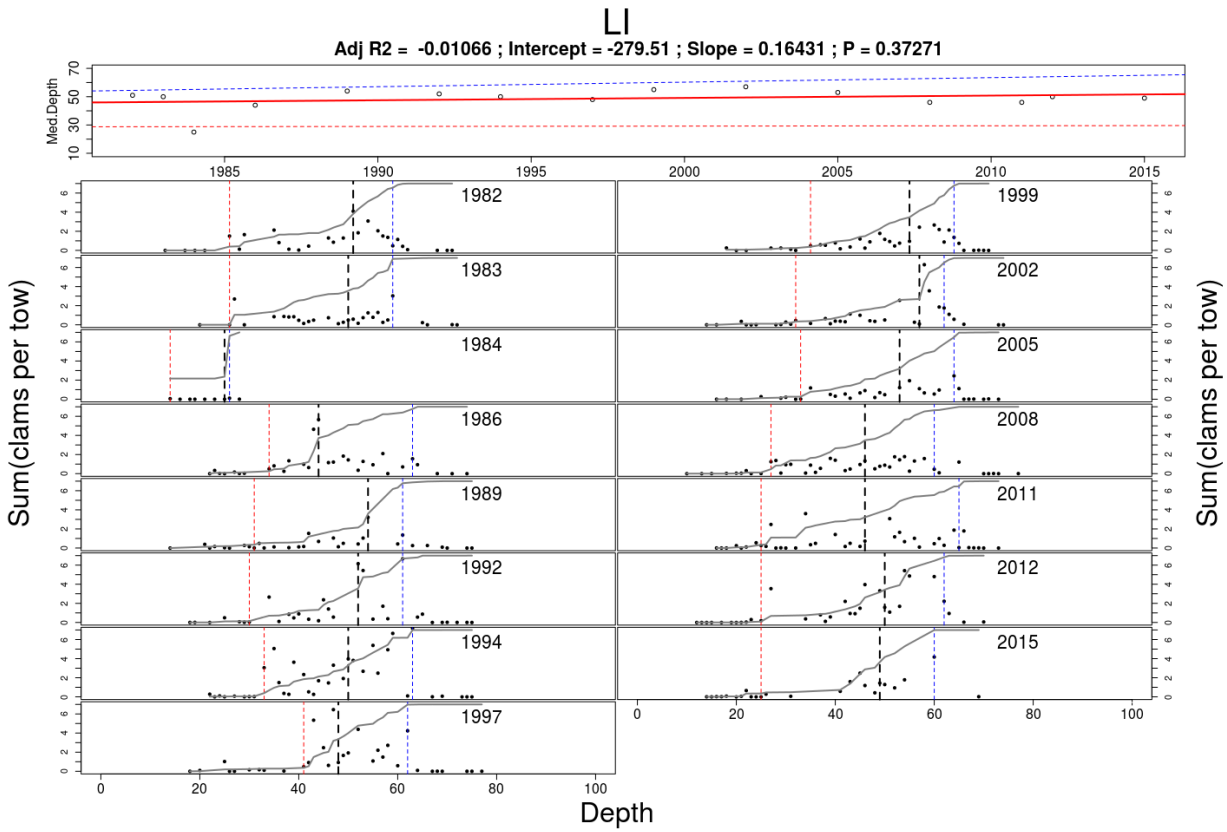

Figure 203: Total ocean quahog caught at depth by year in LI. The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The top panel is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years.

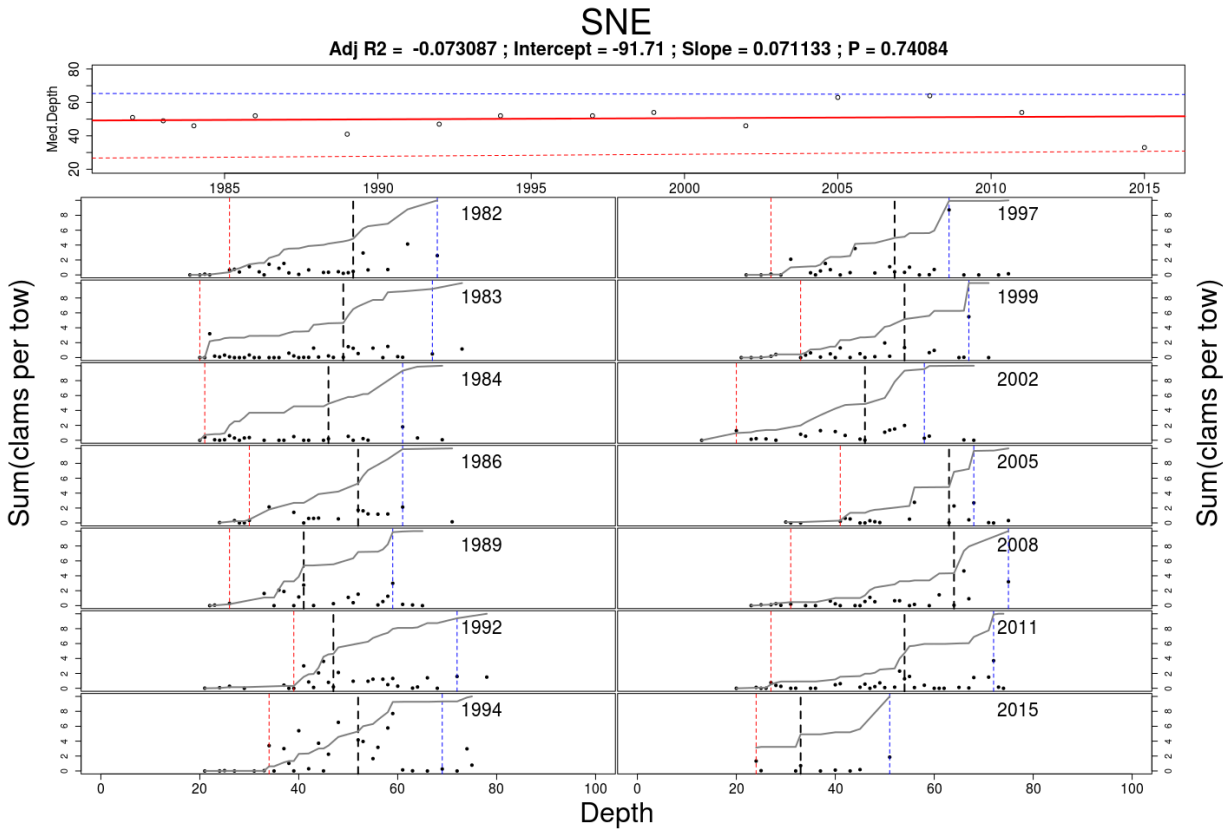

Figure 204: Total ocean quahog caught at depth by year in SNE. The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The top panel is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years.

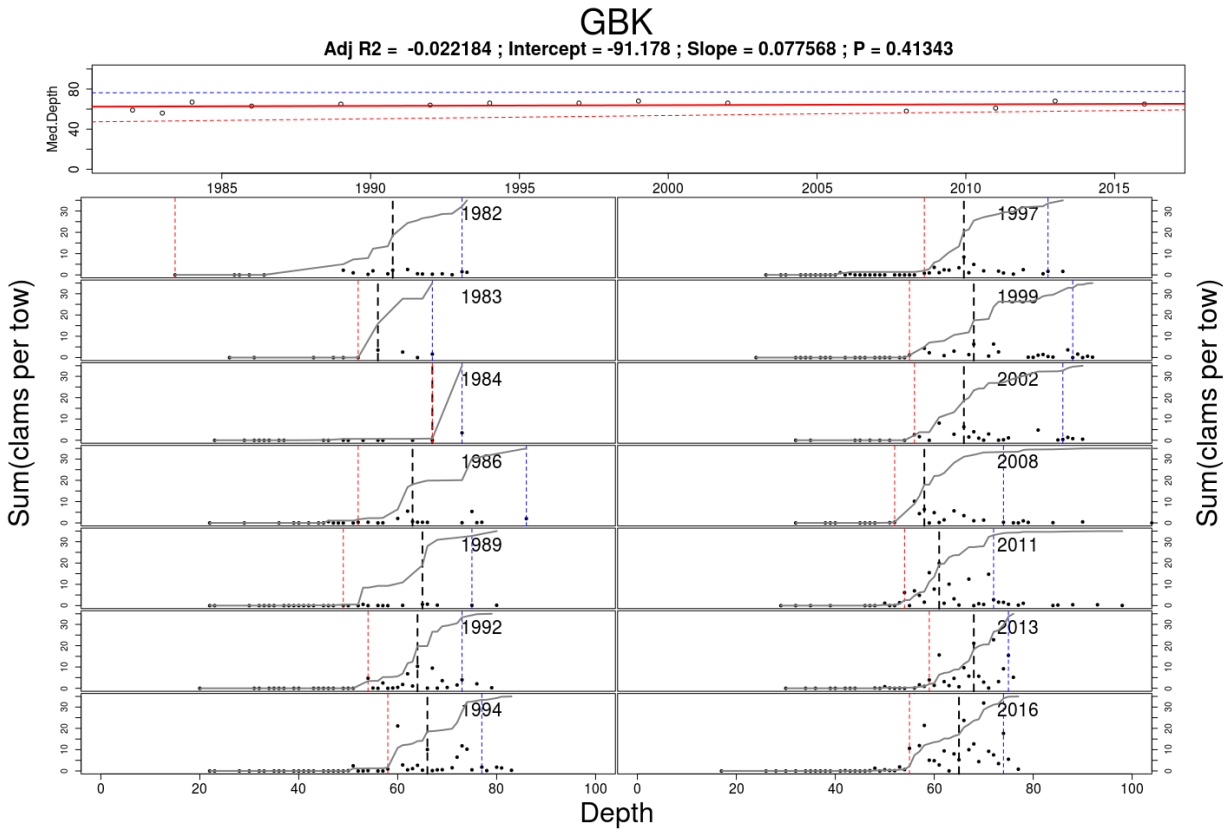

Figure 205: Total ocean quahog caught at depth by year in GBK. The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The top panel is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years.

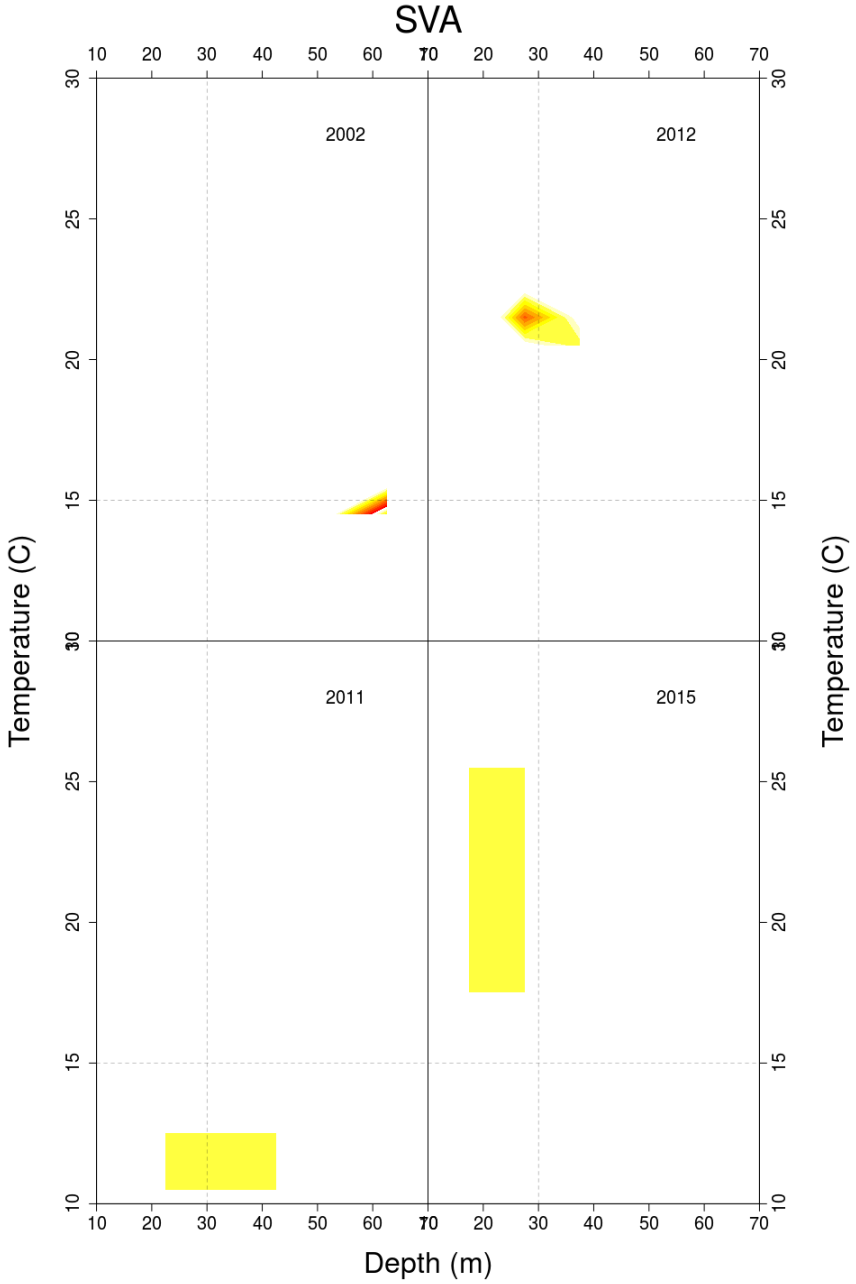

Figure 206: Total ocean quahog caught in the NEFSC clam survey at depth and temperature by year in SVA. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at 15° C and 30 m depth are for reference only.

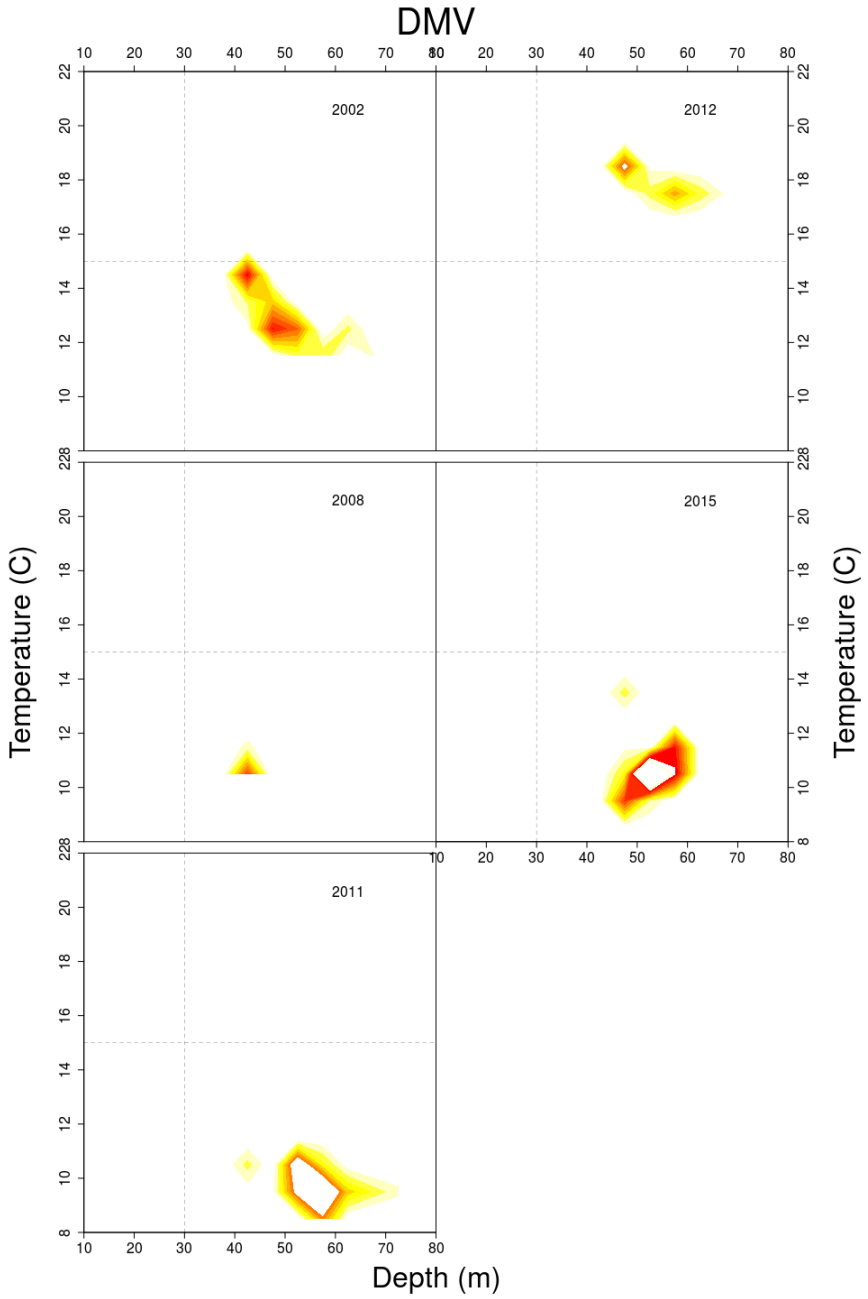

Figure 207: Total ocean quahog caught in the NEFSC clam survey at depth and temperature by year in DMV. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at 15° C and 30 m depth are for reference only.

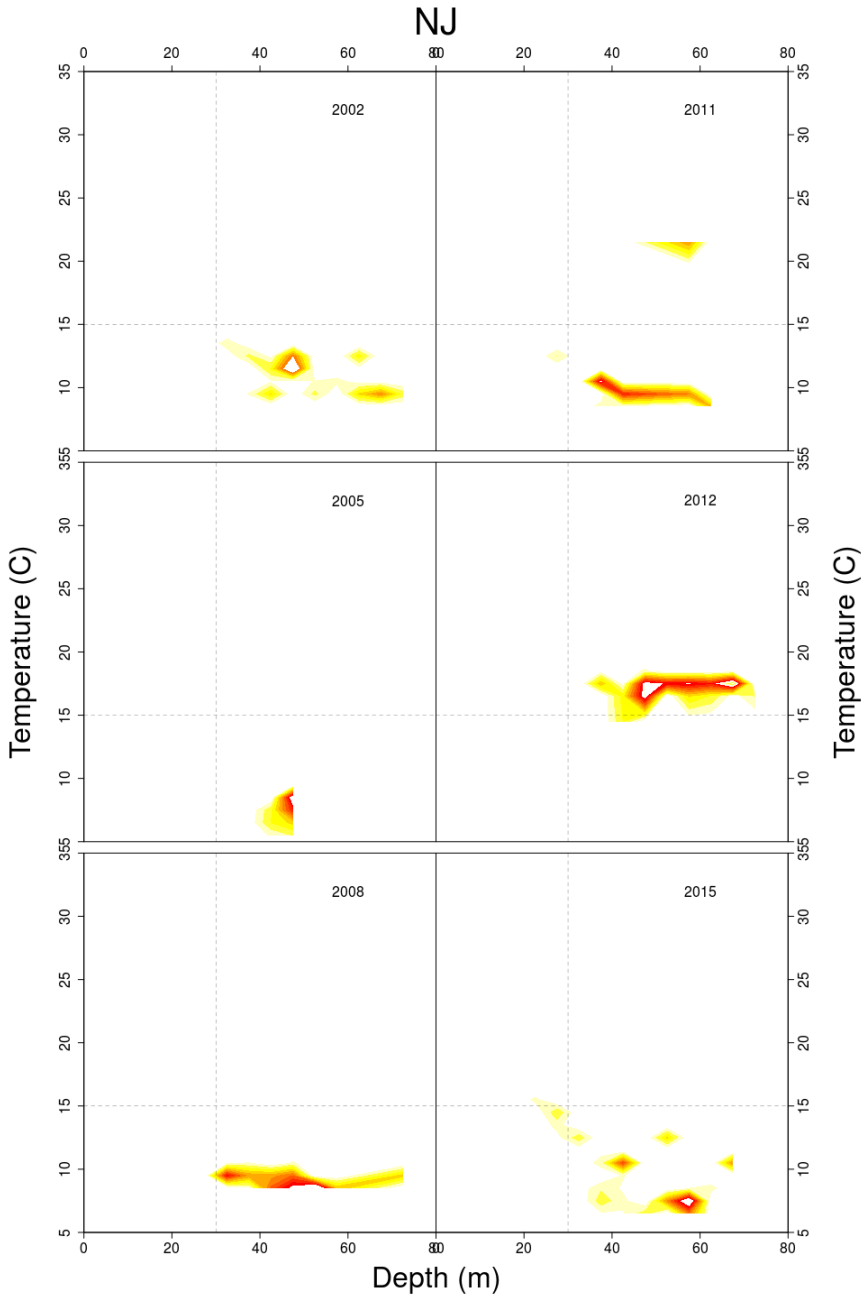

Figure 208: Total ocean quahog caught in the NEFSC clam survey at depth and temperature by year in NJ. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at 15° C and 30 m depth are for reference only.

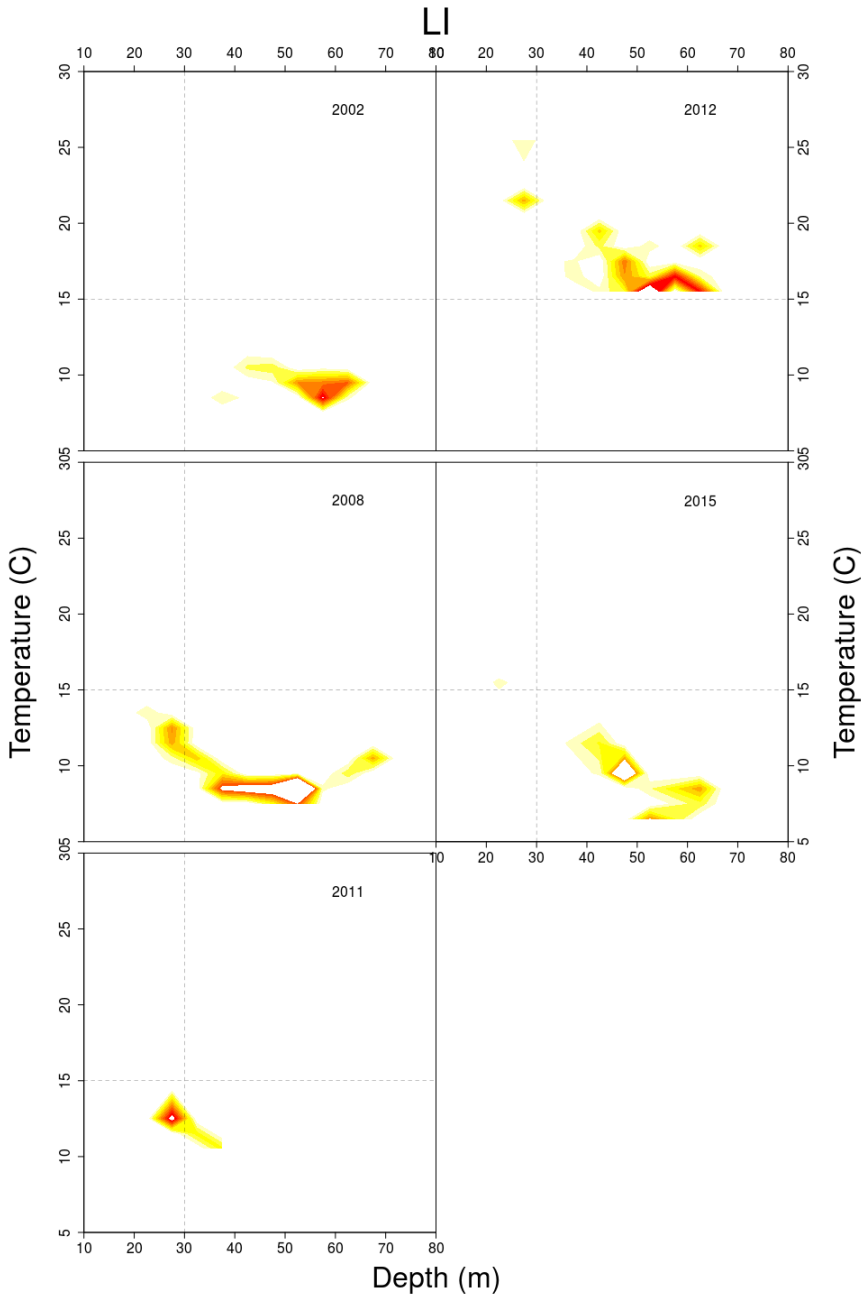

Figure 209: Total ocean quahog caught in the NEFSC clam survey at depth and temperature by year in LI. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at 15° C and 30 m depth are for reference only.

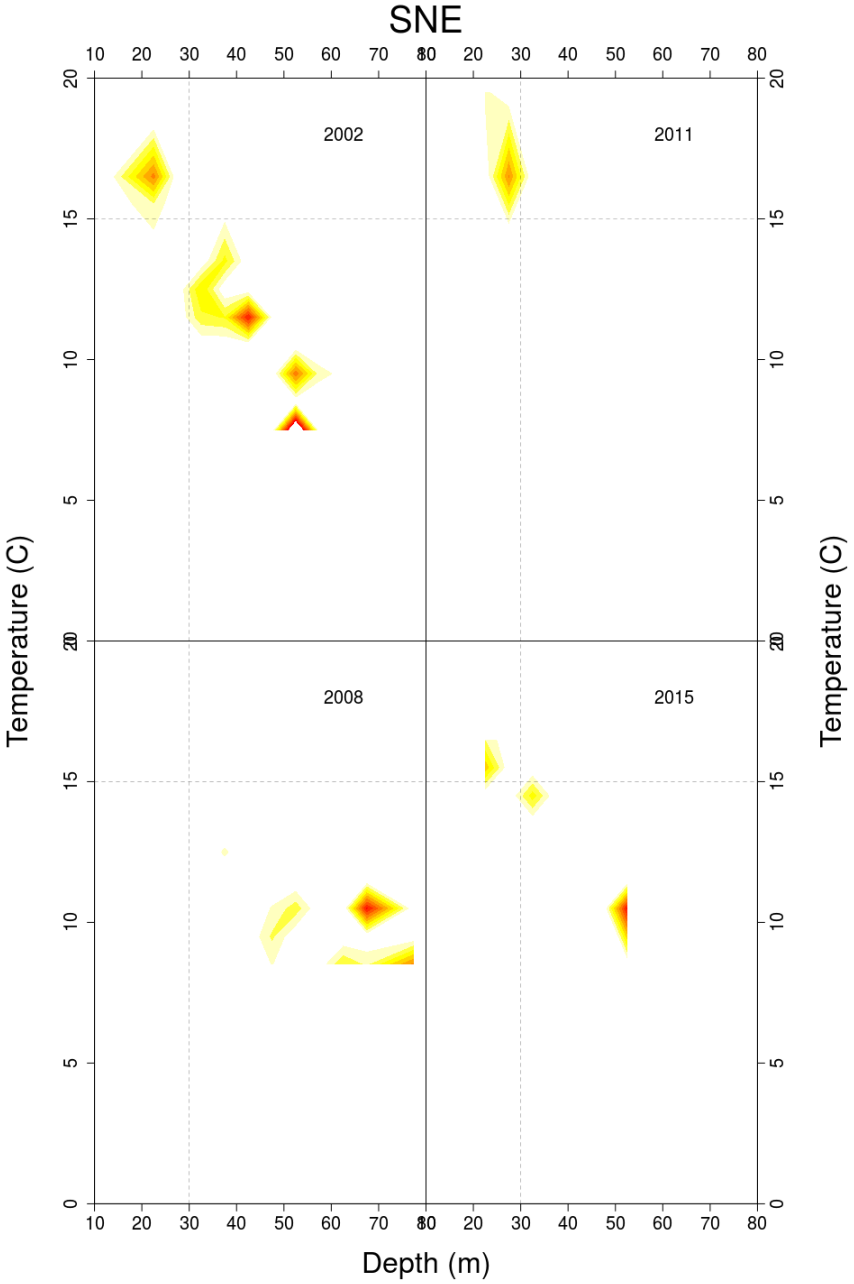

Figure 210: Total ocean quahog caught in the NEFSC clam survey at depth and temperature by year in SNE. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at 15° C and 30 m depth are for reference only.

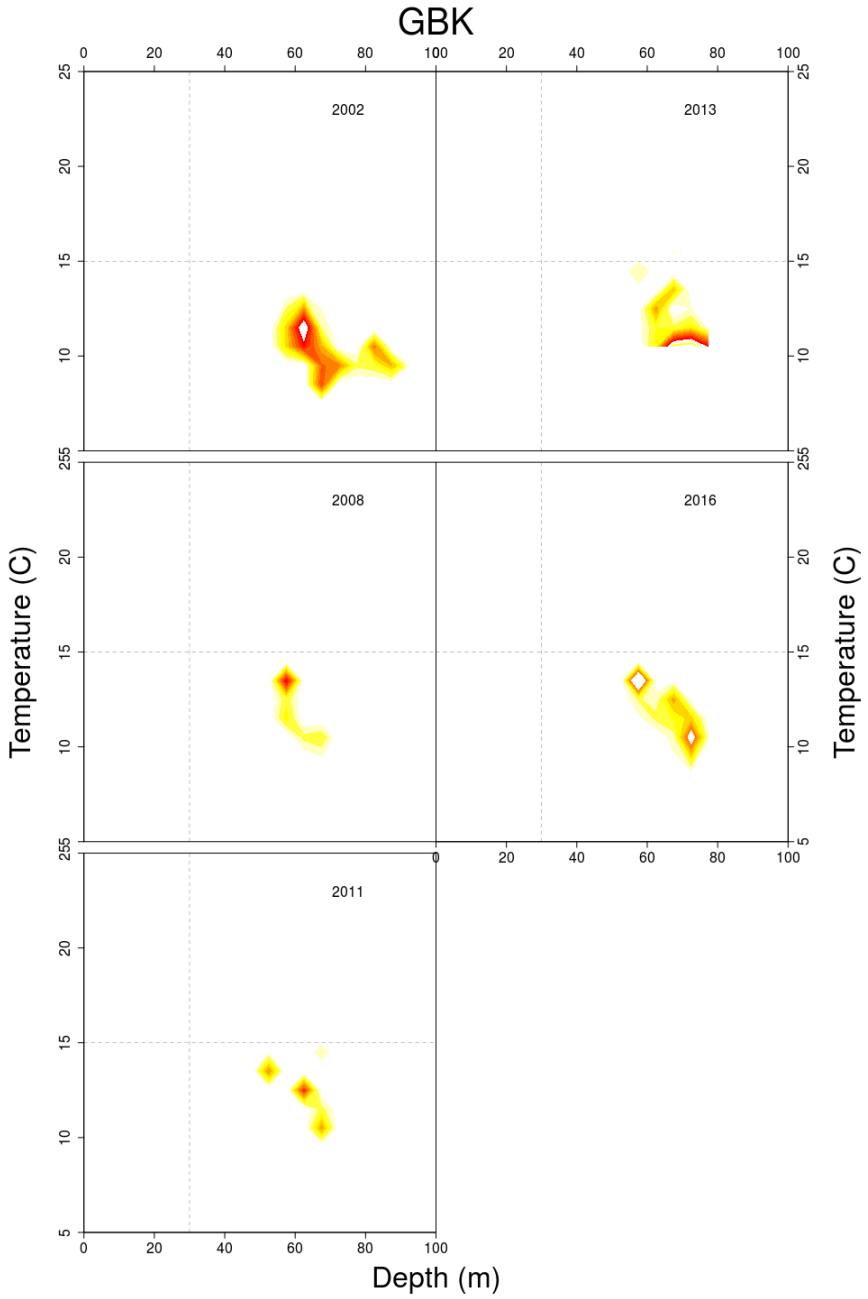

Figure 211: Total ocean quahog caught in the NEFSC clam survey at depth and temperature by year in GBK. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at 15° C and 30 m depth are for reference only.

Appendix 6 Build a bridge

The KLAMZ model configuration used for the 2013 update of the ocean quahog stock assessment (Chute et al. 2013) fit the survey data reasonably well (Figures 212 - 214).

In order to bring the model from 2013 up to date, NEFSC first replaced the lognormal prior distribution with the newly developed beta prior distribution (see Appendix 4). This formulation was somewhat illogical because the efficiency corrected swept area biomass values used as data here called ("`Efficiency_Corrected_Swept_Area_Fishable_Biomass`") were expanded from simple swept area biomass values by the efficiency estimated previously. The model converged and produced a fit with a different trend and scale than previous assessment (Figures 215 - 217), though these results should be discounted based on their internal inconsistencies as described above.

The MCD survey was included in step three, along with its prior distribution as described in Appendix 4. The addition of the new survey induced some changes in both trend and scale relative to the previous step, bringing it more in line with the results from the last assessment (Figures 218 - 220).

Finally, the model was tuned such that the input cv for the RV survey more closely matched the estimated goodness of fit cv. This change induced slight rescaling, but had minimal effect on trend (Figures 221 - 223).

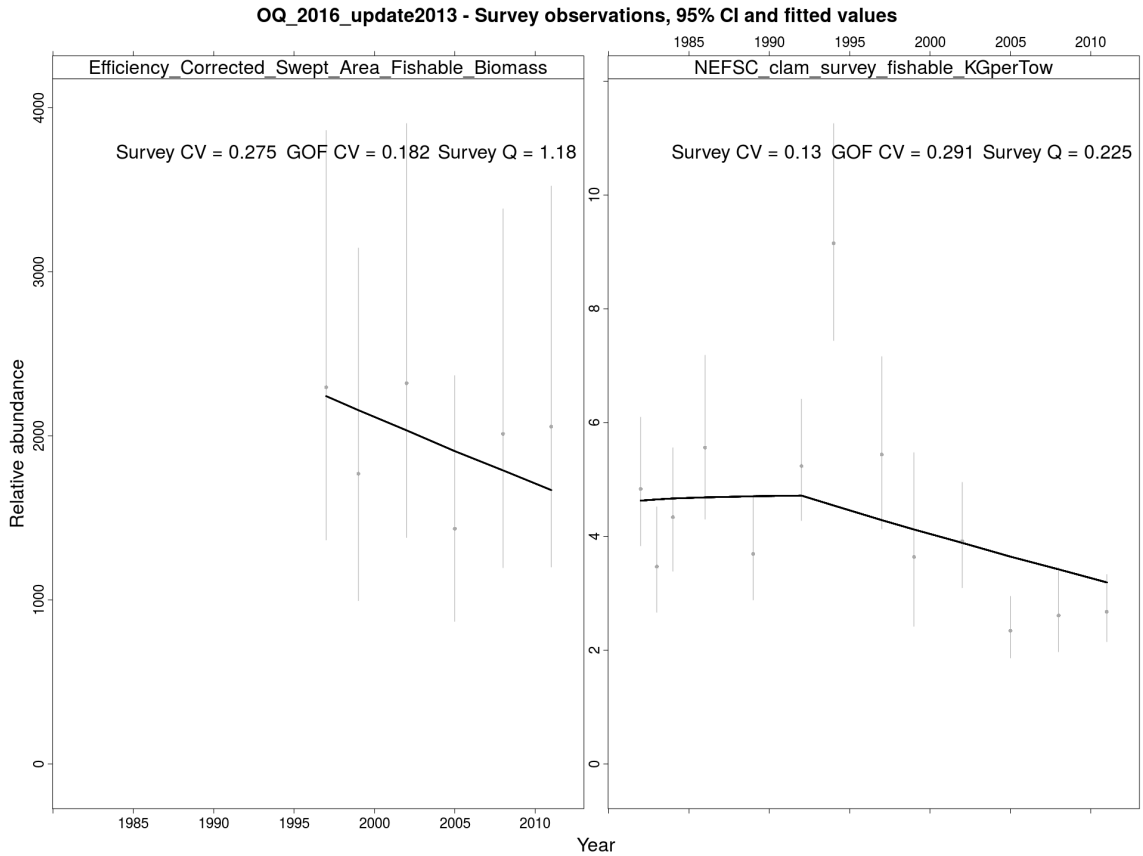

Figure 212: Southern area KLAMZ model fits to the ocean quahog survey data from the previous assessment (data through 2011). The input cv, model fit cv and survey q estimate for each of the surveys are shown in text in each of the panels.

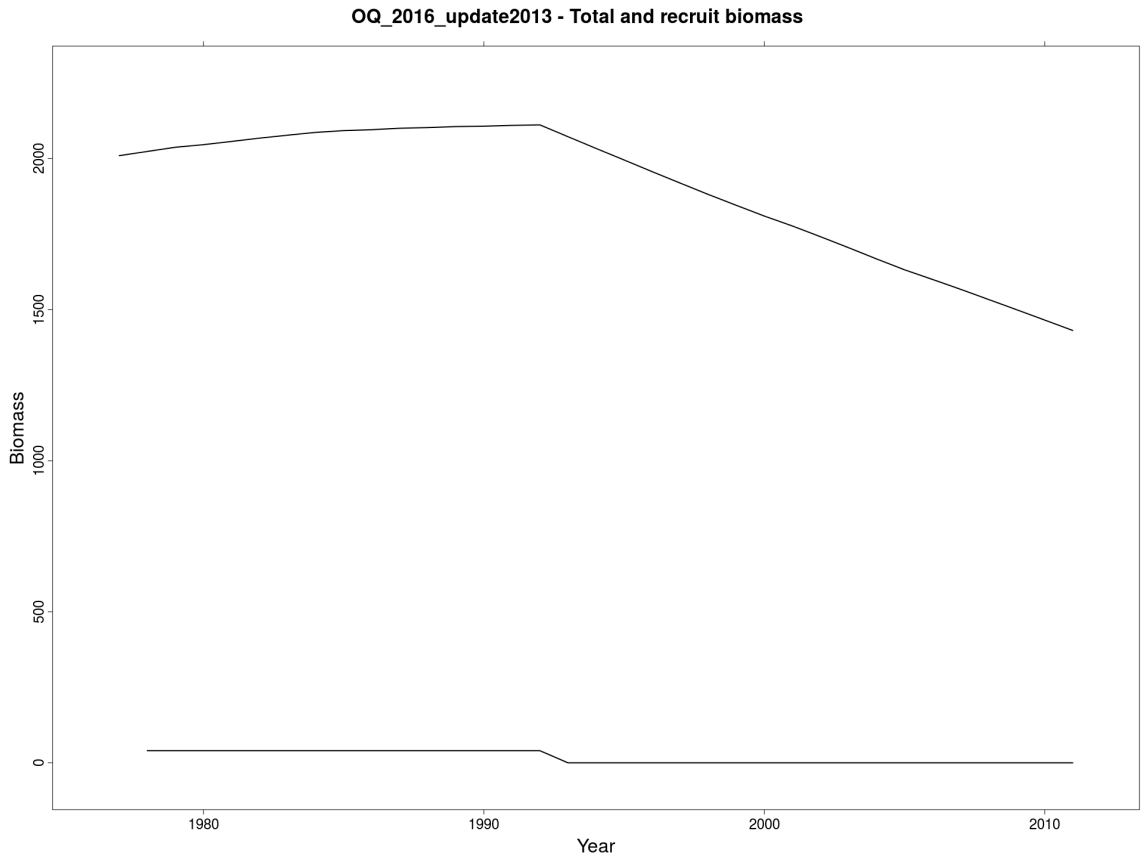

Figure 213: Total biomass and recruits from southern area KLAMZ model fits to the ocean quahog survey data from the previous assessment (data through 2011). Recruitment to the population included a step function in 1993.

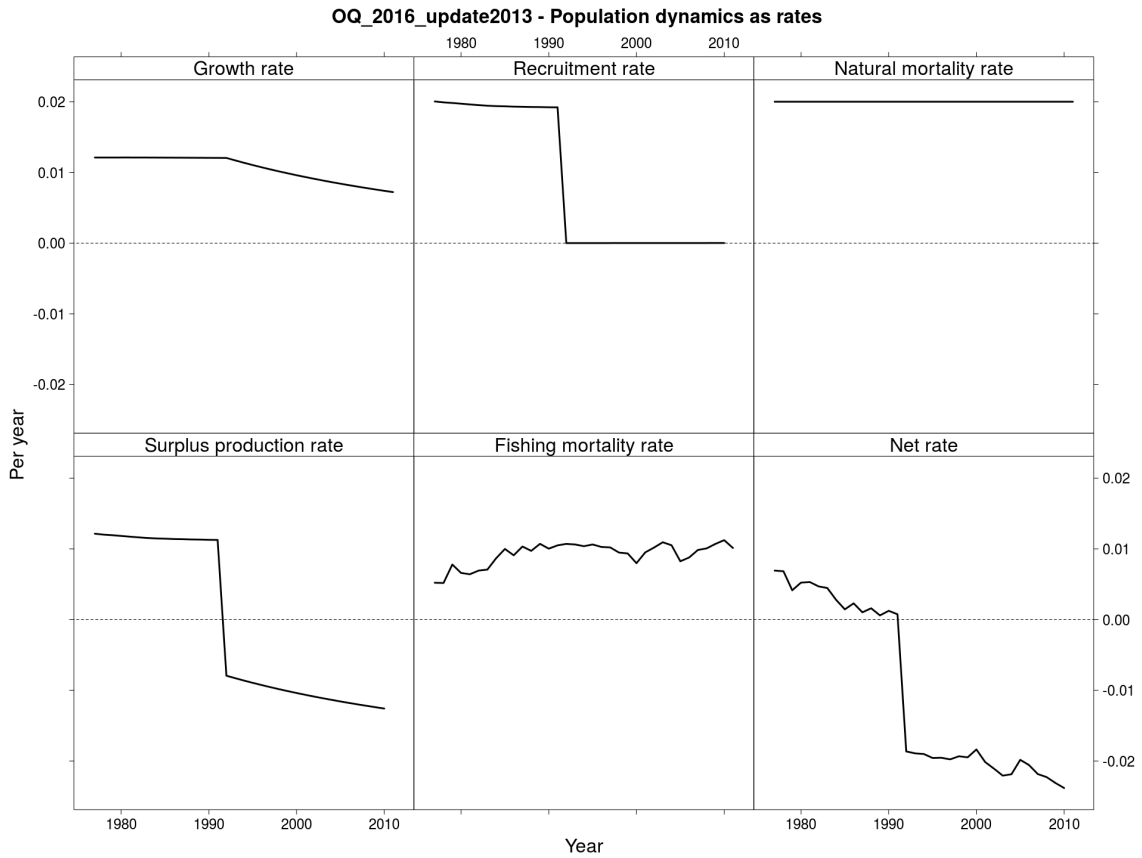

Figure 214: Population dynamics from southern area KLAMZ model fits to the ocean quahog survey data from the previous assessment (data through 2011) presented as rates. Fishing and natural mortality rates were low, and recruitment, growth and surplus production declined over time.

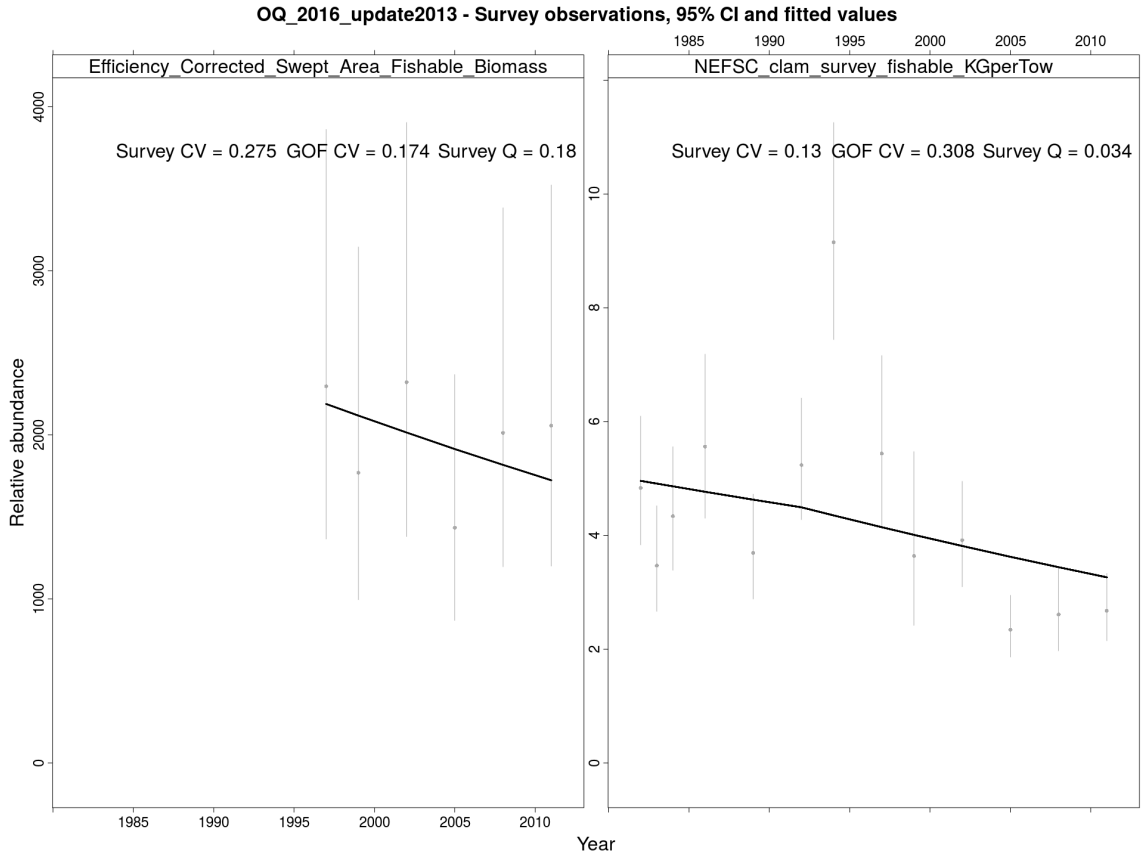

Figure 215: Southern area KLAMZ model fits to the ocean quahog survey data from the previous assessment (data through 2011), but including a beta prior with parameters estimated in the current assessment. The input cv, model fit cv and survey q estimate for each of the three surveys are shown in text in each of the panels.

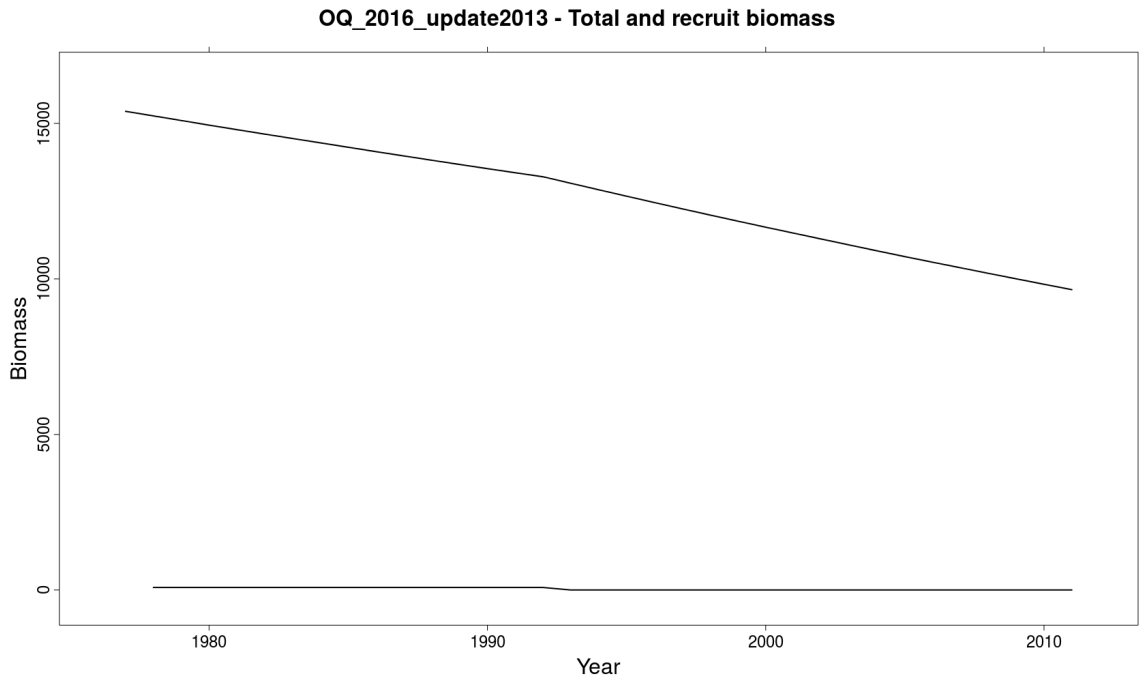

Figure 216: Total biomass and recruits from southern area KLAMZ model fits to the ocean quahog survey data from the previous assessment (data through 2011), but including a beta prior with parameters estimated in the current assessment. Recruitment to the population included a step function in 1993.

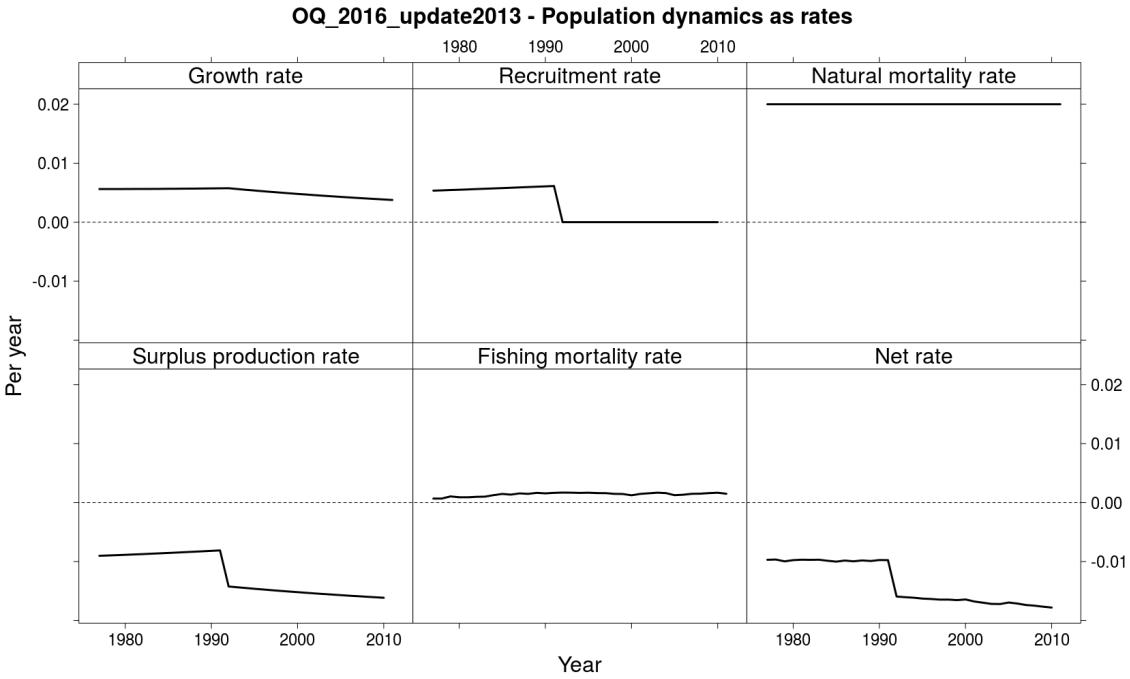

Figure 217: Population dynamics from southern area KLAMZ model fits to the ocean quahog survey data from the previous assessment (data through 2011), but including a beta prior with parameters estimated in the current assessment, presented as rates. Fishing and natural mortality rates were low, and recruitment, growth and surplus production declined over time.

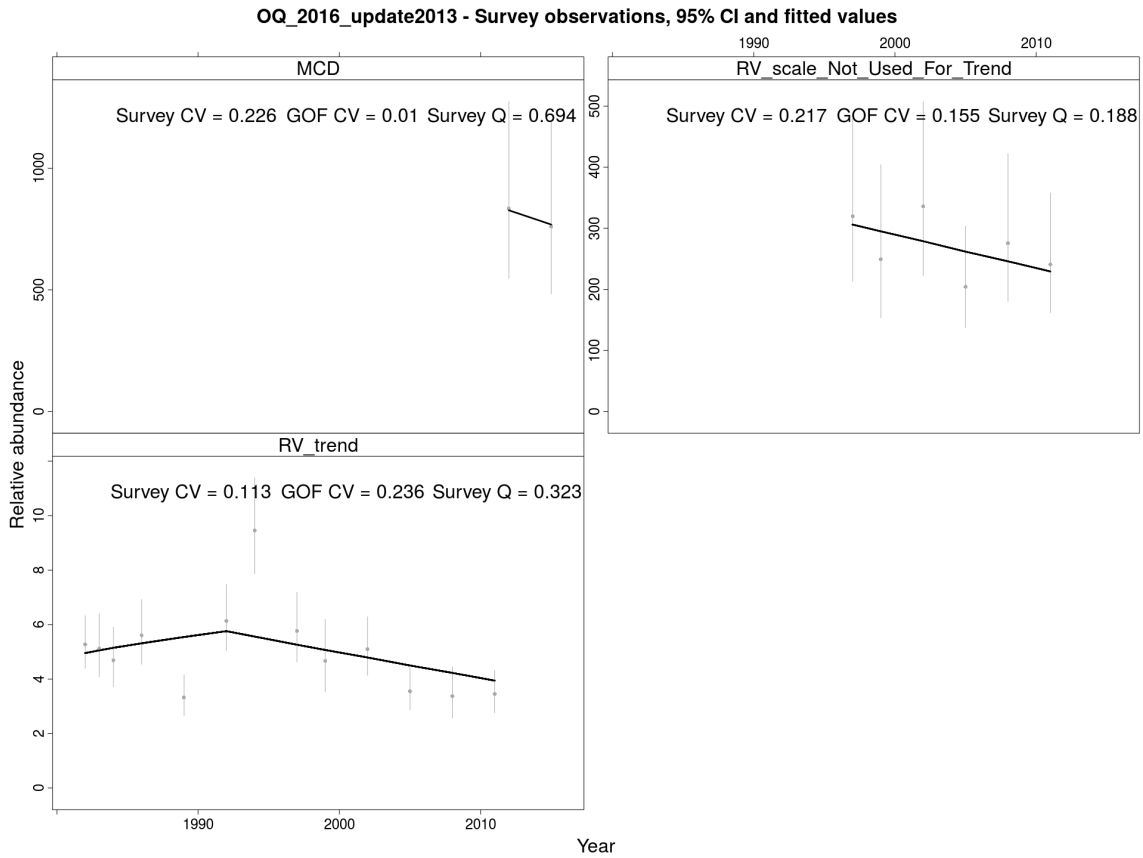

Figure 218: Southern area KLAMZ model fits to the ocean quahog survey data as above, but including new data with a new prior distribution for survey q. The input cv, model fit cv and survey q estimate for each of the surveys are shown in text in each of the panels.

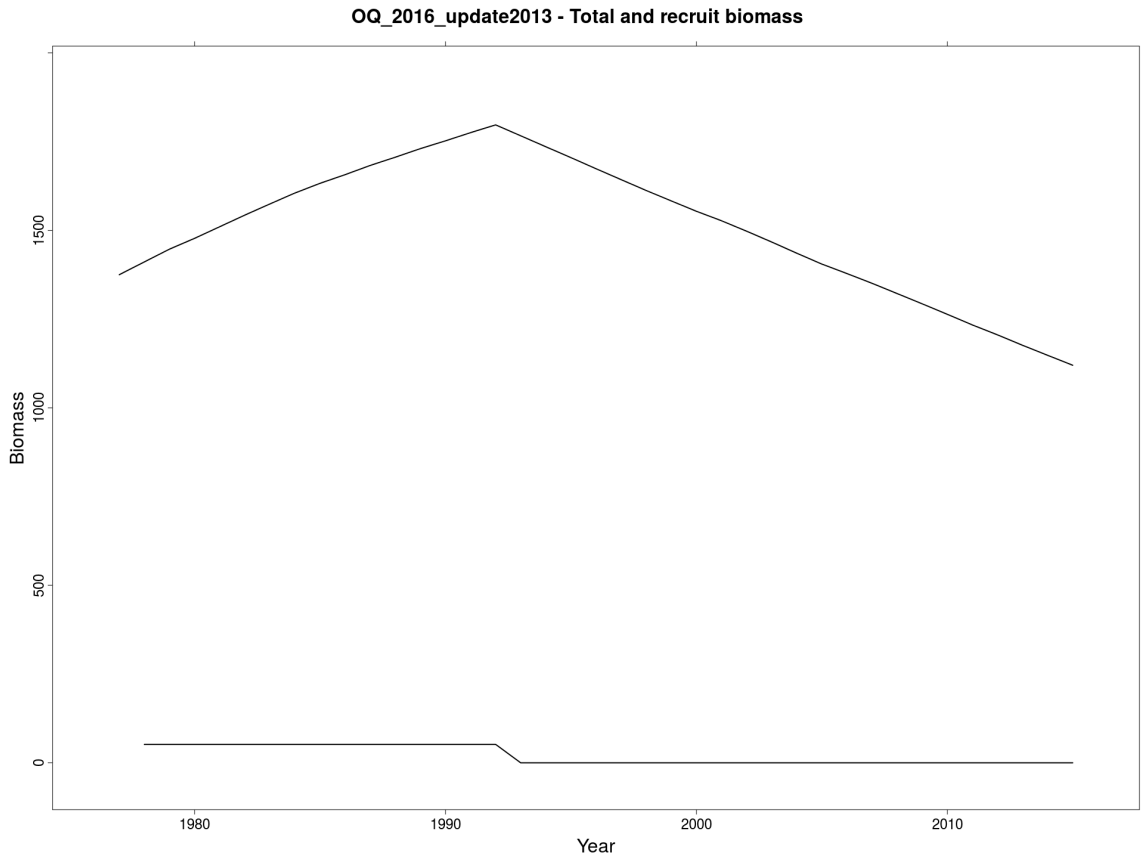

Figure 219: Total biomass and recruits from southern area KLAMZ model fits to the ocean quahog survey data as above, but including new data with a new prior distribution for survey q. Recruitment to the population included a step function in 1993.

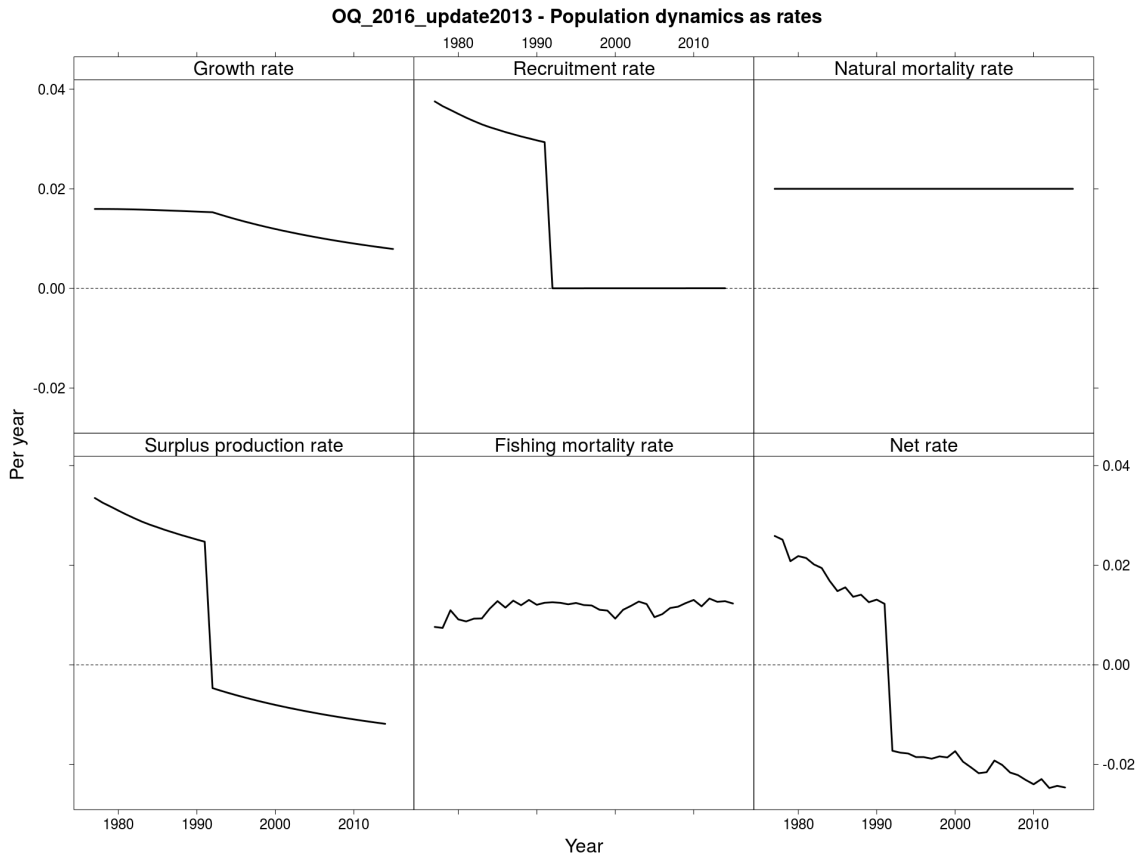

Figure 220: Population dynamics from southern area KLAMZ model fits to the ocean quahog survey data as above, but including new data with a new prior distribution for survey q, presented as rates. Fishing and natural mortality rates were low, and recruitment, growth and surplus production declined over time.

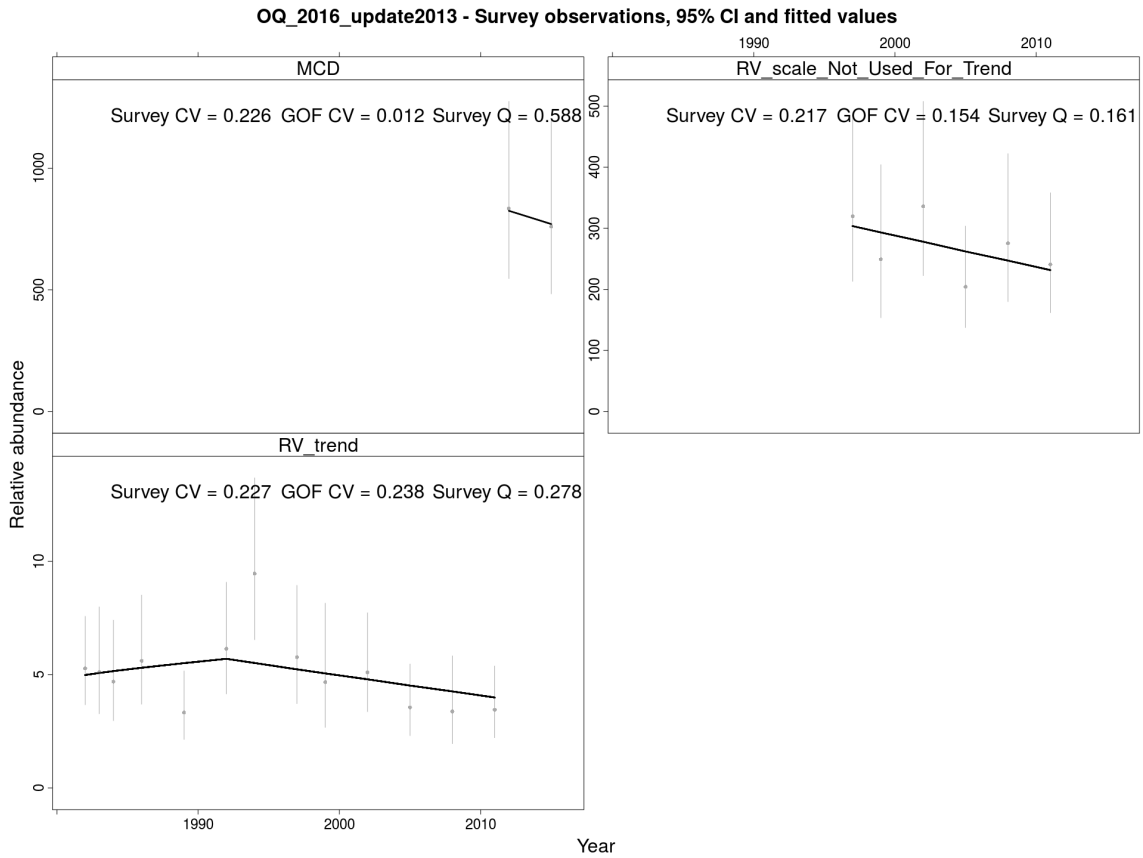

Figure 221: Southern area KLAMZ model fits to the ocean quahog survey data as above, but tuned so that the input cv on the RV survey is close to the goodness of fit cv estimated in the model. The input cv, model fit cv and survey q estimate for each of the surveys are shown in text in each of the panels.

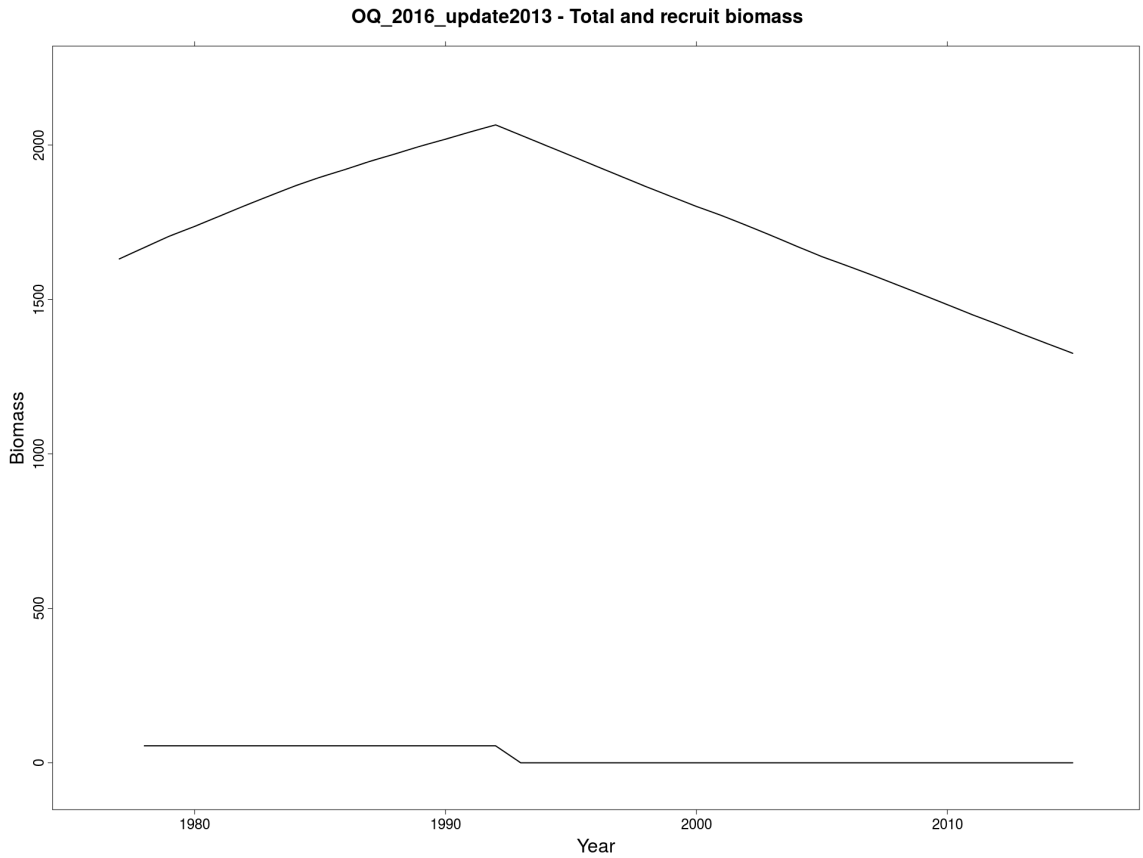

Figure 222: Total biomass and recruits from southern area KLAMZ model fits to the ocean quahog survey data as above, but tuned so that the input cv on the RV survey is close to the goodness of fit cv estimated in the model. Recruitment to the population included a step function in 1993.

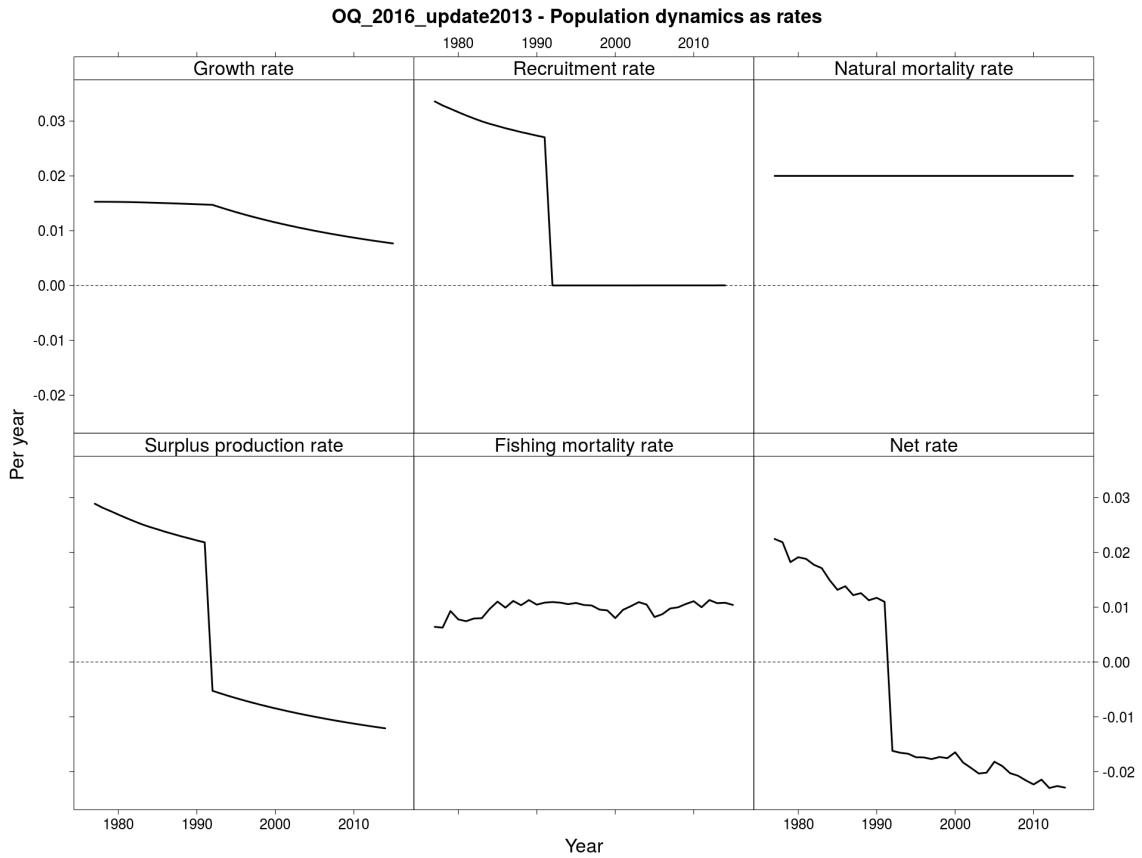

Figure 223: Population dynamics from southern area KLAMZ model fits to the ocean quahog survey data as above, but tuned so that the input cv on the RV survey is close to the goodness of fit cv estimated in the model, presented as rates. Fishing and natural mortality rates were low, and recruitment, growth and surplus production declined over time.

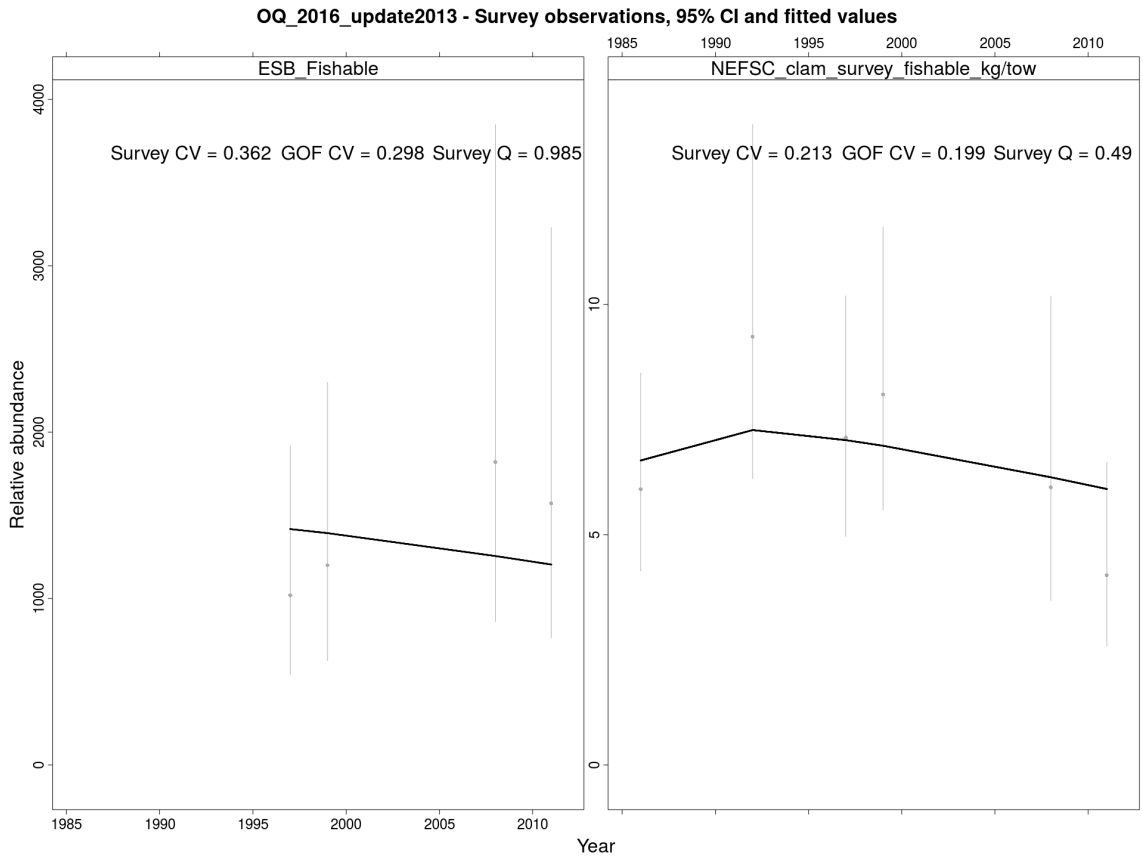

Figure 224: Northern area KLAMZ model fits to the ocean quahog survey data from the previous assessment (data through 2011). The input cv, model fit cv and survey q estimate for each of the surveys are shown in text in each of the panels.

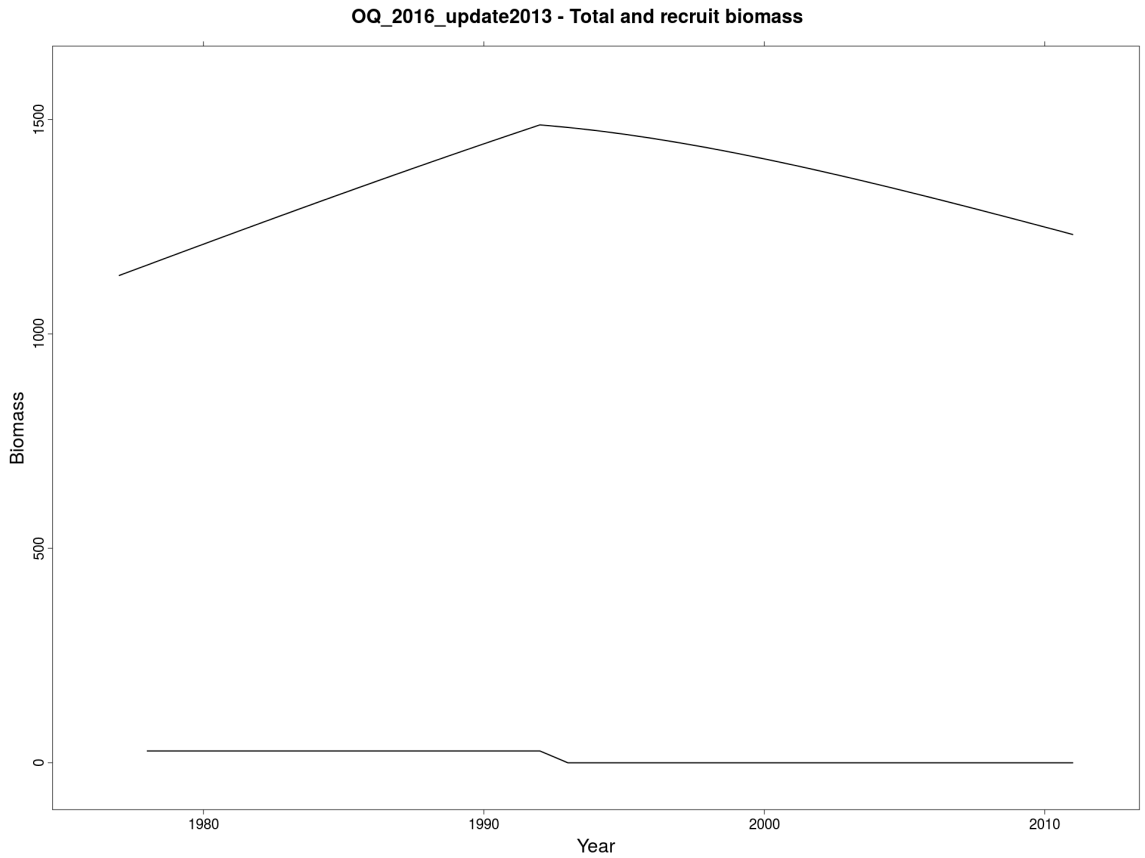

Figure 225: Total biomass and recruits from northern area KLAMZ model fits to the ocean quahog survey data from the previous assessment (data through 2011). Recruitment to the population included a step function in 1993.

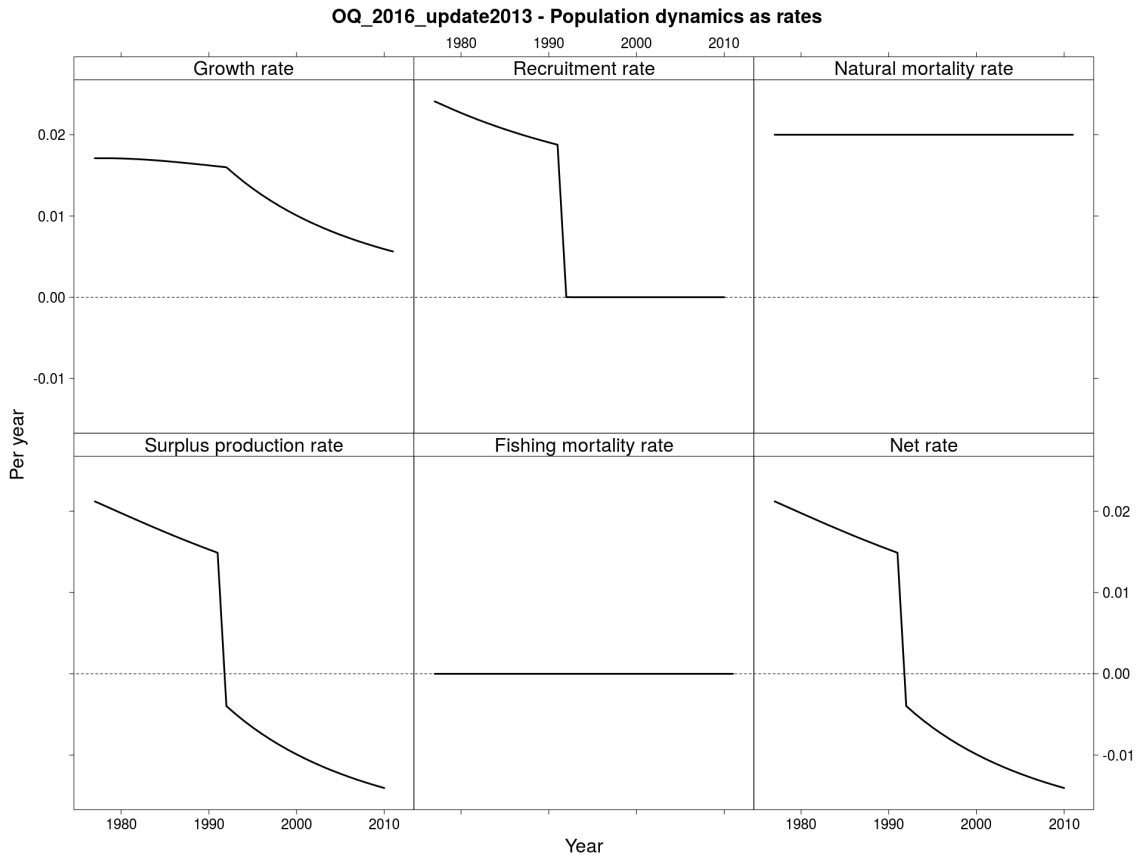

Figure 226: Population dynamics from northern area KLAMZ model fits to the ocean quahog survey data from the previous assessment (data through 2011) presented as rates. Fishing and natural mortality rates were low, and recruitment, growth and surplus production declined over time.

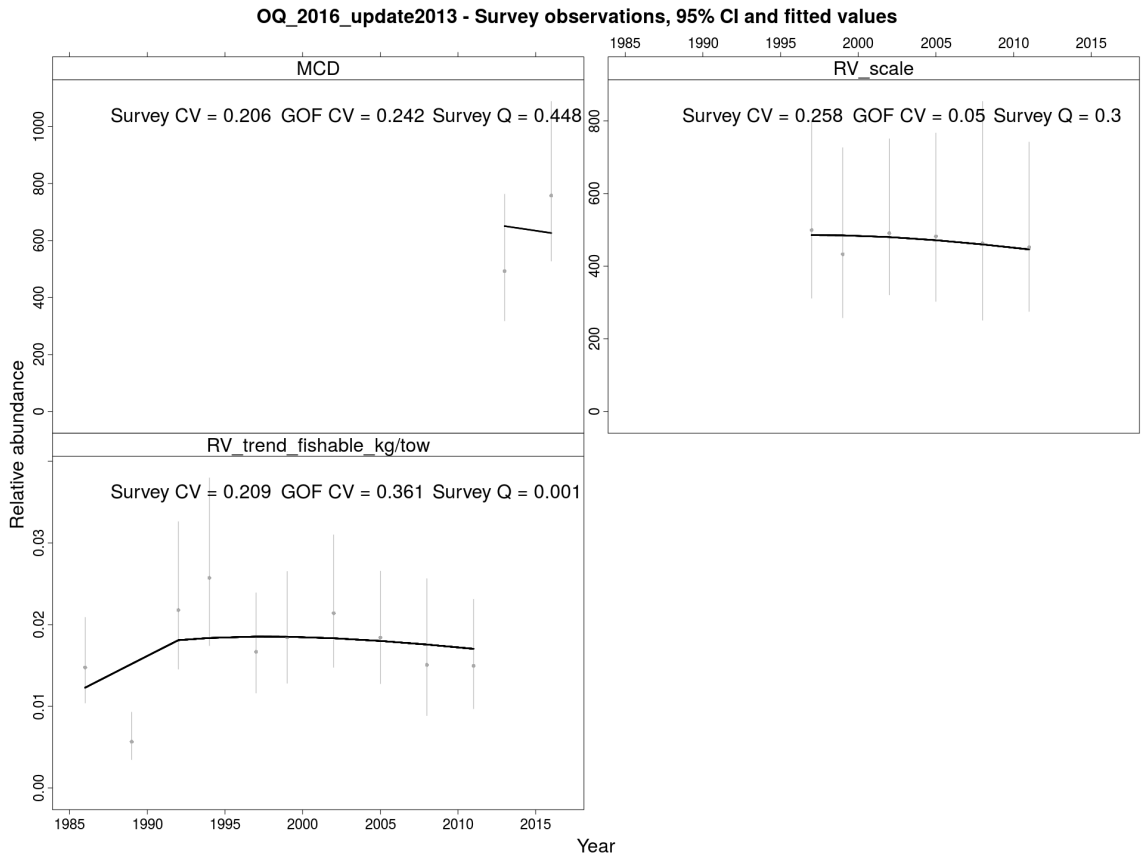

Figure 227: Northern area KLAMZ model fits to the ocean quahog survey data as above, but including new data with a new prior distribution for survey q. The input cv, model fit cv and survey q estimate for each of the surveys are shown in text in each of the panels.

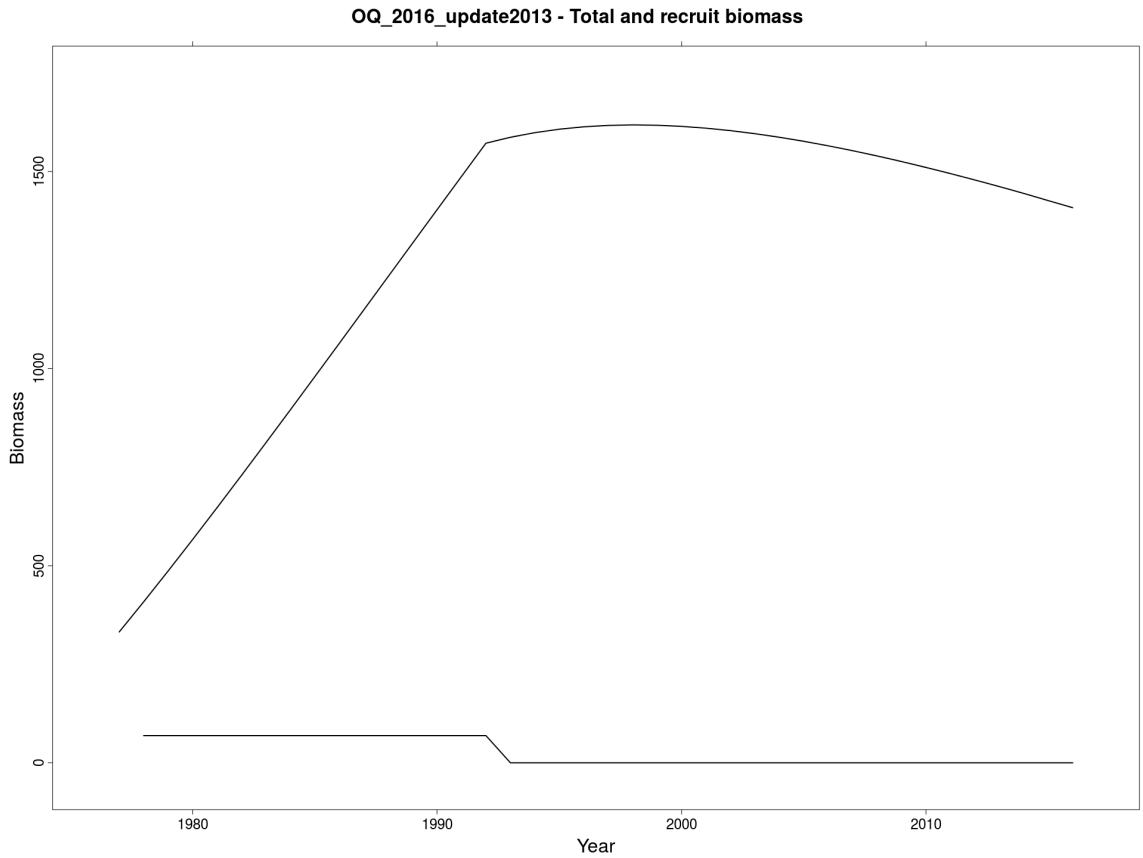

Figure 228: Total biomass and recruits from northern area KLAMZ model fits to the ocean quahog survey data. Recruitment to the population included a step function in 1993.

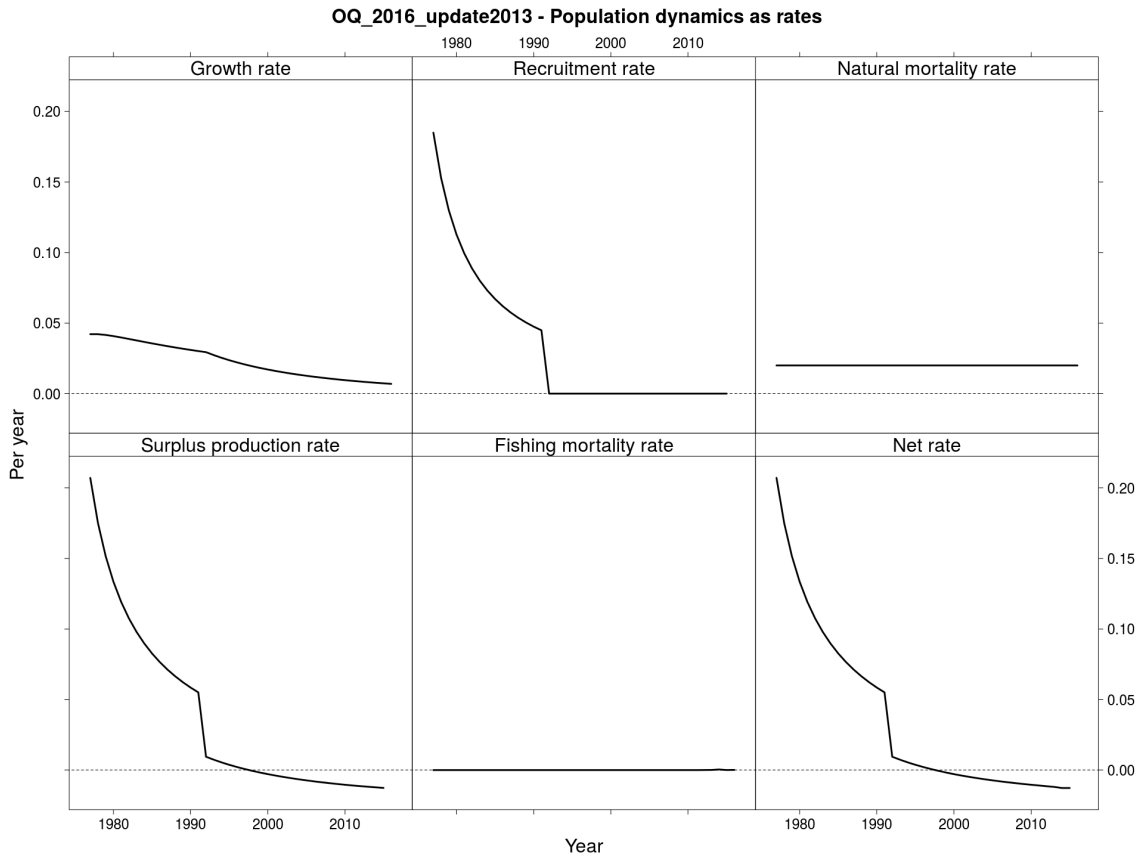

Figure 229: Population dynamics from northern area KLAMZ model fits to the ocean quahog survey data presented as rates. Fishing and natural mortality rates were low, and recruitment, growth and surplus production declined over time.

Appendix 7 Updated report on the ocean quahog resource in Maine waters

Introduction

The Maine fishery for ocean quahog, although harvesting the same species as the rest of the EEZ fishery (*Arctica islandica*), is prosecuted in a different way and fills a different sector of the shellfish market. Maine "mahogany ocean quahog" are harvested at a smaller size (starting at 38 mm or 1.5 inches in shell length, SL) and marketed as a less expensive alternative for *Mercenaria mercenaria* for home and restaurant consumption. The offshore beds targeted by the Maine fishery are made up of small ocean quahog, the maximum size being only about 75mm.

The Maine fishery began to expand into Federal waters in the 1980s due in part to paralytic shellfish poisoning (PSP) closures within state waters. In 1990 it was determined that this fishing activity conflicted with the Magnuson-Stevens Fishery Management Conservation Act which calls for the stock to be managed as a unit throughout its range. The Maine fishery was granted experimental status from 1990-1997. In 1998, the Maine fishery was fully incorporated under Amendment 10 of the surfclam/ocean quahog FMP and given an initial annual quota of 100,000 bushels based on historical landings data. There was no independent assessment of the resource available at that time. The State of Maine is responsible under Amendment 10 to certify harvest areas free of PSP and to conduct stock assessments.

In 2002 the State of Maine conducted a pilot survey to assess the distribution and abundance of ocean quahog along the Maine coast. This survey was a critical first step in establishing distribution, size composition and relative abundance information for the Maine fishery and for directing the design of the current survey work. While this initial survey provided valuable information it did not have the resources to estimate dredge efficiency and therefore was not able to estimate total biomass or biological reference points. The survey conducted in 2005 was focused on estimating dredge efficiency and mapping ocean quahog density on the commercial fishing grounds.

Estimates of biomass and mortality presented in this report are only for the two commercial beds south of Addison (west bed) and Jonesport/GreatWass (east bed), Maine. This approach was chosen due to available resources and because it was conservative. Other ocean quahog beds are known to exist along many parts of the Maine coast. If mortality targets can be met using the estimates from the primary fishing grounds then biomass outside the survey area can act as a *de facto* preserve.

Fishery Data

Data throughout this report are presented in metric units. In the case of landings and LPUE, values are reported in units of Maine bushels, which are about two-thirds the size of the "industry" bushels used as a measure of ocean quahog volume for the rest of the EEZ. To determine the meat yield of a Maine bushel of ocean quahog, all ocean quahog caught by the Maine survey (number and size composition estimated by subsampling) are converted to a total

meat weight then divided by the total number of bushels caught (known). Shell length is converted to meat weight using the equation

$$W = 4.97 \cdot 10^{-6} \cdot SL^{3.5696} \tag{5}$$

where W is meat weight and SL is shell length. The resulting meat yield (10.8 lbs) is for a Maine bushel of ocean quahog averaging around 57 mm SL.

Historically the bulk of ocean quahog fishing activity in Maine has taken place on two large ocean quahog beds just off the coast north of $43^o50'$ latitude: the east bed off the town of Addison and the west bed off Great Wass Island. The two beds cover an area of approximately 60 square nautical miles (Figure 230).

Harvesting takes place year round with the highest market demand during the summer holidays (Memorial Day through Labor Day). Most vessels in the Maine fleet are between 10.7-13.7 m (35-45 ft) and classified as "undertonnage" or "small" in issuing permits. All of the vessels use a "dry" dredge (having no hydraulic jets to loosen the sediments) with a cutter bar set by regulation at no more than 0.91 m (36 in). There are no restrictions on any other dimension of the dredge.

There are no size limits for this fishery, and there is no discarding. The ocean quahog fished from the two commercial beds off Maine are much smaller than most of the rest of the EEZ harvest, averaging between 50 and 60 mm SL (Figure 231), which suits the half- shell market. Even though size of individual ocean quahog has increased since the beginning of the fishery, all the catch brought up in a dredge is still acceptable for this market and are kept. The fishery has no regulatory closed days, although the beds are occasionally closed to fishing as a PSP precaution. Since the summer of 2007, there have been 77 days when the fishing areas were closed and 145 days when the open fishing areas were severely restricted in size due to PSP precautions. These closures usually happen during the summer months.

Maine ocean quahog landings have trended downwards since 2002 (Table 37, Figure 232). The exception to this trend is in 2006 when landings increased to 124,839 bushels after the re-opening of a highly productive portion of the fishing grounds that had been closed in previous years as a precaution against PSP. After the initial boost to landings from additional fishing ground, landings again began to decline. By the end of 2015 only 41,611 bushels out of a 100,000 bushel quota had been landed.

LPUE has been fairly stable since the early 1990s (Figure 232). Changes in LPUE were often the result of regulatory or fishing practice changes, such as the uptick in 2006 which mirrors the peak in landings from the re-opening of productive beds. Despite the intensity of the fishery, the fact that the LPUE has not fallen may be the result of the fishery moving onto the most productive beds (Figure 230), the ocean quahog growing larger in size, and the reduction in total effort since the early 2000s. Since 2008, the number of valid ocean quahog license holders has fallen from 47 to 29, and hours fished per year by the fleet has dropped by more than half in the past 10 years (Figure 233).

Incidental mortality for Maine ocean quahog is unknown. This is an important topic for future research, especially since Maine has a high level of dredging activity relative to the size of the

fleet. For example, in 2008 the ocean quahog fleet fished approximately 10,776 hours, equivalent to 64,656 tows at ten minutes each. Using standard industry dredge dimensions and tow speeds this level of fishing activity represents 31.42 nm^2 of bottom swept by commercial dredges per year. Five percent is added to ocean quahog landings before calculating exploitation rates to make up for incidental mortality, but it is just an estimate based on the fishery for larger ocean quahog in the rest of the EEZ.

Research Surveys

Surveys of the Maine ocean quahog resource were conducted in 2002, 2005, 2006, 2008 and 2011. With the limited funds dedicated for survey work on ocean quahog, it was decided to focus all survey efforts after 2002 on the two large ocean quahog beds off of Addison (west bed) and Great Wass Island (east bed) that are the primary commercial fishing grounds. Therefore survey estimates of biomass pertain only to these two beds and not to the coast of Maine as a whole. Vessel logbooks and the 2002 independent survey abundance indices show that the majority of the ocean quahog resource, and as a result the majority of fishing activity, occurs here.

The first step in designing the 2005 survey was to establish a 1 km^2 grid overlay (using Arcveiw 3.2) over the two beds. Based on number of days at sea available, it was estimated 260 stations could be completed during the survey, so the centers of 260 1 km^2 grids covering the commercial beds were selected as start points for survey tows. These points were transferred to The Cap'n Voyager Software for use on board the survey vessel.

In 2005 the west bed had been the only open fishing grounds for 3 years due to PSP closures. The east bed had been unfished for 3 years but had previously been a productive ocean quahog fishing ground. The 2006 survey took place 9 months after the east bed reopened. All areas were open during the 2008 and 2011 surveys.

Survey gear and procedures

The 2005 and 2006 surveys were conducted from the commercial vessel F/V Promised Land, a 12.8 m (42 ft) Novi Style dragger piloted by Capt. Michael Danforth. All survey tows during these two years were conducted using a dredge with the following dimensions: cutter bar 0.91 m (36 in), 2.44 m (8 ft) long x 1.83 m (6 ft) wide x 1.22 m (4 ft) high, overall weight 1,361 kg (3,000 lbs), bar spacing all grills 19.05 mm ($\frac{3}{4}$ in). The dredge used by the F/V Promise Land during normal fishing activity was used for the survey. After the 2006 survey, The F/V Promise Land was sold and the captain left the fishery. The vessel contracted for the 2008 and 2011 surveys, The F/V Allyson J4, was about the same size as the F/V Promise Land and the captain, Bruce Porter, had been a ocean quahog fisherman for 24 years. The dredge used in 2008 and 2011 was also built for commercial use with the same specifications as the dredge on the Promise Land. The only difference between the dredges was a custom extension on the Promise Land dredge that could hold more sediment, making it roughly 400 lbs heavier than the one used in 2008 and 2011 (Figure 234). During tow operations it was noted that the teeth on the cutter bar of the new dredge shined to depth of 3 inches just as they had in the original dredge. From this we assumed

that the new dredge was cutting to the same depth as the original. It was also felt that since the survey tows were short (two minutes compared to about ten minutes for a commercial tow) in order to avoid any overfilling and subsequent loss of catch the extensions on the catch box of the original dredge would not give it any advantage over the current dredge.

To conduct a survey station, the vessel approaches the center of the selected tow grid, and if suitable bottom is not present at the predetermined start point, the vessel starts crossing runs within the grid. If towable bottom cannot be found, then the grid location is deemed un-towable, a note is made, and the captain continues on to the next grid. When a suitable tow path is found within a grid the dredge is lowered to the bottom by free- spooling until the ratio of cable length to depth is 3:1. Once the desired cable length is reached the drum is locked, a two minute timer is started and a GPS point taken. The dredge is towed into the current at approximately 3.5 knots for two minutes, a second GPS point is taken and the dredge is brought to the surface. Before it is brought onboard, mud is cleaned from the dredge by steaming in tight circles keeping the dredge in the vessel's prop wash (Figure 235).

Once on board, the dredge is emptied and the catch photographed (Figure 236). The catch is placed on a shaker table (Figure 237), bycatch is noted and all live ocean quahog are sorted out. A 5 liter subsample of ocean quahog is taken from each tow to count and measure. The entire catch is processed if it is less than 5 L. The remainder of the catch is placed in calibrated buckets to determine total catch volume. The number of ocean quahog caught in a tow is estimated by counting the number of clams in the 5 L subsample and expanding to the total volume of the catch. All data are analyzed using Excel with variances calculated using a bootstrap program (10,000 iterations) written by Dr. Yong Chen at the University of Maine, Orono.

Tow distances were determined by The Cap'n Software and were checked using ESRI ArcInfo software. All data from each tow are standardized to a 200 m tow prior to further analysis. Due to a number of reasons such as placement of lobster gear, vessel availability and weather, the number of stations completed per survey has varied from 130 to 183.

Estimating dredge efficiency

Maine dry dredges are less efficient (2 to 17 percent, pers. comm. Robert Russell) than the hydraulic dredges used in the rest of the EEZ (up to 95 percent, Medcof and Caddy (1971)). A reliable estimate of dredge efficiency is needed to convert survey densities to a biomass estimate (NEFSC 2004). To assess the efficiency of the Maine dredge, boxcore samples were taken to directly estimate ocean quahog density, tows were then made in the same area with the survey dredge. Considering only ocean quahog of sizes available to the dredge, the ratio of density estimated from the dredge tows to density estimated from the boxcore samples is an estimate of survey dredge efficiency (Thorarinsdottir and Jacobson 2005). The estimated dredge efficiency was 17.9 percent, with a 95% bootstrap confidence interval of 8.0%-34.4%. More details of the dredge efficiency experiments can be found in Northeast Fisheries Science Center (2009), Appendix B2.

Dredge survey results

The original 2005 survey visited 259 potential tow grids. 71% of the stations were towable (183) and 29% were untowable, mostly due to inappropriate substrate, but sometimes due to the presence of fixed gear. During future surveys only the 183 towable grids were revisited. In 2006 130 tows were completed, in 2008, 181 tows were completed, and in 2011, 183 tows were completed.

Tow distance, catch volume and counts were all standardized to a 200m tow. For all surveys the highest concentration of biomass was in the eastern bed. The eastern section has had the most variable open and close status due to PSP. Substrate data (Figure 238) from Kelley et al. (1998) show the complexity of the substrate in the eastern section with highest ocean quahog densities found near the boundary of hard rocky substrate with gravels, sands or mud. Substrate data collected independently using sidescan imaging showed that substrate information was relatively accurate. However, in some cases substrate labeled as "sand" or "gravel-sand mix" near the most productive tows may have been shell hash from old ocean quahog beds that was seen in boxcores from the same area.

Size frequencies for all subsampled ocean quahog (n = 20,737 in 2005; 2,014 in 2006; 4,055 in 2008, 4,316 in 2011 and 4,045 in 2014) show the ocean quahog in the eastern bed were larger in the first two surveys but have converged in the 2014 survey (Figure 239). Cumulative size frequency distributions and a Kolmogorov-Smirnov test were used to test the null hypothesis that the size frequency distributions in the eastern and western areas were the same (Zar 1999). The null hypothesis was rejected (p=0.001). The size difference between the two beds does not currently exist. The increase in median shell size seen over the past nine years may be a result of the fishery targeting the smallest clam sizes for their markets and moving to new areas once remaining ocean quahog become too large.

Because the two beds had different size composition and densities, abundance and biomass were calculated separately for the two beds before making combined estimates for the entire survey area. Abundance estimates (see Table 38 and Figure 240) are calculated using a dredge efficiency that was estimated by applying 10,000 bootstrapped efficiency estimates from the three boxcore trips to 10,000 average abundance estimates from the surveys, and the swept area of the survey. Biomass estimates are made by dividing the population into 1 mm size bins based on survey size frequencies, then converting SL to W using eq. (5).

Growth and per recruit modeling

A sample of 83 ocean quahog from the east bed was recently (February 2013) aged at the University of Iowa, and although the data are preliminary, there is evidence that ocean quahog are growing faster and larger there than previously thought. Kraus et al. (1992) estimated a growth curve for Maine ocean quahog from the east bed which suggested Maine ocean quahog grow more slowly and to smaller sizes than ocean quahog from the mid-Atlantic bight, while the new data places east bed ocean quahog in the middle of the EEZ and Kraus et al. curves and more closely matches maximum shell heights and observed changing size distributions between years of the survey (Figure 241).

Biological and fishery parameters from a variety of sources were used to carry out a per recruit analysis for ocean quahog in Maine waters in 2005. The length-based per recruit model used was from the NOAA Fisheries Toolbox (Yield Per Recruit program,). Age at length and growth information was taken from Kraus et al. (1992). Length-weight parameters were from the 2002 Maine ocean quahog survey. Size at maturity estimates were based on Rowell et al. (1990) who found that ocean quahog females from Nova Scotia became fully mature at an average size of 49.2 mm. Fishery selectivity was modeled as a linear ramp function that was zero at 37 mm SL and one at 47mm, based on the facility of fitting live ocean quahog of increasing size through the grates of a commercial dredge by hand (19.05 mm, 3/4 in. bar spacing). Clams from 34mm to 38mm SL generally passed through the grate with some getting caught. After 41mm almost all clams were thick enough to be retained. The regression model for shell depth and shell length shows that a 19.05 mm ($\frac{3}{4}$ in) bar spacing is the thickness of an ocean quahog with 38.7 mm SL. The biological reference points estimated in per recruit modeling for ocean quahog were F_{max} =0.0561, $F_{0.1}$=0.0247 and $F_{50\%}$ =0.013 $y^{-}1$ (Figure 242). These may be reassessed when the new age and growth data has been fully vetted and can be used in the model.

Sensitivity analysis shows biological reference points from the per recruit model for ocean quahog are most sensitive to fishery selectivity parameters and, in particular, the length at which ocean quahog in Maine waters become fully recruited to the fishery. Commercial port sampling conducted in 2009 confirmed the size selectivity estimates used in the modeling (Figure 231).

Fishing mortality rate

Fishing mortality is estimated as catch in meat weight/average biomass. The survey biomass is used as a proxy for average biomass, as annual mortality rates are low. Following Northeast Fisheries Science Center (2004), the catch for each year used in fishing mortality estimation was landings plus a 5% allowance for incidental mortality to account for clams that are killed during fishing activity but not harvested. The level of incidental mortality in this fishery is an area for future investigation given the amount of gear contact time in very confined fishing areas. Maine ocean quahog catches, biomass estimates and F estimates for 2005, 2006, 2008 2011 and 2014 are given below.

Year	Med. Biomass (mt meats)	Landings (mt meats)+5% incidental mort.	F
2005	25,862	528	0.020
2006	19,012	642	0.033
2008	16,574	348	0.021
2011	19,577	446	0.023
2014	11,957	217	0.018

Fishing mortality estimates for 2008, 2011 and 2014 are roughly equal or below the F0.1 generated by the per recruit model, but higher than the F50%. It should be noted that Fishing mortality rates have remained low even as the surveyed stock has dropped to half the initial biomass surveyed in 2005. This is most likely a result of the greatly reduced fishing effort in recent years. Total fishing hours fell 67% between 2005 and 2015.

Stock Status

Since the entire population of ocean quahog in U.S. waters is managed as a single stock and overfishing definitions apply to the whole stock, it is not possible to evaluate the status of ocean quahog in Maine as the biomass represents less than 1% of the EEZ stock as a whole. It is not possible to compare or evaluate current biomass levels relative to biological reference points associated with maximum productivity, depleted stock or historical levels because no appropriate biological reference points or historical biomass estimates are available.

$F_{0.1}$ might be a reasonable reference point for managers if the goal is to maximize yield per recruit while preserving some spawning stock. Simulation analysis (Clark 2002) indicates that $F_{50\%}$ (1.3% per year) might be a reasonable reference point for managers if the goal was to preserve enough spawning potential to maintain the resource in the long term. However, preservation of spawning potential may not be necessary if recruitment originates mostly outside of Maine waters.

Table 37: Total Maine landings (ME bu.), landings (where effort and catch>0, +Landings), effort (hrs fished) and landings per unit effort (ME bu./hr, LPUE) from vessel logbooks for all vessel classes combined. Only records with both effort and catch data were used to calculate LPUE, which in most years are 100% of the logbook entries as can be seen by comparing columns two and three below.

Year	Total landings	+Landings	Effort	LPUE
1990	1018	1018	286	3.56
1991	36679	34360	17163	2.00
1992	24839	24519	13469	1.82
1993	17144	17144	5748	2.98
1994	21672	21672	5106	4.24
1995	37912	37912	5747	6.60
1996	47025	47025	8483	5.54
1997	72706	72706	11829	6.15
1998	72466	72152	11745	6.14
1999	93015	92285	11151	8.28
2000	121274	119103	12739	9.35
2001	110272	110272	13511	8.16
2002	147191	147191	19681	7.48
2003	119675	119675	17853	6.70
2004	102187	102187	19022	5.37
2005	100115	100115	17063	5.87
2006	121373	121373	14902	8.14
2007	102006	102006	14018	7.28
2008	66926	66926	10776	6.21
2009	56808	56808	9928	5.72
2010	56469	56469	9727	5.81
2011	65307	65307	9145	7.14
2012	65912	65912	7132	9.24
2013	58734	58734	6325	9.29
2014	46109	46109	5066	9.10
2015	41611	41611	5714	7.28

Table 38: Maine ocean quahog survey median abundance and biomass estimates.

Year	Bed	Med. abundance (10^9)	CV	Med. meat wt. (mt)
2005	west	1.73	39.5%	8653
	east	2.40	40.2%	17208
	combined	4.13	43.9%	25861
2006	west	2.00	41.0%	10166
	east	1.23	40.8%	8846
	combined	3.22	48.4%	19012
2008	west	0.71	40.1%	5471
	east	1.09	40.8%	11103
	combined	1.80	46.8%	16574
2011	west	0.75	40.2%	7053
	east	1.23	40.7%	13277
	combined	1.99	48.2%	20330
2014	west	0.50	40.4%	5904
	east	0.49	41.3%	6053
	combined	0.99	39.9%	11957

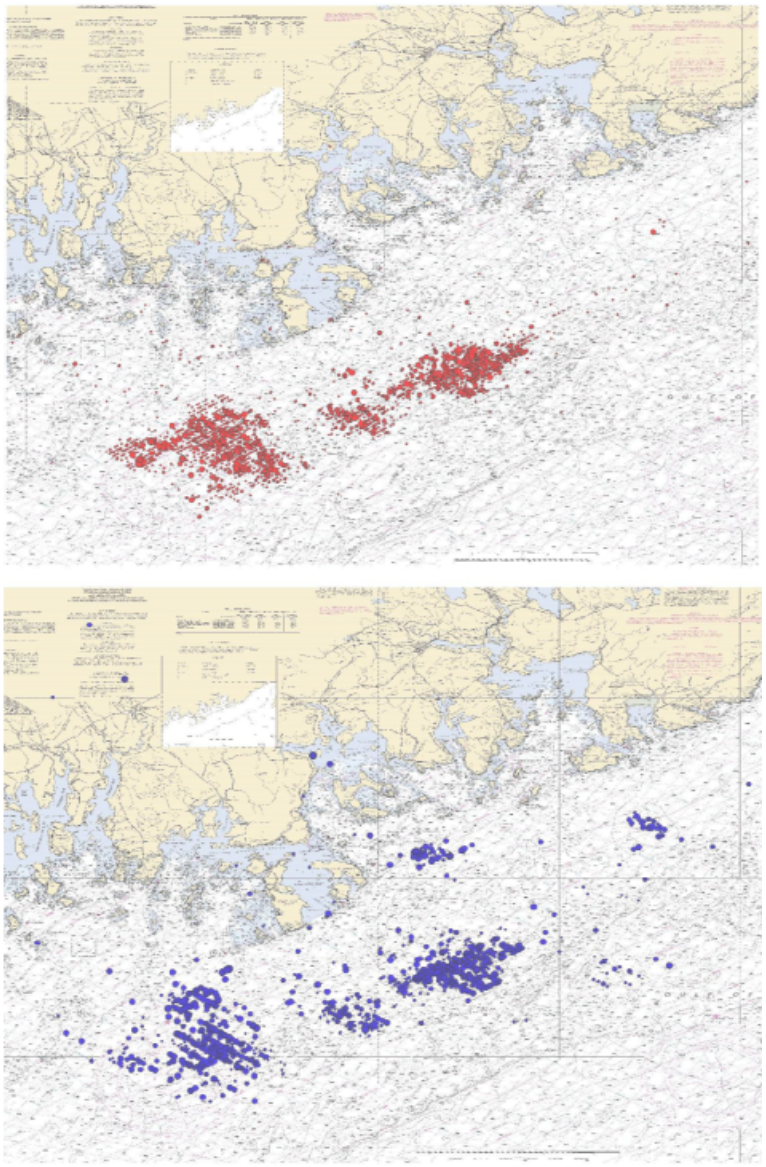

Figure 230: Locations of all reported commercial landings 2003-2008 (top) and 2009-2012 (bottom).

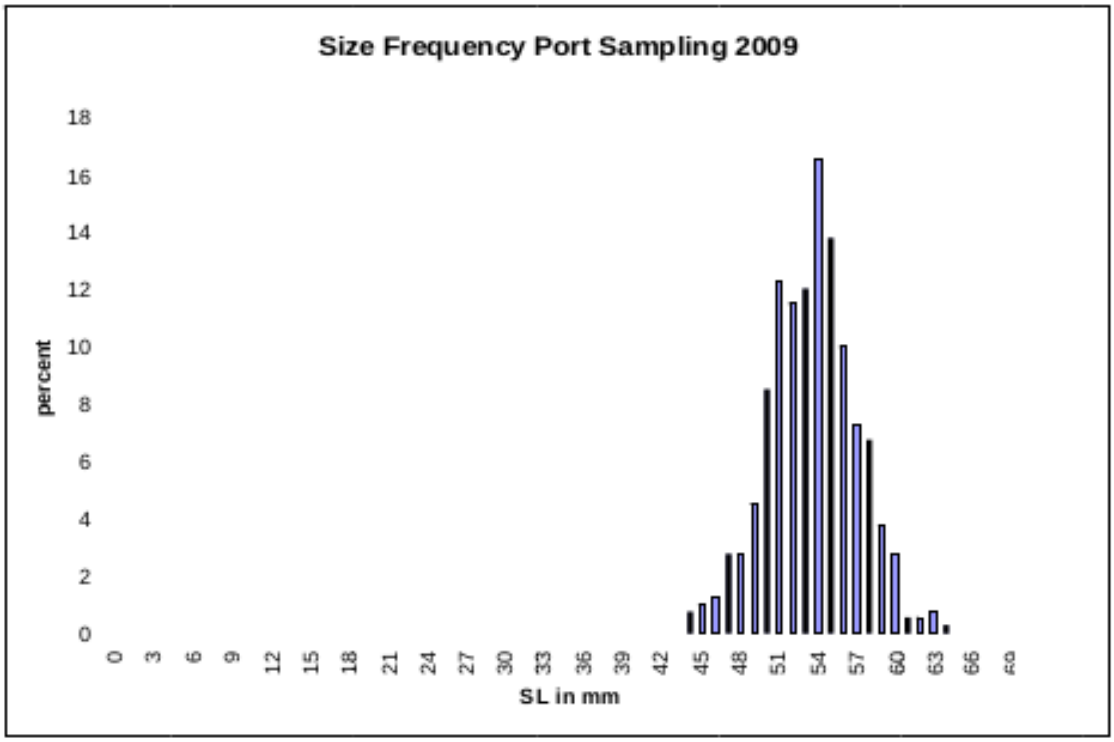

Figure 231: Size frequency for port samples collected in Jan- March 2009 from 6 different vessels.

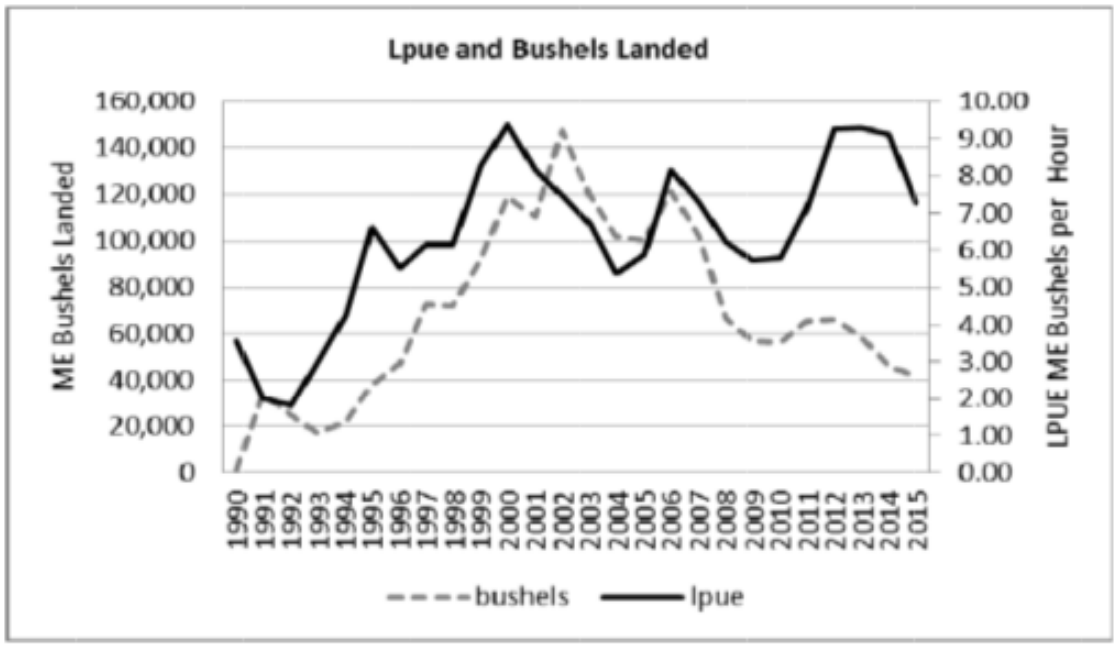

Figure 232: Commercial LPUE and Landings from clam industry logbooks.

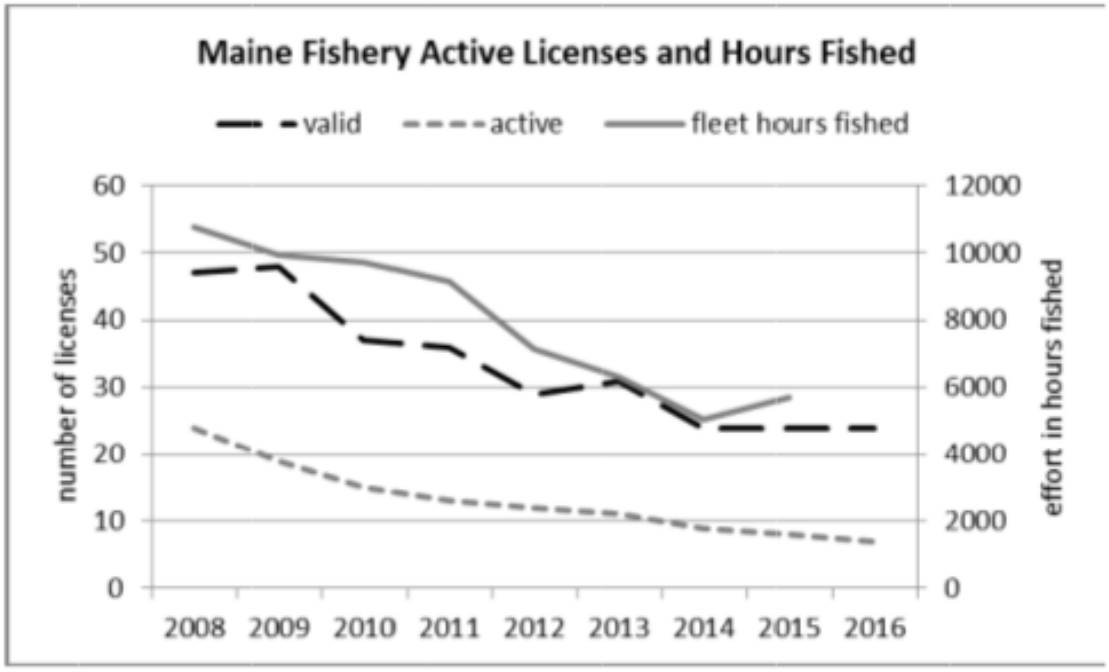

Figure 233: Number of valid and active (fished during the year) ocean quahog licenses for the Maine fishery, with fleet fishing effort through 2015 in thousands of hours shown by the solid line.

Figure 234: At left, the dredge used for the 2005 and 2006 surveys, weighing about 3,000 lbs. At right, the dredge used for the 2008, 2011 and 2014 surveys, weighing about 2,600 lbs.

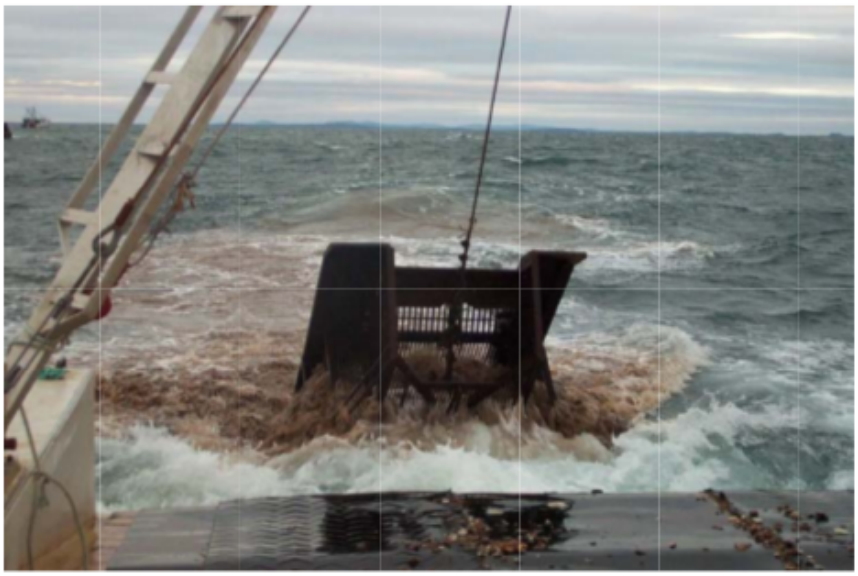

Figure 235: After being brought to the surface, the catch is washed and mud rinsed away in the propeller wash of the survey vessel.

Figure 236: Typical catch from a two-minute survey tow. Note very low bycatch and uniform size of clams.

Figure 237: Processing the survey catch on shaker table, used to remove shell fragments and mud. This step is performed in commercial operations as well.

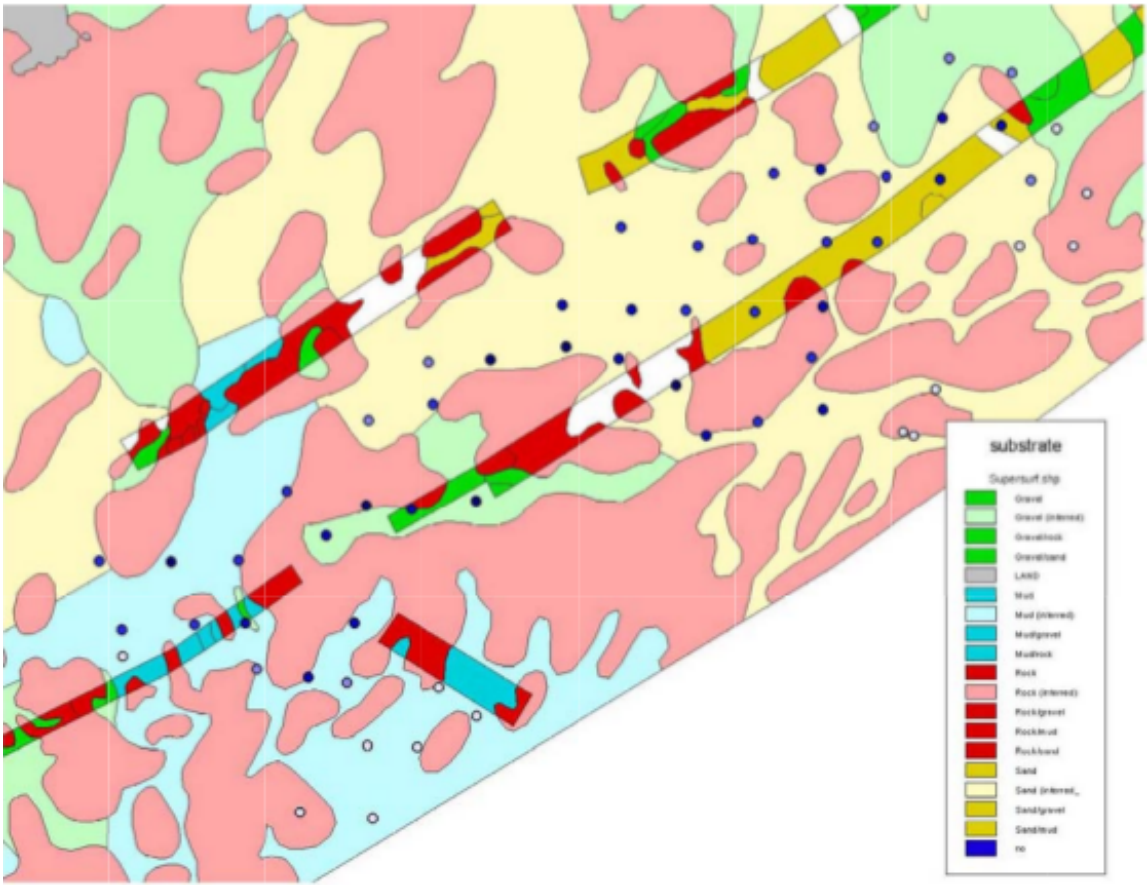

Figure 238: Substrate data from Kelly et al. (1998) showing coincidence of hard bottom edges with high density ocean quahog tows from eastern bed. The tow locations are the dark blue dots, while pink is rock, light blue is mud, yellow is sand and green is gravel substrate.

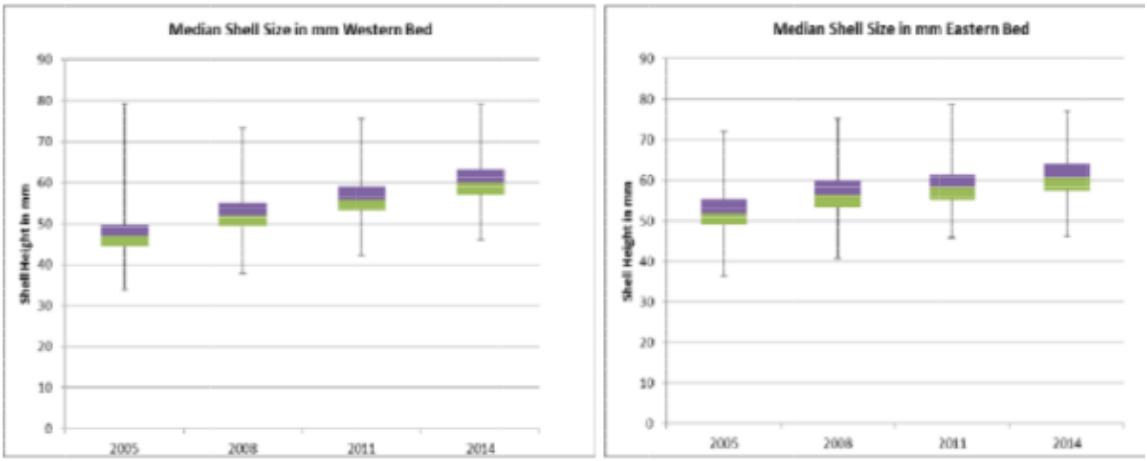

Figure 239: Growth in Maine ocean quahog between the 2005 and 2014 surveys for the west bed (top left) and the east bed (top right), These ocean quahog appear to be growing faster and to a larger size than previous Maine growth data (Kraus et al. 1992) would predict. For instance, the median growth of 13mm between 2005 and 2014 (nine years) in the western bed would be expected to take almost 60 years. There is no longer a size difference between the two beds.

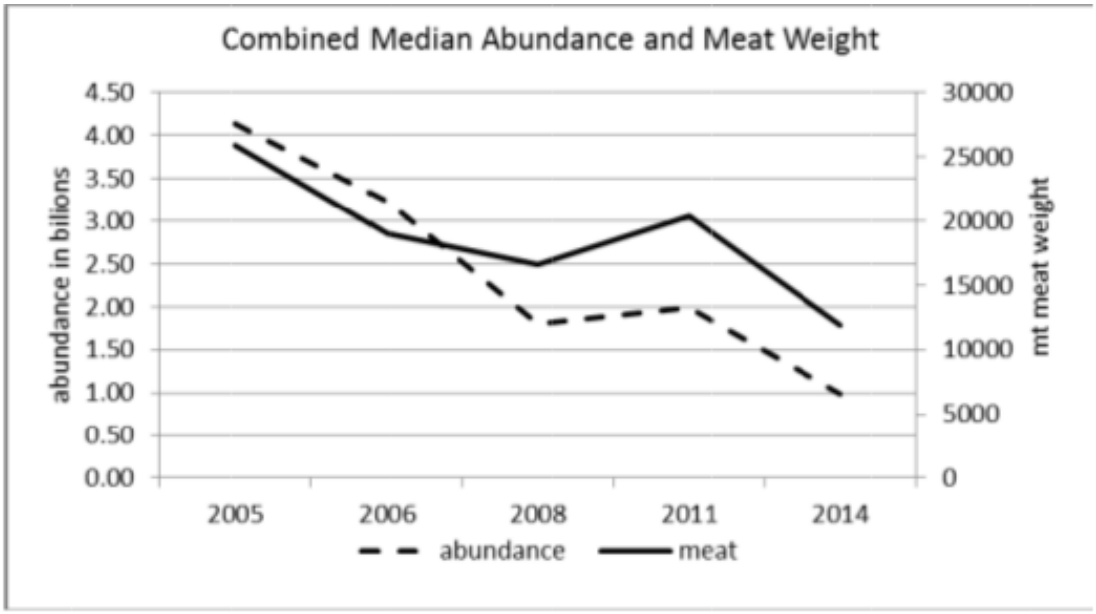

Figure 240: Estimates of abundance in billions of individual ocean quahog (top) and biomass in metric tons of meats for 2005 - 2014.

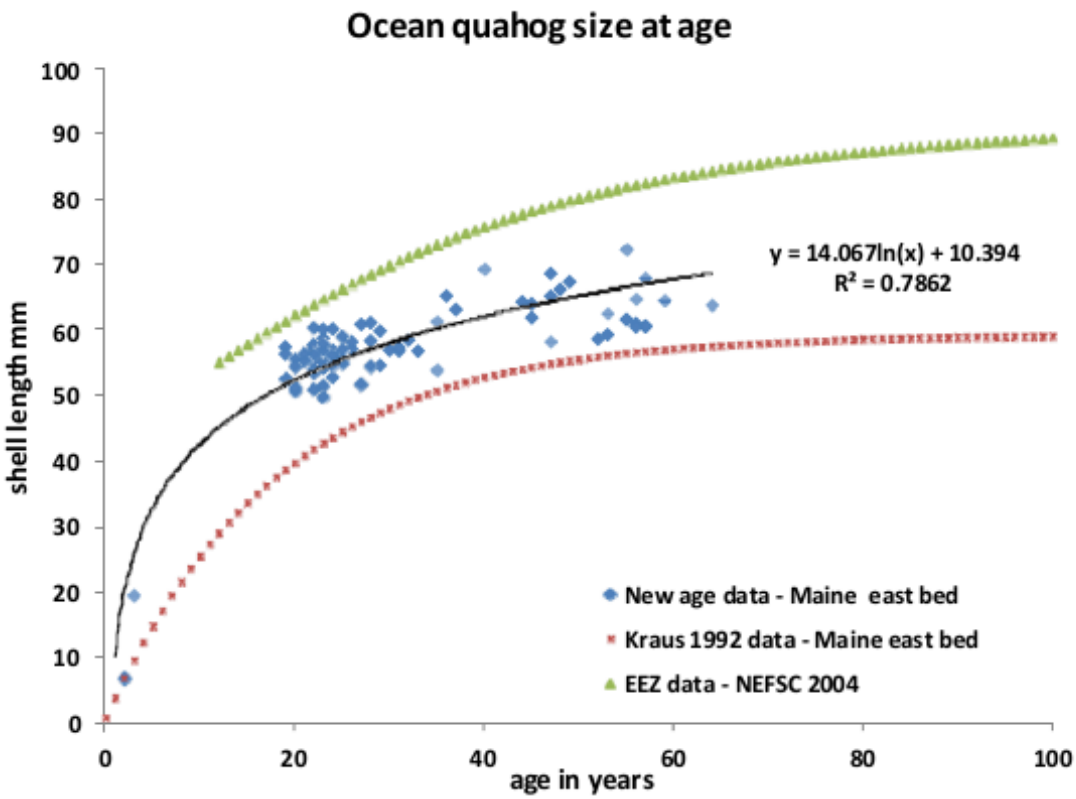

Figure 241: Ocean quahog shell length at age from a major commercial bed off the Maine coast (east bed), and the mid-Atlantic Bight. The blue symbols represent preliminary new age data from the Maine east bed, and the lines represent growth curves from published studies: (Kraus et al. 1992) (Maine east bed, bottom) and (Northeast Fisheries Science Center 2004), (Mid- Atlantic Bight, top).

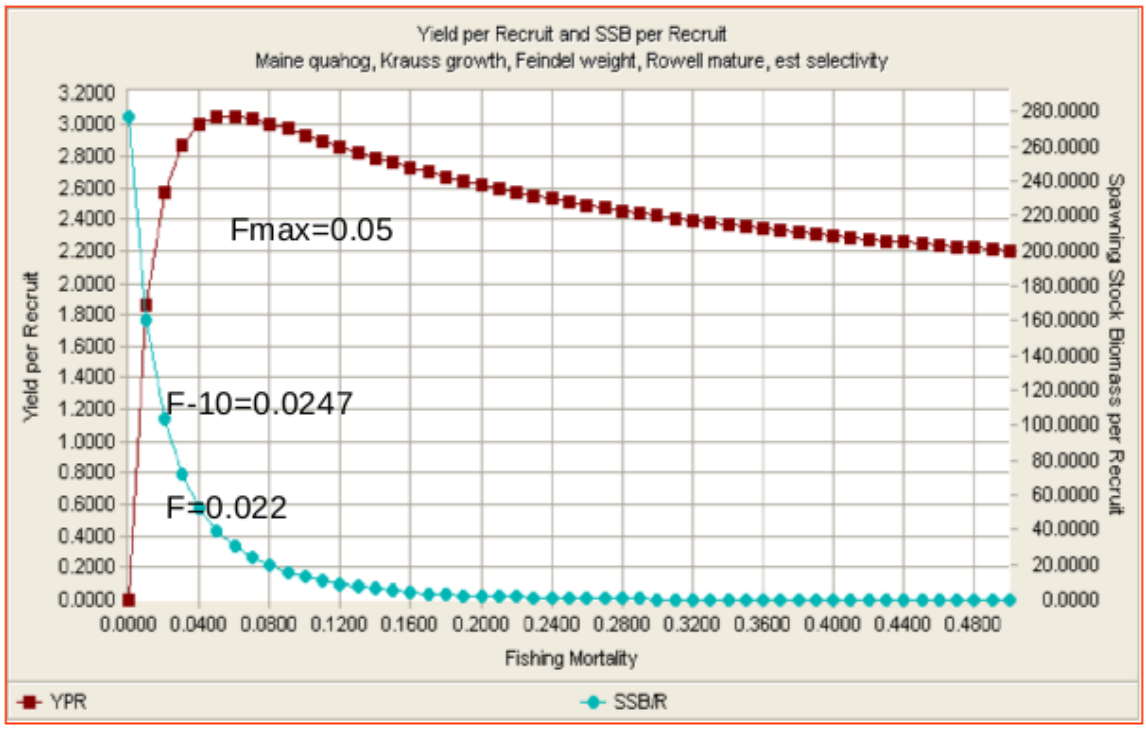

Figure 242: Results of yield per recruit analysis from 2005.

Appendix 8 Changes to MSE

In Hennen (2015) a management strategy evaluation (MSE) was developed to address outstanding questions regarding the optimal biological targets and thresholds for ocean quahog management. The performance of various target fishing mortality rates and various biomass reference points was tested in simulation over short (100 years) and long (1000 years) time horizons. The MSE concluded that the ocean quahog stock could be maintained over a long period of time with a relatively low biomass as long as the fishing mortality rate was kept low ($F < 0.03$). That MSE was modified for purposes of this assessment as described below.

Alterations

The reference point terminology used in Hennen (2015) did not translate well to current ocean quahog management and control rules. Therefore, the biomass (SSB) reference points used for the MSE presented are redefined as SSB_{Target}, which was the desired biomass, below which F is reduced due to management intervention, and SSB_{Cease}, the minimum acceptable biomass below which all fishing is stopped (Figure 243). SSB_{Cease} is not the same as $SSB_{Threshold}$, which is used to determine overfished status in the assessment, because the control rule for ocean quahog and overfishing definitions are not directly related. Overfished status would require managers to establish a rebuilding plan, which has its own set of established rules, but is primarily based on Council action and is beyond the scope of this MSE to model. Importantly, rebuilding plans usually allow some fishing and that may, in fact, fall on the line between SSB_{Cease} and SSB_{Target} such that this MSE does implicitly include the rebuilding plan that follows the control rule exactly. The difference being that the reduction in fishing in this MSE is triggered when the stock falls below SSB_{Target}, rather than at a later point such as $SSB_{Threshold}$.

A coding error resulted in correlated random numbers being generated, which affected the stochastic aspects of the simulated populations in the MSE. This problem was corrected in the current run and resulted in smoother trends in most variables. The difference can be seen in the comparison of Figure 245 and Figure 247.

Hennen (2015) used a growth model that followed Beverton-Holt dynamics

$$L_a = \begin{cases} 0.1 * L_{11} * a + 0.1 & \text{if } \ a < 11 \\ 94.2(1 - e^{(-0.04(a+8.7))}) & \text{if } \ a > 10 \end{cases} \tag{6}$$

The parameters in eq. (6), were averaged from the studies cited in Kilada et al. (2006). W_a and L_a refer to weight and length at age a respectively. Growth was made linear for the first 10 years (from approximately 1 to 5 cm) for lack of better information.

In this revised MSE, growth follows either a Beverton-Holt, or a Tanaka curve (Tanaka (1982); Figure 244).

$$L_a = \frac{1}{\sqrt{0.0019769}} log\left(20.0019769(a-0) + 2\sqrt{0.0019769^2(a-0)^2 + 0.0019769a}\right) + 82.5858 \quad (7)$$

The Tanaka growth equation allows for infinite growth (Figure 244). The affect of the alteration in growth can be seen in Tables 39 - 62 and Figures 248 - 249.

The range of biomass threshold values tested in the current MSE was expanded relative to (Hennen 2015).

Table 39: Average biomass ($\frac{S\hat{S}B}{SSB_0}$) over 100 years of managed fishing simulations at different levels of SSB_{Cease}, the biomass at which fishing is reduced to zero, (columns) and target fishing mortality (rows). Growth followed Beverton-Holt dynamics.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	1.02	1.03	1.04	1.02	1.04	1.03	1.03	1.02	1.02	0.99
0.007	0.92	0.91	0.92	0.91	0.92	0.91	0.92	0.91	0.90	0.89
0.012	0.81	0.80	0.80	0.81	0.81	0.81	0.80	0.80	0.79	0.78
0.017	0.73	0.72	0.72	0.72	0.72	0.71	0.72	0.71	0.72	0.72
0.022	0.64	0.64	0.64	0.65	0.64	0.64	0.65	0.65	0.66	0.68
0.027	0.58	0.58	0.57	0.58	0.59	0.58	0.60	0.61	0.62	0.64
0.032	0.51	0.53	0.52	0.52	0.53	0.54	0.55	0.58	0.60	0.62
0.037	0.48	0.48	0.48	0.48	0.50	0.51	0.53	0.55	0.58	0.60
0.042	0.45	0.44	0.44	0.45	0.46	0.48	0.51	0.54	0.56	0.59
0.047	0.39	0.40	0.41	0.42	0.44	0.46	0.49	0.52	0.55	0.58
0.052	0.38	0.37	0.39	0.39	0.42	0.45	0.47	0.50	0.54	0.57
0.057	0.35	0.35	0.35	0.38	0.41	0.43	0.46	0.49	0.52	0.56
0.062	0.32	0.33	0.34	0.36	0.39	0.42	0.45	0.48	0.52	0.55
0.067	0.30	0.31	0.33	0.35	0.38	0.40	0.44	0.48	0.51	0.54
0.072	0.29	0.29	0.31	0.34	0.36	0.40	0.43	0.47	0.51	0.54
0.077	0.27	0.28	0.30	0.33	0.36	0.40	0.43	0.46	0.50	0.54
0.082	0.26	0.27	0.29	0.32	0.35	0.39	0.42	0.46	0.49	0.53
0.087	0.24	0.25	0.28	0.31	0.34	0.38	0.41	0.45	0.49	0.53
0.092	0.23	0.25	0.27	0.30	0.34	0.38	0.41	0.45	0.49	0.53
0.097	0.21	0.24	0.26	0.30	0.33	0.37	0.41	0.45	0.48	0.52
0.102	0.20	0.23	0.26	0.30	0.33	0.37	0.40	0.44	0.48	0.52
0.107	0.20	0.23	0.25	0.29	0.32	0.36	0.40	0.44	0.47	0.52
0.112	0.19	0.22	0.25	0.28	0.32	0.36	0.40	0.44	0.48	0.51
0.117	0.19	0.21	0.25	0.28	0.31	0.35	0.39	0.43	0.47	0.51
0.122	0.18	0.21	0.24	0.27	0.31	0.35	0.39	0.42	0.46	0.50
0.127	0.17	0.20	0.23	0.27	0.31	0.35	0.39	0.43	0.46	0.50
0.132	0.17	0.20	0.23	0.27	0.31	0.34	0.38	0.42	0.46	0.50
0.137	0.17	0.19	0.23	0.27	0.30	0.34	0.38	0.42	0.46	0.50
0.142	0.16	0.19	0.23	0.26	0.30	0.34	0.38	0.42	0.45	0.50
0.147	0.16	0.19	0.22	0.26	0.30	0.33	0.37	0.41	0.45	0.50
0.152	0.17	0.19	0.21	0.25	0.30	0.35	0.35	0.38	0.45	0.49

Table 40: Average biomass ($\frac{S\hat{S}B}{SSB_0}$) over 1000 years of fishing simulations at different levels of SSB_{Cease}, the biomass at which fishing is reduced to zero, (columns) and target fishing mortality (rows). Growth followed Beverton-Holt dynamics.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.88	0.87	0.88	0.88	0.87	0.88	0.88	0.87	0.85	0.80
0.007	0.62	0.60	0.60	0.61	0.62	0.60	0.61	0.63	0.63	0.64
0.012	0.41	0.38	0.37	0.42	0.44	0.45	0.49	0.51	0.55	0.58
0.017	0.26	0.26	0.28	0.32	0.36	0.40	0.44	0.49	0.52	0.56
0.022	0.19	0.21	0.24	0.29	0.33	0.37	0.42	0.45	0.50	0.53
0.027	0.15	0.18	0.22	0.27	0.31	0.36	0.40	0.44	0.48	0.53
0.032	0.12	0.16	0.21	0.25	0.30	0.35	0.39	0.43	0.48	0.52
0.037	0.11	0.15	0.20	0.24	0.29	0.33	0.38	0.42	0.47	0.51
0.042	0.10	0.14	0.19	0.23	0.28	0.33	0.37	0.42	0.46	0.51
0.047	0.09	0.14	0.19	0.23	0.28	0.32	0.37	0.42	0.45	0.50
0.052	0.09	0.13	0.18	0.22	0.28	0.32	0.37	0.41	0.46	0.50
0.057	0.08	0.13	0.18	0.22	0.27	0.31	0.36	0.41	0.45	0.49
0.062	0.08	0.13	0.17	0.22	0.27	0.31	0.36	0.40	0.45	0.48
0.067	0.08	0.12	0.17	0.22	0.26	0.31	0.36	0.40	0.44	0.49
0.072	0.08	0.12	0.17	0.21	0.26	0.31	0.35	0.40	0.44	0.48
0.077	0.07	0.12	0.16	0.21	0.26	0.31	0.35	0.39	0.44	0.47
0.082	0.07	0.12	0.16	0.21	0.26	0.30	0.35	0.39	0.43	0.48
0.087	0.07	0.12	0.16	0.21	0.26	0.30	0.34	0.39	0.44	0.49
0.092	0.07	0.12	0.16	0.21	0.25	0.30	0.34	0.38	0.43	0.48
0.097	0.07	0.11	0.16	0.21	0.25	0.30	0.34	0.38	0.43	0.47
0.102	0.07	0.11	0.16	0.21	0.25	0.30	0.34	0.38	0.43	0.47
0.107	0.06	0.11	0.16	0.21	0.24	0.29	0.34	0.38	0.42	0.47
0.112	0.06	0.11	0.15	0.20	0.24	0.29	0.33	0.39	0.43	0.47
0.117	0.06	0.11	0.16	0.20	0.24	0.29	0.33	0.38	0.42	0.47
0.122	0.06	0.11	0.15	0.20	0.25	0.29	0.33	0.37	0.42	0.46
0.127	0.06	0.11	0.15	0.20	0.24	0.29	0.33	0.37	0.42	0.46
0.132	0.06	0.11	0.15	0.20	0.25	0.28	0.33	0.37	0.42	0.46
0.137	0.06	0.11	0.15	0.20	0.24	0.28	0.32	0.37	0.42	0.47
0.142	0.06	0.11	0.15	0.19	0.24	0.28	0.32	0.37	0.42	0.46
0.147	0.06	0.10	0.15	0.19	0.24	0.28	0.33	0.37	0.41	0.47
0.152	0.06	0.10	0.13	0.18	0.25	0.28	0.29	0.35	0.42	0.46

Table 41: Relative average yield over 100 years of managed fishing simulations at different levels of SSB_{Cease}, the biomass at which fishing is reduced to zero, (columns) and target fishing mortality (rows). Growth followed Beverton-Holt dynamics.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.16	0.15	0.16	0.15	0.16	0.15	0.15	0.16	0.16	0.18
0.007	0.35	0.35	0.35	0.34	0.35	0.35	0.35	0.34	0.33	0.31
0.012	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.48	0.47	0.44
0.017	0.63	0.62	0.62	0.62	0.61	0.61	0.61	0.59	0.57	0.52
0.022	0.70	0.71	0.70	0.70	0.70	0.69	0.68	0.64	0.61	0.56
0.027	0.77	0.78	0.77	0.77	0.77	0.74	0.72	0.67	0.62	0.58
0.032	0.81	0.83	0.82	0.81	0.79	0.76	0.72	0.67	0.64	0.60
0.037	0.86	0.86	0.86	0.84	0.82	0.77	0.73	0.70	0.67	0.62
0.042	0.90	0.89	0.87	0.86	0.82	0.77	0.74	0.72	0.67	0.60
0.047	0.89	0.90	0.90	0.86	0.84	0.79	0.74	0.73	0.68	0.65
0.052	0.93	0.91	0.91	0.85	0.82	0.80	0.77	0.73	0.68	0.68
0.057	0.94	0.92	0.88	0.87	0.84	0.81	0.76	0.73	0.69	0.62
0.062	0.95	0.93	0.90	0.86	0.82	0.82	0.77	0.73	0.69	0.65
0.067	0.95	0.92	0.90	0.86	0.84	0.79	0.77	0.74	0.69	0.64
0.072	0.97	0.92	0.89	0.87	0.83	0.80	0.77	0.75	0.70	0.67
0.077	0.95	0.92	0.88	0.86	0.84	0.82	0.79	0.74	0.73	0.71
0.082	0.96	0.92	0.88	0.86	0.85	0.81	0.78	0.74	0.72	0.66
0.087	0.94	0.91	0.88	0.87	0.84	0.82	0.78	0.75	0.71	0.63
0.092	0.95	0.92	0.88	0.87	0.84	0.83	0.79	0.75	0.70	0.69
0.097	0.92	0.92	0.89	0.86	0.82	0.81	0.79	0.75	0.71	0.67
0.102	0.91	0.91	0.89	0.88	0.85	0.81	0.79	0.76	0.72	0.68
0.107	0.94	0.91	0.88	0.85	0.84	0.80	0.78	0.76	0.72	0.70
0.112	0.92	0.91	0.88	0.87	0.85	0.82	0.78	0.75	0.71	0.69
0.117	0.95	0.91	0.90	0.86	0.84	0.81	0.79	0.76	0.73	0.67
0.122	0.94	0.90	0.88	0.84	0.85	0.85	0.80	0.77	0.71	0.65
0.127	0.90	0.90	0.88	0.87	0.85	0.82	0.79	0.77	0.72	0.66
0.132	0.90	0.89	0.88	0.87	0.84	0.82	0.79	0.77	0.71	0.70
0.137	0.92	0.90	0.89	0.86	0.85	0.83	0.79	0.76	0.73	0.72
0.142	0.91	0.90	0.90	0.87	0.85	0.81	0.79	0.77	0.73	0.69
0.147	0.90	0.89	0.90	0.86	0.85	0.82	0.79	0.76	0.74	0.68
0.152	1.00	0.89	0.86	0.83	0.76	0.82	0.74	0.74	0.70	0.67

Table 42: Relative average yield over 1000 years of fishing simulations at different levels of SSB_{Cease}, the biomass at which fishing is reduced to zero, (columns) and target fishing mortality (rows). Growth followed Beverton-Holt dynamics.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.46	0.46	0.48	0.47	0.47	0.46	0.46	0.47	0.46	0.52
0.007	0.80	0.81	0.79	0.81	0.80	0.80	0.78	0.78	0.76	0.72
0.012	0.92	0.88	0.87	0.90	0.94	0.90	0.93	0.88	0.87	0.85
0.017	0.80	0.81	0.83	0.86	0.86	0.96	0.88	0.91	0.85	0.91
0.022	0.75	0.81	0.82	0.85	0.89	0.90	0.96	0.89	0.90	0.91
0.027	0.70	0.69	0.78	0.86	0.87	0.93	0.92	0.93	0.90	0.88
0.032	0.56	0.74	0.75	0.82	0.86	0.91	0.92	0.85	0.89	0.90
0.037	0.59	0.71	0.73	0.86	0.86	0.89	0.87	0.97	0.94	0.91
0.042	0.60	0.70	0.71	0.78	0.87	0.83	0.91	0.93	0.91	0.89
0.047	0.56	0.66	0.76	0.79	0.90	0.88	0.92	0.98	0.90	0.95
0.052	0.58	0.66	0.74	0.77	0.87	0.84	0.95	0.98	0.92	0.95
0.057	0.56	0.65	0.75	0.84	0.86	0.89	0.90	0.95	0.92	0.88
0.062	0.54	0.65	0.77	0.82	0.86	0.93	0.95	0.93	0.92	0.92
0.067	0.53	0.65	0.76	0.83	0.87	0.85	0.89	0.97	0.95	0.89
0.072	0.55	0.65	0.72	0.82	0.84	0.86	0.91	0.91	0.89	0.92
0.077	0.53	0.66	0.71	0.79	0.87	0.93	0.90	0.92	0.93	0.94
0.082	0.53	0.64	0.71	0.80	0.88	0.92	0.90	0.93	0.93	0.93
0.087	0.52	0.66	0.73	0.78	0.85	0.90	0.90	0.96	0.92	0.92
0.092	0.53	0.66	0.75	0.78	0.85	0.94	0.88	0.86	0.93	0.84
0.097	0.52	0.64	0.73	0.85	0.86	0.94	0.94	0.88	0.95	1.00
0.102	0.51	0.65	0.68	0.82	0.84	0.91	0.92	0.94	0.91	0.95
0.107	0.52	0.62	0.72	0.88	0.86	0.86	0.87	0.96	0.89	0.93
0.112	0.51	0.64	0.71	0.79	0.83	0.88	0.91	0.93	0.92	0.99
0.117	0.53	0.64	0.75	0.79	0.85	0.89	0.86	0.97	0.97	0.89
0.122	0.53	0.63	0.73	0.79	0.87	0.93	0.89	0.90	0.90	0.88
0.127	0.51	0.63	0.71	0.76	0.88	0.89	0.91	0.93	0.87	0.94
0.132	0.51	0.64	0.70	0.77	0.85	0.86	0.91	0.94	0.90	0.92
0.137	0.52	0.65	0.72	0.79	0.81	0.91	0.91	0.93	0.94	0.93
0.142	0.47	0.63	0.71	0.81	0.84	0.86	0.87	0.93	0.96	0.85
0.147	0.48	0.62	0.72	0.78	0.85	0.92	0.93	0.89	0.91	0.84
0.152	0.74	0.51	0.48	0.61	0.91	0.68	0.74	0.88	0.99	0.81

Table 43: Relative average coefficient of variation in yield over 100 years of managed fishing simulations at different levels of SSB_{Cease}, the biomass at which fishing is reduced to zero, (columns) and target fishing mortality (rows). Growth followed Beverton-Holt dynamics.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.019	0.019	0.020	0.019	0.020	0.020	0.019	0.021	0.024	0.031
0.007	0.047	0.048	0.046	0.047	0.047	0.048	0.046	0.048	0.050	0.064
0.012	0.077	0.079	0.079	0.077	0.075	0.078	0.079	0.082	0.094	0.148
0.017	0.103	0.106	0.108	0.109	0.110	0.108	0.115	0.129	0.170	0.204
0.022	0.137	0.134	0.139	0.135	0.138	0.144	0.165	0.199	0.232	0.279
0.027	0.163	0.169	0.169	0.169	0.175	0.194	0.224	0.254	0.300	0.335
0.032	0.201	0.191	0.196	0.203	0.229	0.251	0.278	0.316	0.340	0.379
0.037	0.224	0.219	0.226	0.238	0.272	0.296	0.324	0.353	0.382	0.419
0.042	0.242	0.248	0.266	0.290	0.306	0.350	0.368	0.388	0.422	0.478
0.047	0.281	0.277	0.292	0.326	0.342	0.384	0.407	0.417	0.464	0.480
0.052	0.294	0.306	0.329	0.366	0.384	0.410	0.429	0.458	0.497	0.508
0.057	0.328	0.339	0.370	0.385	0.410	0.435	0.474	0.491	0.522	0.575
0.062	0.350	0.374	0.389	0.417	0.443	0.461	0.495	0.519	0.548	0.595
0.067	0.380	0.398	0.424	0.449	0.478	0.508	0.521	0.544	0.591	0.638
0.072	0.395	0.431	0.455	0.476	0.505	0.530	0.550	0.576	0.613	0.653
0.077	0.434	0.455	0.486	0.503	0.513	0.542	0.575	0.610	0.624	0.639
0.082	0.454	0.483	0.512	0.529	0.542	0.564	0.601	0.622	0.662	0.703
0.087	0.481	0.505	0.527	0.549	0.572	0.587	0.623	0.644	0.682	0.739
0.092	0.508	0.518	0.551	0.568	0.593	0.612	0.641	0.680	0.716	0.724
0.097	0.529	0.545	0.566	0.587	0.618	0.641	0.667	0.694	0.732	0.756
0.102	0.561	0.566	0.597	0.607	0.632	0.659	0.676	0.709	0.751	0.783
0.107	0.575	0.596	0.622	0.632	0.657	0.687	0.711	0.725	0.779	0.786
0.112	0.589	0.611	0.630	0.644	0.680	0.698	0.726	0.753	0.804	0.815
0.117	0.592	0.634	0.645	0.679	0.698	0.719	0.748	0.770	0.807	0.856
0.122	0.616	0.649	0.673	0.701	0.703	0.721	0.750	0.787	0.851	0.886
0.127	0.649	0.666	0.690	0.706	0.726	0.748	0.780	0.810	0.868	0.910
0.132	0.674	0.687	0.716	0.722	0.748	0.777	0.800	0.810	0.880	0.890
0.137	0.682	0.695	0.716	0.741	0.765	0.783	0.816	0.850	0.894	0.904
0.142	0.717	0.723	0.734	0.754	0.777	0.815	0.845	0.860	0.902	0.954
0.147	0.737	0.734	0.750	0.781	0.792	0.821	0.854	0.889	0.927	1.000
0.152	0.627	0.777	0.821	0.821	0.817	0.861	0.902	0.880	0.973	0.973

Table 44: Relative average coefficient of variation in yield over 1000 years of fishing simulations at different levels of SSB_{Cease}, the biomass at which fishing is reduced to zero, (columns) and target fishing mortality (rows). Growth followed Beverton-Holt dynamics.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.020	0.020	0.020	0.019	0.021	0.018	0.019	0.023	0.029	0.059
0.007	0.045	0.045	0.046	0.044	0.047	0.049	0.055	0.068	0.092	0.123
0.012	0.082	0.093	0.097	0.087	0.085	0.105	0.108	0.132	0.147	0.180
0.017	0.172	0.153	0.148	0.152	0.162	0.144	0.173	0.167	0.211	0.215
0.022	0.210	0.191	0.201	0.199	0.187	0.194	0.191	0.223	0.230	0.261
0.027	0.267	0.271	0.241	0.224	0.224	0.218	0.246	0.245	0.277	0.276
0.032	0.389	0.282	0.279	0.263	0.249	0.251	0.266	0.292	0.295	0.308
0.037	0.406	0.318	0.319	0.273	0.284	0.284	0.303	0.295	0.304	0.332
0.042	0.407	0.361	0.356	0.323	0.308	0.330	0.316	0.317	0.332	0.366
0.047	0.485	0.394	0.352	0.341	0.309	0.340	0.338	0.327	0.371	0.355
0.052	0.470	0.418	0.375	0.377	0.339	0.375	0.349	0.343	0.384	0.376
0.057	0.533	0.452	0.385	0.364	0.364	0.375	0.384	0.372	0.389	0.424
0.062	0.579	0.474	0.395	0.398	0.391	0.381	0.379	0.390	0.402	0.442
0.067	0.609	0.475	0.428	0.395	0.404	0.415	0.416	0.394	0.434	0.463
0.072	0.617	0.506	0.476	0.437	0.438	0.442	0.431	0.441	0.440	0.459
0.077	0.650	0.518	0.480	0.454	0.424	0.433	0.439	0.456	0.457	0.502
0.082	0.671	0.543	0.507	0.474	0.443	0.441	0.462	0.459	0.479	0.491
0.087	0.728	0.547	0.503	0.500	0.473	0.479	0.487	0.469	0.481	0.507
0.092	0.709	0.561	0.519	0.506	0.486	0.452	0.503	0.511	0.496	0.527
0.097	0.729	0.606	0.541	0.473	0.490	0.476	0.492	0.530	0.504	0.534
0.102	0.789	0.603	0.587	0.513	0.520	0.496	0.500	0.523	0.521	0.550
0.107	0.798	0.644	0.583	0.492	0.529	0.544	0.555	0.507	0.558	0.549
0.112	0.813	0.656	0.596	0.554	0.556	0.530	0.536	0.531	0.569	0.564
0.117	0.798	0.669	0.585	0.575	0.549	0.540	0.580	0.542	0.561	0.619
0.122	0.804	0.684	0.610	0.563	0.542	0.551	0.583	0.575	0.592	0.613
0.127	0.877	0.711	0.648	0.624	0.559	0.561	0.587	0.577	0.630	0.613
0.132	0.869	0.717	0.658	0.631	0.579	0.604	0.569	0.587	0.606	0.627
0.137	0.865	0.715	0.654	0.615	0.610	0.587	0.596	0.603	0.611	0.648
0.142	0.996	0.734	0.671	0.626	0.620	0.629	0.628	0.614	0.629	0.646
0.147	0.981	0.761	0.685	0.649	0.616	0.608	0.614	0.645	0.656	0.688
0.152	0.675	1.000	0.990	0.829	0.504	0.791	0.759	0.648	0.645	0.731

Table 45: Average biomass ($\frac{S\hat{S}B}{SSB_0}$) over 100 years of fishing simulations at different levels of SSB_{Target}, the biomass at which fishing is reduced linearly, (columns) and target fishing mortality (rows). Growth followed Beverton-Holt dynamics.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	1.02	1.04	1.05	1.03	1.02	1.01	1.04	1.02	1.03	1.03
0.007	0.91	0.88	0.91	0.91	0.92	0.92	0.93	0.92	0.92	0.90
0.012	0.85	0.81	0.80	0.80	0.80	0.80	0.81	0.81	0.81	0.81
0.017	0.75	0.72	0.74	0.72	0.71	0.72	0.72	0.72	0.72	0.71
0.022	0.63	0.66	0.63	0.63	0.63	0.64	0.64	0.64	0.65	0.65
0.027	0.57	0.58	0.60	0.58	0.58	0.58	0.59	0.57	0.59	0.59
0.032	0.48	0.52	0.53	0.52	0.52	0.51	0.52	0.54	0.54	0.54
0.037	0.45	0.49	0.48	0.48	0.48	0.48	0.49	0.50	0.51	0.51
0.042	0.44	0.44	0.44	0.45	0.44	0.45	0.46	0.47	0.48	0.48
0.047	0.39	0.39	0.40	0.41	0.42	0.41	0.42	0.43	0.45	0.45
0.052	0.39	0.36	0.38	0.38	0.38	0.39	0.40	0.42	0.43	0.44
0.057	0.34	0.36	0.34	0.36	0.36	0.38	0.39	0.40	0.41	0.42
0.062	0.31	0.32	0.32	0.33	0.35	0.36	0.37	0.37	0.40	0.42
0.067	0.29	0.30	0.31	0.32	0.33	0.34	0.35	0.37	0.38	0.39
0.072	0.29	0.29	0.30	0.31	0.32	0.33	0.34	0.37	0.37	0.37
0.077	0.28	0.28	0.28	0.29	0.31	0.31	0.34	0.35	0.37	0.38
0.082	0.26	0.25	0.28	0.28	0.29	0.31	0.31	0.34	0.35	0.36
0.087	0.24	0.25	0.26	0.27	0.28	0.30	0.31	0.33	0.34	0.36
0.092	0.22	0.24	0.25	0.25	0.27	0.29	0.30	0.32	0.34	0.35
0.097	0.20	0.24	0.24	0.26	0.26	0.28	0.30	0.30	0.33	0.33
0.102	0.20	0.22	0.23	0.24	0.26	0.26	0.29	0.30	0.32	0.35
0.107	0.19	0.22	0.23	0.24	0.25	0.27	0.31	0.30	0.32	0.35
0.112	0.18	0.20	0.22	0.24	0.25	0.27	0.29	0.30	0.31	0.34
0.117	0.19	0.21	0.22	0.22	0.25	0.26	0.29	0.29	0.33	0.32
0.122	0.19	0.20	0.21	0.21	0.23	0.25	0.27	0.28	0.31	0.31
0.127	0.18	0.19	0.21	0.21	0.23	0.25	0.28	0.27	0.30	0.33
0.132	0.15	0.19	0.20	0.20	0.23	0.25	0.27	0.28	0.30	0.33
0.137	0.16	0.18	0.19	0.21	0.22	0.23	0.26	0.29	0.30	0.31
0.142	0.16	0.18	0.19	0.20	0.22	0.24	0.26	0.26	0.29	0.32
0.147	0.16	0.18	0.18	0.19	0.22	0.24	0.25	0.26	0.30	0.29

Table 46: Average biomass ($\frac{S\hat{S}B}{SSB_0}$) over 1000 years of fishing simulations at different levels of SSB_{Target}, the biomass below which fishing is reduced linearly, (columns) and target fishing mortality (rows). Growth followed Beverton-Holt dynamics.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.87	0.87	0.89	0.87	0.90	0.87	0.87	0.88	0.87	0.87
0.007	0.63	0.58	0.56	0.64	0.60	0.61	0.62	0.59	0.61	0.60
0.012	0.52	0.43	0.44	0.38	0.43	0.40	0.42	0.44	0.44	0.47
0.017	0.19	0.24	0.26	0.27	0.32	0.33	0.34	0.38	0.39	0.39
0.022	0.15	0.20	0.22	0.24	0.25	0.30	0.31	0.33	0.34	0.35
0.027	0.16	0.18	0.19	0.18	0.22	0.25	0.29	0.32	0.32	0.35
0.032	0.12	0.15	0.18	0.19	0.20	0.23	0.25	0.27	0.30	0.33
0.037	0.10	0.15	0.16	0.18	0.19	0.22	0.26	0.27	0.29	0.28
0.042	0.10	0.14	0.16	0.15	0.18	0.22	0.22	0.26	0.28	0.28
0.047	0.09	0.13	0.12	0.15	0.18	0.21	0.21	0.23	0.28	0.28
0.052	0.09	0.12	0.16	0.14	0.17	0.21	0.22	0.24	0.27	0.29
0.057	0.08	0.12	0.14	0.13	0.17	0.21	0.23	0.23	0.27	0.28
0.062	0.07	0.12	0.09	0.13	0.17	0.20	0.22	0.22	0.27	0.31
0.067	0.07	0.11	0.09	0.13	0.17	0.18	0.18	0.23	0.26	0.26
0.072	0.07	0.11	0.09	0.13	0.17	0.20	0.23	0.23	0.26	0.24
0.077	0.07	0.11	0.08	0.12	0.16	0.18	0.22	0.23	0.27	0.28
0.082	0.07	0.11	0.13	0.12	0.16	0.19	0.18	0.22	0.26	0.27
0.087	0.07	0.11	0.13	0.12	0.15	0.19	0.18	0.21	0.24	0.26
0.092	0.06	0.10	0.12	0.12	0.16	0.19	0.20	0.21	0.25	0.27
0.097	0.06	0.10	0.13	0.12	0.15	0.16	0.20	0.21	0.25	0.23
0.102	0.06	0.10	0.07	0.11	0.15	0.16	0.17	0.21	0.24	0.28
0.107	0.06	0.10	0.07	0.11	0.15	0.19	0.22	0.21	0.25	0.27
0.112	0.06	0.10	0.12	0.11	0.15	0.19	0.22	0.21	0.24	0.25
0.117	0.06	0.10	0.12	0.11	0.16	0.18	0.21	0.21	0.25	0.22
0.122	0.06	0.10	0.12	0.11	0.14	0.18	0.17	0.21	0.25	0.24
0.127	0.06	0.10	0.14	0.11	0.15	0.17	0.21	0.21	0.24	0.26
0.132	0.05	0.09	0.11	0.11	0.14	0.18	0.20	0.21	0.24	0.26
0.137	0.05	0.10	0.06	0.11	0.14	0.16	0.19	0.21	0.25	0.24
0.142	0.05	0.10	0.09	0.11	0.14	0.17	0.17	0.20	0.22	0.27
0.147	0.05	0.09	0.07	0.10	0.14	0.17	0.16	0.20	0.24	0.22

Table 47: Relative average yield over 100 years of fishing simulations at different levels of SSB_{Target}, the biomass at which fishing is reduced linearly, (columns) and target fishing mortality (rows). Growth followed Beverton-Holt dynamics.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.15	0.16	0.14	0.14	0.14	0.17	0.17	0.16	0.16	0.15
0.007	0.36	0.36	0.34	0.36	0.35	0.34	0.34	0.34	0.33	0.34
0.012	0.49	0.48	0.49	0.50	0.50	0.49	0.49	0.49	0.49	0.49
0.017	0.66	0.59	0.62	0.61	0.60	0.61	0.61	0.59	0.60	0.60
0.022	0.71	0.70	0.68	0.69	0.69	0.70	0.69	0.69	0.69	0.68
0.027	0.76	0.76	0.77	0.77	0.76	0.76	0.76	0.73	0.74	0.73
0.032	0.77	0.81	0.79	0.82	0.80	0.78	0.78	0.79	0.77	0.77
0.037	0.82	0.89	0.86	0.85	0.84	0.83	0.83	0.80	0.81	0.79
0.042	0.88	0.88	0.87	0.88	0.86	0.86	0.84	0.81	0.81	0.79
0.047	0.88	0.87	0.90	0.87	0.89	0.84	0.83	0.82	0.83	0.80
0.052	0.98	0.88	0.91	0.90	0.88	0.85	0.86	0.84	0.82	0.80
0.057	0.92	0.92	0.90	0.90	0.89	0.86	0.84	0.85	0.81	0.82
0.062	0.92	0.91	0.90	0.89	0.90	0.88	0.84	0.83	0.83	0.81
0.067	0.92	0.91	0.92	0.89	0.89	0.87	0.85	0.83	0.81	0.82
0.072	0.96	0.93	0.93	0.89	0.88	0.87	0.85	0.82	0.83	0.81
0.077	1.00	0.94	0.91	0.89	0.88	0.87	0.86	0.85	0.82	0.82
0.082	0.94	0.87	0.93	0.89	0.86	0.86	0.86	0.85	0.83	0.81
0.087	0.96	0.93	0.95	0.88	0.90	0.87	0.83	0.85	0.84	0.82
0.092	0.90	0.91	0.90	0.86	0.87	0.89	0.85	0.86	0.83	0.83
0.097	0.87	0.91	0.89	0.89	0.88	0.88	0.85	0.85	0.84	0.83
0.102	0.91	0.87	0.91	0.89	0.87	0.88	0.84	0.86	0.82	0.81
0.107	0.88	0.88	0.92	0.89	0.90	0.87	0.85	0.83	0.82	0.82
0.112	0.87	0.85	0.88	0.86	0.88	0.86	0.86	0.85	0.81	0.82
0.117	0.91	0.88	0.92	0.87	0.89	0.87	0.86	0.83	0.83	0.83
0.122	0.96	0.90	0.89	0.90	0.87	0.85	0.86	0.85	0.82	0.83
0.127	0.94	0.86	0.88	0.87	0.86	0.86	0.86	0.84	0.82	0.82
0.132	0.80	0.88	0.86	0.85	0.86	0.86	0.84	0.87	0.83	0.83
0.137	0.90	0.89	0.90	0.89	0.87	0.85	0.84	0.84	0.82	0.84
0.142	0.89	0.88	0.90	0.88	0.88	0.85	0.86	0.85	0.84	0.84
0.147	0.91	0.89	0.88	0.86	0.87	0.85	0.86	0.84	0.84	0.81

Table 48: Relative average yield over 1000 years of fishing simulations at different levels of SSB_{Target}, the biomass below which fishing is reduced linearly, (columns) and target fishing mortality (rows). Growth followed Beverton-Holt dynamics.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.26	0.24	0.24	0.23	0.23	0.26	0.26	0.26	0.25	0.25
0.007	0.42	0.44	0.40	0.46	0.43	0.42	0.43	0.41	0.43	0.43
0.012	0.63	0.48	0.52	0.45	0.50	0.48	0.50	0.49	0.46	0.48
0.017	0.34	0.38	0.42	0.42	0.46	0.47	0.46	0.48	0.45	0.48
0.022	0.31	0.40	0.44	0.43	0.40	0.50	0.47	0.41	0.46	0.47
0.027	0.42	0.46	0.38	0.41	0.40	0.40	0.49	0.46	0.41	0.47
0.032	0.35	0.35	0.37	0.41	0.36	0.42	0.39	0.43	0.45	0.47
0.037	0.28	0.38	0.35	0.42	0.35	0.40	0.39	0.44	0.43	0.46
0.042	0.36	0.38	0.33	0.37	0.38	0.41	0.41	0.40	0.44	0.42
0.047	0.26	0.38	0.32	0.37	0.37	0.39	0.43	0.41	0.44	0.45
0.052	0.31	0.32	0.37	0.36	0.40	0.41	0.39	0.41	0.41	0.42
0.057	0.30	0.33	0.31	0.36	0.35	0.40	0.40	0.42	0.42	0.46
0.062	0.29	0.31	0.31	0.36	0.38	0.42	0.43	0.43	0.45	0.46
0.067	0.25	0.30	0.34	0.41	0.39	0.38	0.38	0.43	0.41	0.44
0.072	0.27	0.31	0.31	0.42	0.40	0.39	0.40	0.40	0.43	0.45
0.077	0.33	0.35	0.33	0.35	0.39	0.42	0.37	0.41	0.42	0.42
0.082	0.27	0.31	0.30	0.35	0.35	0.39	0.39	0.41	0.42	0.45
0.087	0.27	0.36	0.34	0.36	0.34	0.39	0.40	0.42	0.43	0.44
0.092	0.28	0.28	0.33	0.34	0.35	0.41	0.40	0.41	0.44	0.44
0.097	0.27	0.33	0.31	0.35	0.33	0.40	0.41	0.43	0.44	0.44
0.102	0.21	0.32	0.29	0.34	0.36	0.40	0.38	0.41	0.40	0.44
0.107	0.25	0.36	0.35	0.33	0.35	0.40	0.41	0.43	0.39	0.44
0.112	0.25	0.32	0.32	0.31	0.35	0.39	0.41	0.43	0.41	0.44
0.117	0.29	0.28	0.32	0.33	0.40	0.41	0.40	0.42	0.42	0.42
0.122	0.28	0.35	0.32	0.35	0.34	0.41	0.37	0.41	0.42	0.42
0.127	0.28	0.34	0.36	0.32	0.36	0.37	0.40	0.42	0.39	0.42
0.132	0.25	0.32	0.28	0.31	0.33	0.38	0.39	0.41	0.41	0.42
0.137	0.24	0.37	0.31	0.36	0.36	0.40	0.38	0.42	0.40	0.45
0.142	0.27	0.36	0.26	0.33	0.34	0.36	0.36	0.43	0.40	0.46
0.147	0.27	0.30	0.27	0.37	0.31	0.38	0.39	0.40	0.43	0.43

Table 49: Relative average coefficient of variation in yield over 100 years of fishing simulations at different levels of SSB_{Target}, the biomass at which fishing is reduced linearly, (columns) and target fishing mortality (rows). Growth followed Beverton-Holt dynamics.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.020	0.019	0.019	0.018	0.020	0.020	0.020	0.020	0.019	0.020
0.007	0.045	0.051	0.052	0.047	0.047	0.047	0.045	0.048	0.047	0.049
0.012	0.077	0.075	0.078	0.078	0.077	0.080	0.075	0.077	0.079	0.079
0.017	0.111	0.107	0.103	0.109	0.105	0.109	0.109	0.106	0.111	0.110
0.022	0.151	0.138	0.137	0.137	0.143	0.136	0.138	0.141	0.145	0.146
0.027	0.168	0.158	0.166	0.168	0.168	0.178	0.173	0.178	0.187	0.194
0.032	0.211	0.205	0.193	0.195	0.206	0.204	0.214	0.217	0.226	0.229
0.037	0.226	0.216	0.222	0.215	0.231	0.228	0.247	0.263	0.271	0.276
0.042	0.232	0.243	0.257	0.260	0.265	0.271	0.289	0.303	0.307	0.327
0.047	0.296	0.277	0.283	0.286	0.287	0.327	0.319	0.332	0.345	0.358
0.052	0.292	0.321	0.305	0.308	0.330	0.353	0.363	0.380	0.389	0.399
0.057	0.326	0.330	0.348	0.349	0.363	0.374	0.406	0.410	0.425	0.413
0.062	0.348	0.384	0.379	0.385	0.386	0.411	0.425	0.439	0.441	0.456
0.067	0.387	0.406	0.396	0.412	0.407	0.430	0.447	0.465	0.480	0.482
0.072	0.390	0.454	0.412	0.438	0.460	0.469	0.474	0.504	0.495	0.504
0.077	0.406	0.433	0.453	0.465	0.476	0.491	0.505	0.529	0.541	0.542
0.082	0.456	0.483	0.475	0.501	0.512	0.517	0.532	0.538	0.553	0.557
0.087	0.483	0.467	0.491	0.529	0.529	0.542	0.562	0.558	0.571	0.577
0.092	0.514	0.545	0.535	0.551	0.571	0.562	0.573	0.591	0.586	0.603
0.097	0.548	0.558	0.553	0.550	0.577	0.575	0.594	0.599	0.605	0.623
0.102	0.607	0.554	0.568	0.591	0.571	0.586	0.629	0.621	0.646	0.656
0.107	0.603	0.602	0.574	0.606	0.618	0.624	0.639	0.655	0.673	0.672
0.112	0.626	0.623	0.598	0.643	0.639	0.658	0.658	0.667	0.694	0.691
0.117	0.586	0.646	0.626	0.652	0.650	0.652	0.696	0.695	0.704	0.701
0.122	0.618	0.627	0.651	0.664	0.679	0.684	0.700	0.712	0.725	0.717
0.127	0.629	0.670	0.680	0.704	0.690	0.705	0.715	0.718	0.747	0.746
0.132	0.717	0.687	0.715	0.709	0.721	0.728	0.744	0.733	0.743	0.766
0.137	0.718	0.681	0.699	0.717	0.719	0.728	0.756	0.758	0.793	0.765
0.142	0.704	0.719	0.723	0.742	0.751	0.763	0.769	0.765	0.791	0.784
0.147	0.742	0.728	0.758	0.738	0.782	0.775	0.780	0.796	0.799	0.828

Table 50: Relative average coefficient of variation in yield over 1000 years of fishing simulations at different levels of SSB_{Target}, the biomass below which fishing is reduced linearly, (columns) and target fishing mortality (rows). Growth followed Beverton-Holt dynamics.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.018	0.020	0.018	0.017	0.018	0.018	0.020	0.018	0.019	0.020
0.007	0.034	0.047	0.053	0.036	0.045	0.042	0.043	0.051	0.043	0.046
0.012	0.047	0.077	0.069	0.092	0.071	0.088	0.081	0.098	0.109	0.107
0.017	0.250	0.182	0.166	0.171	0.140	0.134	0.136	0.134	0.159	0.151
0.022	0.300	0.224	0.182	0.194	0.211	0.171	0.183	0.210	0.196	0.185
0.027	0.210	0.189	0.262	0.231	0.243	0.256	0.209	0.221	0.255	0.225
0.032	0.315	0.320	0.300	0.263	0.310	0.264	0.279	0.279	0.262	0.253
0.037	0.431	0.279	0.327	0.294	0.349	0.305	0.325	0.295	0.298	0.276
0.042	0.324	0.340	0.359	0.348	0.338	0.317	0.335	0.340	0.318	0.332
0.047	0.524	0.368	0.434	0.364	0.350	0.372	0.336	0.347	0.339	0.331
0.052	0.462	0.436	0.391	0.377	0.383	0.369	0.389	0.374	0.378	0.373
0.057	0.489	0.442	0.470	0.417	0.437	0.411	0.414	0.392	0.401	0.362
0.062	0.522	0.482	0.497	0.432	0.424	0.398	0.404	0.405	0.390	0.393
0.067	0.609	0.544	0.474	0.413	0.435	0.426	0.458	0.410	0.427	0.404
0.072	0.646	0.597	0.568	0.419	0.443	0.460	0.465	0.476	0.437	0.417
0.077	0.505	0.494	0.521	0.500	0.490	0.444	0.499	0.473	0.471	0.471
0.082	0.681	0.614	0.600	0.519	0.539	0.477	0.487	0.473	0.475	0.453
0.087	0.654	0.489	0.568	0.558	0.584	0.513	0.497	0.481	0.473	0.482
0.092	0.666	0.699	0.610	0.569	0.558	0.493	0.514	0.519	0.494	0.463
0.097	0.678	0.597	0.636	0.554	0.607	0.514	0.527	0.491	0.506	0.492
0.102	0.950	0.621	0.710	0.582	0.584	0.528	0.570	0.543	0.561	0.526
0.107	0.836	0.586	0.580	0.644	0.643	0.561	0.551	0.525	0.573	0.521
0.112	0.862	0.655	0.670	0.714	0.617	0.585	0.578	0.553	0.577	0.525
0.117	0.707	0.795	0.692	0.682	0.577	0.550	0.617	0.560	0.597	0.551
0.122	0.928	0.619	0.690	0.697	0.668	0.564	0.610	0.594	0.585	0.563
0.127	0.717	0.668	0.666	0.723	0.634	0.633	0.621	0.577	0.635	0.602
0.132	0.835	0.753	0.787	0.742	0.696	0.637	0.628	0.616	0.615	0.601
0.137	1.000	0.630	0.775	0.685	0.680	0.638	0.660	0.606	0.670	0.582
0.142	0.881	0.677	0.925	0.705	0.698	0.687	0.686	0.615	0.665	0.599
0.147	0.894	0.850	0.878	0.694	0.783	0.669	0.668	0.639	0.634	0.633

Table 51: Average biomass ($\frac{S\hat{S}B}{SSB_0}$) over 100 years of fishing simulations at different levels of SSB_{Cease}, the biomass at which fishing is reduced to zero, (columns) and target fishing mortality (rows). Growth followed a Tanaka curve based on estimates of ocean quahog from Long Island.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	1.04	1.04	1.04	1.05	1.04	1.03	1.01	0.97	0.51	0.55
0.007	0.94	0.94	0.94	0.94	0.94	0.94	0.92	0.90	0.58	0.56
0.012	0.84	0.85	0.86	0.85	0.86	0.85	0.83	0.81	0.73	0.57
0.017	0.78	0.79	0.77	0.78	0.78	0.78	0.75	0.72	0.65	0.56
0.022	0.71	0.71	0.72	0.70	0.71	0.71	0.68	0.67	0.65	0.58
0.027	0.66	0.66	0.66	0.66	0.67	0.65	0.64	0.64	0.62	0.60
0.032	0.60	0.62	0.61	0.62	0.61	0.61	0.62	0.59	0.61	0.61
0.037	0.57	0.57	0.58	0.57	0.58	0.58	0.57	0.58	0.59	0.60
0.042	0.54	0.53	0.53	0.54	0.54	0.55	0.56	0.55	0.57	0.58
0.047	0.51	0.49	0.50	0.50	0.50	0.51	0.52	0.53	0.56	0.58
0.052	0.47	0.47	0.48	0.49	0.48	0.50	0.51	0.52	0.55	0.57
0.057	0.45	0.45	0.45	0.45	0.46	0.48	0.50	0.51	0.54	0.57
0.062	0.40	0.42	0.42	0.43	0.44	0.46	0.49	0.51	0.53	0.56
0.067	0.41	0.40	0.41	0.41	0.43	0.45	0.48	0.49	0.52	0.56
0.072	0.38	0.38	0.39	0.39	0.41	0.44	0.46	0.49	0.52	0.54
0.077	0.36	0.37	0.37	0.38	0.40	0.43	0.45	0.48	0.51	0.53
0.082	0.34	0.35	0.36	0.38	0.40	0.42	0.45	0.48	0.51	0.54
0.087	0.33	0.33	0.35	0.36	0.39	0.41	0.44	0.47	0.50	0.54
0.092	0.32	0.32	0.33	0.36	0.37	0.41	0.43	0.46	0.49	0.52
0.097	0.30	0.31	0.33	0.34	0.37	0.41	0.43	0.46	0.49	0.53
0.102	0.30	0.30	0.31	0.34	0.36	0.39	0.43	0.45	0.49	0.52
0.107	0.28	0.29	0.31	0.33	0.36	0.39	0.42	0.45	0.48	0.52
0.112	0.28	0.28	0.29	0.32	0.35	0.38	0.42	0.45	0.48	0.50
0.117	0.27	0.27	0.29	0.32	0.35	0.38	0.41	0.45	0.49	0.51
0.122	0.26	0.27	0.28	0.31	0.35	0.38	0.41	0.44	0.47	0.51
0.127	0.24	0.26	0.28	0.31	0.34	0.37	0.41	0.44	0.47	0.51
0.132	0.24	0.24	0.27	0.30	0.33	0.37	0.40	0.44	0.48	0.49
0.137	0.24	0.24	0.28	0.30	0.33	0.36	0.40	0.43	0.47	0.49
0.142	0.22	0.24	0.26	0.29	0.33	0.37	0.40	0.43	0.47	0.50
0.147	0.22	0.23	0.26	0.29	0.33	0.36	0.39	0.43	0.46	0.50

Table 52: Average biomass ($\frac{S\hat{S}B}{SSB_0}$) over 1000 years of fishing simulations at different levels of SSB_{Cease}, the biomass at which fishing is reduced to zero, (columns) and target fishing mortality (rows). Growth followed a Tanaka curve based on estimates of ocean quahog from Long Island.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.90	0.90	0.90	0.91	0.92	0.88	0.86	0.79	0.51	0.54
0.007	0.65	0.65	0.66	0.64	0.64	0.66	0.62	0.60	0.53	0.55
0.012	0.45	0.48	0.49	0.48	0.48	0.50	0.50	0.51	0.52	0.54
0.017	0.30	0.34	0.33	0.36	0.39	0.43	0.44	0.47	0.50	0.53
0.022	0.26	0.27	0.29	0.32	0.35	0.40	0.42	0.46	0.49	0.53
0.027	0.19	0.22	0.26	0.29	0.33	0.37	0.41	0.44	0.48	0.52
0.032	0.16	0.19	0.23	0.27	0.31	0.36	0.40	0.44	0.48	0.52
0.037	0.15	0.18	0.22	0.26	0.30	0.35	0.39	0.43	0.47	0.50
0.042	0.13	0.17	0.21	0.25	0.29	0.34	0.38	0.42	0.46	0.50
0.047	0.13	0.16	0.20	0.24	0.29	0.33	0.38	0.42	0.46	0.50
0.052	0.11	0.15	0.20	0.24	0.28	0.33	0.37	0.41	0.46	0.49
0.057	0.10	0.15	0.19	0.23	0.28	0.32	0.37	0.41	0.45	0.49
0.062	0.10	0.14	0.18	0.23	0.27	0.32	0.36	0.41	0.45	0.48
0.067	0.10	0.14	0.18	0.23	0.27	0.32	0.36	0.40	0.45	0.48
0.072	0.09	0.13	0.18	0.22	0.27	0.31	0.36	0.40	0.44	0.49
0.077	0.09	0.13	0.18	0.22	0.27	0.31	0.36	0.40	0.44	0.46
0.082	0.08	0.13	0.17	0.22	0.26	0.31	0.36	0.40	0.44	0.47
0.087	0.08	0.13	0.17	0.22	0.26	0.31	0.35	0.39	0.43	0.48
0.092	0.08	0.12	0.17	0.22	0.26	0.30	0.35	0.39	0.43	0.47
0.097	0.08	0.12	0.17	0.21	0.26	0.30	0.35	0.39	0.43	0.46
0.102	0.08	0.12	0.17	0.21	0.26	0.30	0.35	0.38	0.43	0.46
0.107	0.07	0.12	0.17	0.21	0.26	0.30	0.34	0.38	0.43	0.47
0.112	0.07	0.12	0.16	0.21	0.25	0.30	0.34	0.39	0.42	0.45
0.117	0.07	0.12	0.16	0.21	0.26	0.29	0.34	0.38	0.43	0.47
0.122	0.07	0.12	0.16	0.21	0.25	0.29	0.34	0.38	0.41	0.46
0.127	0.07	0.12	0.16	0.21	0.25	0.29	0.34	0.38	0.42	0.46
0.132	0.07	0.11	0.16	0.20	0.25	0.29	0.34	0.38	0.43	0.44
0.137	0.07	0.11	0.16	0.21	0.25	0.29	0.34	0.38	0.42	0.45
0.142	0.07	0.11	0.16	0.20	0.25	0.29	0.33	0.38	0.42	0.45
0.147	0.07	0.11	0.16	0.20	0.25	0.29	0.33	0.37	0.42	0.43

Table 53: Relative average yield over 100 years of fishing simulations at different levels of SSB_{Cease}, the biomass at which fishing is reduced to zero, (columns) and target fishing mortality (rows). Growth followed a Tanaka curve based on estimates of ocean quahog from Long Island.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.11	0.12	0.12	0.11	0.11	0.12	0.12	0.12	0.12	0.12
0.007	0.25	0.26	0.26	0.26	0.26	0.25	0.25	0.23	0.22	0.21
0.012	0.39	0.39	0.39	0.39	0.39	0.39	0.38	0.36	0.33	0.27
0.017	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.45	0.39	0.31
0.022	0.57	0.57	0.57	0.57	0.57	0.57	0.54	0.52	0.47	0.36
0.027	0.64	0.64	0.64	0.64	0.64	0.63	0.60	0.57	0.49	0.41
0.032	0.69	0.69	0.70	0.70	0.69	0.67	0.67	0.57	0.54	0.48
0.037	0.74	0.74	0.74	0.74	0.74	0.72	0.66	0.61	0.56	0.48
0.042	0.78	0.78	0.78	0.78	0.76	0.75	0.70	0.61	0.57	0.49
0.047	0.82	0.80	0.82	0.80	0.77	0.74	0.69	0.61	0.58	0.53
0.052	0.85	0.84	0.85	0.84	0.81	0.76	0.71	0.65	0.61	0.55
0.057	0.88	0.87	0.88	0.84	0.81	0.76	0.72	0.65	0.60	0.55
0.062	0.86	0.89	0.88	0.86	0.80	0.76	0.74	0.66	0.60	0.59
0.067	0.92	0.91	0.90	0.86	0.81	0.77	0.74	0.66	0.59	0.60
0.072	0.91	0.91	0.91	0.86	0.82	0.78	0.72	0.66	0.60	0.59
0.077	0.92	0.93	0.91	0.85	0.84	0.76	0.73	0.71	0.63	0.57
0.082	0.93	0.94	0.92	0.89	0.83	0.78	0.75	0.69	0.63	0.59
0.087	0.97	0.93	0.94	0.88	0.84	0.80	0.73	0.69	0.64	0.56
0.092	0.96	0.95	0.91	0.91	0.80	0.80	0.72	0.66	0.61	0.56
0.097	0.97	0.96	0.92	0.88	0.86	0.82	0.74	0.68	0.63	0.59
0.102	0.98	0.96	0.93	0.87	0.86	0.80	0.74	0.68	0.63	0.59
0.107	0.96	0.97	0.94	0.89	0.85	0.80	0.75	0.68	0.62	0.61
0.112	1.00	0.95	0.90	0.89	0.83	0.79	0.74	0.69	0.66	0.60
0.117	0.99	0.96	0.91	0.88	0.84	0.80	0.74	0.68	0.64	0.57
0.122	0.99	0.98	0.90	0.89	0.87	0.80	0.72	0.69	0.64	0.60
0.127	0.99	0.95	0.94	0.88	0.87	0.82	0.74	0.70	0.63	0.62
0.132	0.98	0.92	0.91	0.88	0.84	0.80	0.74	0.73	0.63	0.61
0.137	1.00	0.93	0.95	0.89	0.86	0.81	0.75	0.72	0.61	0.61
0.142	0.99	0.96	0.92	0.88	0.86	0.83	0.76	0.71	0.67	0.61
0.147	0.99	0.94	0.92	0.89	0.86	0.82	0.72	0.69	0.64	0.60

Table 54: Relative average yield over 1000 years of fishing simulations at different levels of SSB_{Cease}, the biomass at which fishing is reduced to zero, (columns) and target fishing mortality (rows). Growth followed a Tanaka curve based on estimates of ocean quahog from Long Island.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.39	0.42	0.42	0.38	0.37	0.40	0.41	0.42	0.43	0.44
0.007	0.68	0.69	0.69	0.70	0.70	0.68	0.67	0.67	0.66	0.68
0.012	0.86	0.88	0.90	0.87	0.86	0.86	0.81	0.80	0.83	0.82
0.017	0.79	0.87	0.82	0.84	0.84	0.87	0.81	0.84	0.89	0.84
0.022	0.82	0.84	0.85	0.84	0.85	0.90	0.84	0.92	0.92	0.89
0.027	0.71	0.76	0.86	0.85	0.85	0.86	0.88	0.90	0.89	0.88
0.032	0.69	0.76	0.81	0.84	0.87	0.88	0.90	0.87	0.91	0.91
0.037	0.72	0.74	0.81	0.85	0.88	0.85	0.88	0.85	0.85	0.84
0.042	0.67	0.75	0.77	0.88	0.84	0.87	0.89	0.89	0.95	0.93
0.047	0.69	0.73	0.76	0.78	0.83	0.84	0.86	0.81	0.85	0.94
0.052	0.63	0.71	0.80	0.85	0.87	0.94	0.90	0.88	0.87	0.80
0.057	0.61	0.72	0.81	0.81	0.80	0.86	0.88	0.86	0.88	0.83
0.062	0.59	0.70	0.74	0.84	0.82	0.85	0.85	0.88	0.85	0.97
0.067	0.65	0.71	0.73	0.81	0.90	0.88	0.91	0.86	0.86	0.92
0.072	0.60	0.66	0.76	0.81	0.82	0.87	0.89	0.85	0.90	0.91
0.077	0.59	0.68	0.74	0.82	0.83	0.81	0.84	0.89	0.84	0.93
0.082	0.59	0.68	0.78	0.85	0.82	0.86	0.92	0.84	0.84	0.76
0.087	0.63	0.68	0.76	0.84	0.85	0.84	0.86	0.84	0.80	0.83
0.092	0.61	0.69	0.75	0.84	0.80	0.89	0.84	0.82	0.78	1.00
0.097	0.57	0.68	0.75	0.80	0.87	0.89	0.88	0.81	0.77	0.80
0.102	0.60	0.67	0.75	0.81	0.78	0.79	0.88	0.86	0.82	0.78
0.107	0.57	0.69	0.80	0.81	0.86	0.87	0.83	0.81	0.84	0.84
0.112	0.59	0.65	0.72	0.78	0.80	0.84	0.83	0.91	0.87	0.84
0.117	0.58	0.65	0.73	0.82	0.79	0.84	0.83	0.84	0.85	0.76
0.122	0.61	0.65	0.75	0.81	0.86	0.80	0.82	0.82	0.81	0.76
0.127	0.56	0.68	0.75	0.80	0.82	0.91	0.82	0.90	0.74	0.90
0.132	0.55	0.65	0.75	0.77	0.78	0.85	0.87	0.88	0.81	0.81
0.137	0.63	0.65	0.76	0.82	0.85	0.87	0.83	0.90	0.79	0.86
0.142	0.59	0.67	0.72	0.75	0.84	0.89	0.88	0.84	0.84	0.77
0.147	0.56	0.65	0.73	0.78	0.84	0.91	0.79	0.83	0.78	0.74

Table 55: Relative average coefficient of variation in yield over 100 years of fishing simulations at different levels of SSB_{Cease}, the biomass at which fishing is reduced to zero, (columns) and target fishing mortality (rows). Growth followed a Tanaka curve based on estimates of ocean quahog from Long Island.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.016	0.017	0.017	0.016	0.015	0.018	0.021	0.029	0.212	0.273
0.007	0.043	0.042	0.041	0.042	0.043	0.042	0.046	0.055	0.104	0.148
0.012	0.070	0.067	0.067	0.065	0.068	0.070	0.074	0.084	0.123	0.172
0.017	0.093	0.093	0.096	0.094	0.093	0.093	0.109	0.128	0.179	0.261
0.022	0.119	0.118	0.113	0.119	0.120	0.121	0.141	0.164	0.212	0.306
0.027	0.145	0.144	0.138	0.142	0.138	0.147	0.174	0.215	0.280	0.371
0.032	0.171	0.163	0.166	0.160	0.162	0.177	0.199	0.275	0.318	0.401
0.037	0.184	0.182	0.181	0.182	0.189	0.210	0.267	0.316	0.359	0.456
0.042	0.203	0.208	0.205	0.203	0.222	0.243	0.295	0.364	0.392	0.468
0.047	0.208	0.228	0.228	0.230	0.260	0.297	0.339	0.420	0.436	0.491
0.052	0.242	0.242	0.241	0.244	0.276	0.317	0.363	0.426	0.473	0.557
0.057	0.257	0.261	0.258	0.284	0.322	0.365	0.398	0.468	0.503	0.566
0.062	0.293	0.284	0.286	0.306	0.357	0.401	0.416	0.479	0.533	0.561
0.067	0.284	0.299	0.308	0.330	0.374	0.403	0.438	0.512	0.568	0.608
0.072	0.317	0.318	0.320	0.379	0.411	0.438	0.487	0.549	0.600	0.618
0.077	0.340	0.335	0.354	0.391	0.427	0.476	0.507	0.534	0.618	0.648
0.082	0.355	0.353	0.373	0.397	0.448	0.500	0.511	0.575	0.637	0.655
0.087	0.370	0.382	0.391	0.433	0.460	0.509	0.543	0.602	0.663	0.730
0.092	0.376	0.391	0.430	0.430	0.507	0.521	0.599	0.654	0.698	0.706
0.097	0.395	0.413	0.438	0.475	0.498	0.526	0.602	0.664	0.702	0.759
0.102	0.412	0.423	0.453	0.502	0.536	0.572	0.610	0.677	0.718	0.812
0.107	0.442	0.441	0.467	0.507	0.536	0.586	0.644	0.711	0.756	0.783
0.112	0.432	0.470	0.513	0.533	0.579	0.622	0.664	0.719	0.767	0.823
0.117	0.464	0.480	0.536	0.556	0.583	0.620	0.690	0.730	0.793	0.905
0.122	0.469	0.492	0.528	0.557	0.582	0.651	0.720	0.753	0.818	0.864
0.127	0.496	0.521	0.533	0.590	0.610	0.643	0.735	0.761	0.839	0.837
0.132	0.512	0.557	0.577	0.603	0.639	0.685	0.729	0.770	0.886	0.928
0.137	0.501	0.569	0.563	0.612	0.640	0.697	0.760	0.797	0.930	0.940
0.142	0.535	0.561	0.595	0.636	0.648	0.697	0.764	0.831	0.870	0.960
0.147	0.543	0.590	0.616	0.641	0.670	0.710	0.804	0.854	0.925	1.000

Table 56: Relative average coefficient of variation in yield over 1000 years of fishing simulations at different levels of SSB_{Cease}, the biomass at which fishing is reduced to zero, (columns) and target fishing mortality (rows). Growth followed a Tanaka curve based on estimates of ocean quahog from Long Island.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.022	0.021	0.023	0.022	0.020	0.024	0.026	0.046	0.163	0.193
0.007	0.055	0.056	0.055	0.057	0.055	0.057	0.083	0.109	0.160	0.170
0.012	0.102	0.094	0.091	0.102	0.103	0.113	0.139	0.177	0.180	0.196
0.017	0.193	0.156	0.169	0.161	0.181	0.186	0.211	0.221	0.223	0.271
0.022	0.221	0.207	0.205	0.216	0.221	0.217	0.252	0.244	0.270	0.302
0.027	0.311	0.292	0.239	0.250	0.260	0.271	0.278	0.290	0.311	0.346
0.032	0.362	0.328	0.307	0.288	0.286	0.302	0.304	0.328	0.327	0.352
0.037	0.382	0.372	0.337	0.318	0.325	0.335	0.339	0.364	0.390	0.447
0.042	0.433	0.389	0.375	0.341	0.362	0.359	0.368	0.380	0.390	0.439
0.047	0.445	0.429	0.416	0.407	0.388	0.403	0.392	0.426	0.417	0.426
0.052	0.513	0.461	0.408	0.406	0.396	0.380	0.400	0.429	0.441	0.534
0.057	0.588	0.484	0.422	0.439	0.447	0.421	0.449	0.466	0.485	0.499
0.062	0.625	0.514	0.495	0.455	0.468	0.460	0.469	0.459	0.500	0.503
0.067	0.587	0.536	0.518	0.482	0.442	0.462	0.464	0.495	0.502	0.525
0.072	0.662	0.582	0.537	0.489	0.519	0.500	0.508	0.518	0.521	0.555
0.077	0.690	0.602	0.552	0.524	0.525	0.534	0.530	0.527	0.577	0.592
0.082	0.707	0.617	0.560	0.514	0.549	0.542	0.513	0.557	0.571	0.641
0.087	0.710	0.637	0.577	0.559	0.547	0.570	0.561	0.582	0.623	0.646
0.092	0.748	0.653	0.608	0.551	0.583	0.554	0.582	0.600	0.645	0.570
0.097	0.825	0.691	0.624	0.600	0.568	0.565	0.572	0.636	0.664	0.683
0.102	0.786	0.705	0.630	0.611	0.632	0.648	0.607	0.647	0.641	0.707
0.107	0.847	0.702	0.609	0.628	0.604	0.599	0.631	0.665	0.642	0.704
0.112	0.879	0.758	0.683	0.656	0.652	0.637	0.657	0.643	0.675	0.690
0.117	0.899	0.782	0.713	0.657	0.668	0.658	0.667	0.689	0.691	0.719
0.122	0.849	0.820	0.716	0.657	0.634	0.717	0.698	0.728	0.771	0.782
0.127	0.924	0.785	0.727	0.679	0.696	0.643	0.719	0.693	0.817	0.666
0.132	0.979	0.809	0.744	0.730	0.721	0.693	0.685	0.701	0.771	0.835
0.137	0.892	0.838	0.744	0.693	0.698	0.679	0.730	0.719	0.810	0.836
0.142	0.961	0.839	0.794	0.780	0.703	0.699	0.729	0.741	0.782	0.849
0.147	1.000	0.872	0.774	0.765	0.724	0.686	0.810	0.768	0.817	0.927

Table 57: Average biomass ($\frac{S\hat{S}B}{SSB_0}$) over 100 years of fishing simulations at different levels of SSB_{Target}, the biomass at which fishing is reduced relative to target fishing mortality, (columns) and target fishing mortality (rows). Growth followed a Tanaka curve based on estimates of ocean quahog from Long Island.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	1.05	1.05	1.04	1.04	1.04	1.04	1.04	1.03	1.04	1.04
0.007	0.93	0.92	0.93	0.94	0.95	0.94	0.94	0.94	0.94	0.94
0.012	0.87	0.84	0.83	0.84	0.84	0.85	0.86	0.85	0.86	0.85
0.017	0.75	0.81	0.77	0.79	0.77	0.80	0.78	0.78	0.77	0.77
0.022	0.70	0.70	0.70	0.72	0.72	0.70	0.71	0.71	0.72	0.72
0.027	0.66	0.68	0.64	0.65	0.67	0.68	0.67	0.66	0.66	0.66
0.032	0.61	0.66	0.60	0.62	0.60	0.61	0.61	0.60	0.62	0.63
0.037	0.60	0.58	0.57	0.58	0.59	0.58	0.58	0.58	0.59	0.58
0.042	0.53	0.50	0.55	0.54	0.53	0.52	0.53	0.54	0.56	0.56
0.047	0.48	0.46	0.52	0.51	0.51	0.50	0.50	0.50	0.52	0.52
0.052	0.48	0.50	0.49	0.48	0.47	0.47	0.48	0.49	0.50	0.51
0.057	0.44	0.45	0.44	0.45	0.45	0.45	0.48	0.47	0.48	0.49
0.062	0.40	0.40	0.41	0.43	0.43	0.43	0.44	0.45	0.47	0.47
0.067	0.41	0.41	0.41	0.40	0.41	0.42	0.43	0.43	0.46	0.46
0.077	0.39	0.40	0.37	0.37	0.38	0.39	0.39	0.41	0.42	0.44
0.082	0.39	0.34	0.34	0.36	0.35	0.38	0.40	0.40	0.41	0.43
0.092	0.31	0.32	0.33	0.35	0.33	0.37	0.35	0.38	0.39	0.40
0.097	0.30	0.34	0.32	0.32	0.34	0.34	0.36	0.38	0.38	0.39
0.142	0.25	0.23	0.25	0.25	0.28	0.30	0.30	0.33	0.34	0.33

Table 58: Average biomass ($\frac{S\hat{S}B}{SSB_0}$) over 1000 years of fishing simulations at different levels of SSB_{Target}, the biomass at which fishing is reduced linearly, (columns) and target fishing mortality (rows). Growth followed a Tanaka curve based on estimates of ocean quahog from Long Island.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.890	0.900	0.920	0.900	0.920	0.890	0.910	0.900	0.900	0.900
0.007	0.680	0.650	0.620	0.630	0.680	0.660	0.670	0.660	0.630	0.670
0.012	0.480	0.510	0.430	0.460	0.500	0.460	0.490	0.500	0.510	0.500
0.017	0.300	0.380	0.300	0.330	0.330	0.370	0.380	0.410	0.420	0.430
0.022	0.260	0.270	0.250	0.280	0.300	0.320	0.330	0.350	0.380	0.400
0.027	0.160	0.210	0.200	0.240	0.280	0.280	0.320	0.320	0.350	0.370
0.032	0.150	0.220	0.200	0.220	0.240	0.260	0.290	0.310	0.340	0.340
0.037	0.130	0.170	0.180	0.210	0.220	0.240	0.280	0.290	0.310	0.330
0.042	0.120	0.150	0.170	0.200	0.200	0.230	0.260	0.280	0.320	0.330
0.047	0.120	0.140	0.170	0.190	0.200	0.230	0.240	0.250	0.280	0.320
0.052	0.110	0.140	0.170	0.170	0.190	0.230	0.210	0.260	0.290	0.310
0.057	0.100	0.140	0.140	0.160	0.190	0.220	0.250	0.240	0.280	0.290
0.062	0.090	0.130	0.140	0.150	0.180	0.200	0.240	0.240	0.260	0.310
0.067	0.100	0.130	0.150	0.150	0.170	0.200	0.220	0.230	0.270	0.270
0.077	0.090	0.130	0.120	0.130	0.170	0.190	0.210	0.230	0.260	0.270
0.082	0.090	0.120	0.110	0.140	0.160	0.200	0.230	0.230	0.260	0.290
0.092	0.070	0.120	0.130	0.140	0.160	0.200	0.190	0.230	0.260	0.280
0.097	0.070	0.120	0.130	0.130	0.170	0.190	0.220	0.230	0.250	0.270
0.142	0.070	0.100	0.080	0.120	0.150	0.190	0.170	0.240	0.250	0.230

Table 59: Relative average yield over 100 years of fishing simulations at different levels of SSB_{Target}, the biomass at which fishing is reduced relative to target fishing mortality, (columns) and target fishing mortality (rows). Growth followed a Tanaka curve based on estimates of ocean quahog from Long Island.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.10	0.11	0.11	0.10	0.11	0.11	0.10	0.11	0.11	0.11
0.007	0.23	0.25	0.24	0.25	0.24	0.24	0.24	0.25	0.25	0.24
0.012	0.36	0.35	0.36	0.37	0.37	0.37	0.37	0.37	0.37	0.37
0.017	0.47	0.47	0.47	0.47	0.46	0.46	0.46	0.46	0.46	0.46
0.022	0.52	0.53	0.53	0.53	0.54	0.53	0.54	0.54	0.54	0.54
0.027	0.61	0.61	0.59	0.60	0.60	0.60	0.61	0.60	0.60	0.59
0.032	0.66	0.66	0.65	0.65	0.65	0.66	0.66	0.65	0.65	0.64
0.037	0.71	0.69	0.69	0.71	0.70	0.69	0.70	0.69	0.69	0.68
0.042	0.74	0.72	0.74	0.75	0.74	0.72	0.73	0.73	0.69	0.71
0.047	0.75	0.73	0.77	0.76	0.77	0.75	0.75	0.74	0.74	0.71
0.052	0.82	0.81	0.81	0.80	0.79	0.78	0.79	0.77	0.75	0.75
0.057	0.82	0.82	0.81	0.81	0.81	0.80	0.81	0.77	0.75	0.75
0.062	0.78	0.80	0.82	0.85	0.84	0.82	0.79	0.79	0.77	0.74
0.067	0.85	0.85	0.85	0.84	0.83	0.83	0.82	0.77	0.78	0.77
0.077	0.92	0.93	0.86	0.85	0.86	0.85	0.82	0.80	0.77	0.77
0.082	0.95	0.87	0.85	0.87	0.84	0.84	0.83	0.81	0.78	0.78
0.092	0.90	0.89	0.92	0.94	0.88	0.87	0.82	0.79	0.78	0.78
0.097	0.88	0.97	0.92	0.90	0.88	0.83	0.82	0.83	0.79	0.79
0.142	1.00	0.90	0.94	0.88	0.89	0.85	0.85	0.82	0.78	0.79

Table 60: Relative average yield over 1000 years of fishing simulations at different levels of SSB_{Target}, the biomass at which fishing is reduced linearly, (columns) and target fishing mortality (rows). Growth followed a Tanaka curve based on estimates of ocean quahog from Long Island.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.27	0.28	0.27	0.26	0.26	0.27	0.25	0.27	0.27	0.26
0.007	0.46	0.47	0.46	0.47	0.45	0.47	0.48	0.49	0.46	0.46
0.012	0.57	0.62	0.54	0.57	0.62	0.58	0.59	0.61	0.59	0.57
0.017	0.57	0.68	0.53	0.58	0.55	0.58	0.57	0.57	0.57	0.57
0.022	0.58	0.59	0.56	0.57	0.59	0.55	0.55	0.60	0.58	0.59
0.027	0.38	0.55	0.50	0.55	0.54	0.55	0.60	0.57	0.57	0.57
0.032	0.43	0.56	0.44	0.53	0.53	0.54	0.59	0.56	0.56	0.56
0.037	0.38	0.49	0.51	0.57	0.57	0.53	0.58	0.57	0.55	0.56
0.042	0.37	0.48	0.46	0.56	0.49	0.52	0.55	0.58	0.54	0.58
0.047	0.52	0.44	0.53	0.54	0.49	0.52	0.53	0.50	0.54	0.55
0.052	0.49	0.48	0.45	0.52	0.47	0.50	0.54	0.56	0.59	0.58
0.057	0.43	0.55	0.48	0.50	0.52	0.53	0.54	0.55	0.52	0.56
0.062	0.35	0.45	0.49	0.50	0.47	0.52	0.52	0.57	0.53	0.58
0.067	0.48	0.49	0.45	0.50	0.46	0.56	0.53	0.52	0.54	0.55
0.077	0.46	0.45	0.44	0.45	0.48	0.51	0.51	0.53	0.52	0.54
0.082	0.52	0.46	0.42	0.47	0.46	0.50	0.54	0.53	0.52	0.57
0.092	0.38	0.46	0.46	0.55	0.47	0.52	0.50	0.50	0.53	0.54
0.097	0.39	0.50	0.44	0.51	0.47	0.47	0.53	0.56	0.53	0.54
0.142	0.45	0.47	0.44	0.44	0.46	0.53	0.51	0.51	0.55	0.56

Table 61: Relative average coefficient of variation in yield over 100 years of fishing simulations at different levels of SSB_{Target}, the biomass at which fishing is reduced relative to target fishing mortality, (columns) and target fishing mortality (rows). Growth followed a Tanaka curve based on estimates of ocean quahog from Long Island.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.011	0.013	0.015	0.014	0.016	0.015	0.014	0.017	0.016	0.016
0.007	0.041	0.044	0.038	0.040	0.040	0.039	0.038	0.039	0.040	0.037
0.012	0.061	0.062	0.069	0.066	0.062	0.060	0.063	0.063	0.064	0.064
0.017	0.101	0.083	0.092	0.085	0.093	0.083	0.087	0.085	0.088	0.090
0.022	0.114	0.111	0.117	0.110	0.107	0.110	0.113	0.115	0.111	0.113
0.027	0.152	0.129	0.142	0.135	0.131	0.127	0.125	0.134	0.138	0.142
0.032	0.161	0.136	0.162	0.147	0.156	0.152	0.151	0.160	0.161	0.166
0.037	0.161	0.166	0.173	0.166	0.166	0.172	0.173	0.175	0.177	0.187
0.042	0.185	0.211	0.190	0.183	0.191	0.199	0.201	0.205	0.232	0.227
0.047	0.209	0.229	0.192	0.209	0.205	0.214	0.223	0.241	0.235	0.259
0.052	0.221	0.218	0.224	0.227	0.232	0.236	0.235	0.252	0.263	0.278
0.057	0.240	0.235	0.239	0.249	0.252	0.258	0.263	0.292	0.313	0.310
0.062	0.281	0.281	0.270	0.262	0.265	0.263	0.289	0.304	0.325	0.348
0.067	0.255	0.277	0.270	0.288	0.296	0.300	0.303	0.346	0.354	0.368
0.077	0.281	0.283	0.310	0.332	0.328	0.338	0.357	0.393	0.410	0.412
0.082	0.288	0.330	0.360	0.337	0.364	0.369	0.378	0.404	0.423	0.425
0.092	0.363	0.358	0.353	0.338	0.377	0.392	0.442	0.459	0.466	0.468
0.097	0.396	0.340	0.369	0.398	0.387	0.437	0.456	0.454	0.487	0.481
0.142	0.461	0.532	0.488	0.558	0.535	0.570	0.583	0.627	0.644	0.627

Table 62: Relative average coefficient of variation in yield over 1000 years of fishing simulations at different levels of SSB_{Target}, the biomass at which fishing is reduced linearly, (columns) and target fishing mortality (rows). Growth followed a Tanaka curve based on estimates of ocean quahog from Long Island.

F_{Target}	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.002	0.030	0.025	0.024	0.023	0.024	0.025	0.023	0.023	0.025	0.025
0.007	0.053	0.062	0.069	0.067	0.062	0.061	0.053	0.060	0.067	0.065
0.012	0.115	0.101	0.114	0.122	0.097	0.124	0.116	0.109	0.123	0.133
0.017	0.211	0.160	0.243	0.176	0.205	0.196	0.208	0.204	0.211	0.214
0.022	0.234	0.234	0.237	0.232	0.224	0.257	0.277	0.249	0.266	0.257
0.027	0.463	0.334	0.363	0.294	0.322	0.344	0.270	0.323	0.320	0.322
0.032	0.450	0.327	0.441	0.351	0.361	0.363	0.340	0.354	0.343	0.362
0.037	0.543	0.464	0.419	0.359	0.366	0.423	0.384	0.390	0.398	0.416
0.042	0.635	0.450	0.518	0.415	0.467	0.449	0.432	0.427	0.464	0.416
0.047	0.452	0.548	0.463	0.441	0.514	0.484	0.498	0.525	0.472	0.482
0.052	0.555	0.599	0.559	0.501	0.562	0.534	0.499	0.481	0.473	0.496
0.057	0.671	0.487	0.561	0.570	0.557	0.548	0.539	0.539	0.574	0.530
0.062	0.781	0.638	0.576	0.600	0.612	0.568	0.590	0.540	0.575	0.533
0.067	0.602	0.585	0.680	0.614	0.670	0.573	0.596	0.612	0.587	0.588
0.077	0.774	0.766	0.713	0.711	0.667	0.638	0.655	0.627	0.651	0.643
0.082	0.672	0.706	0.774	0.742	0.722	0.681	0.644	0.662	0.664	0.628
0.092	0.938	0.761	0.754	0.642	0.765	0.697	0.720	0.749	0.714	0.676
0.097	0.880	0.733	0.854	0.730	0.799	0.818	0.738	0.697	0.748	0.686
0.142	0.883	0.918	1.000	0.993	0.962	0.873	0.926	0.960	0.892	0.831

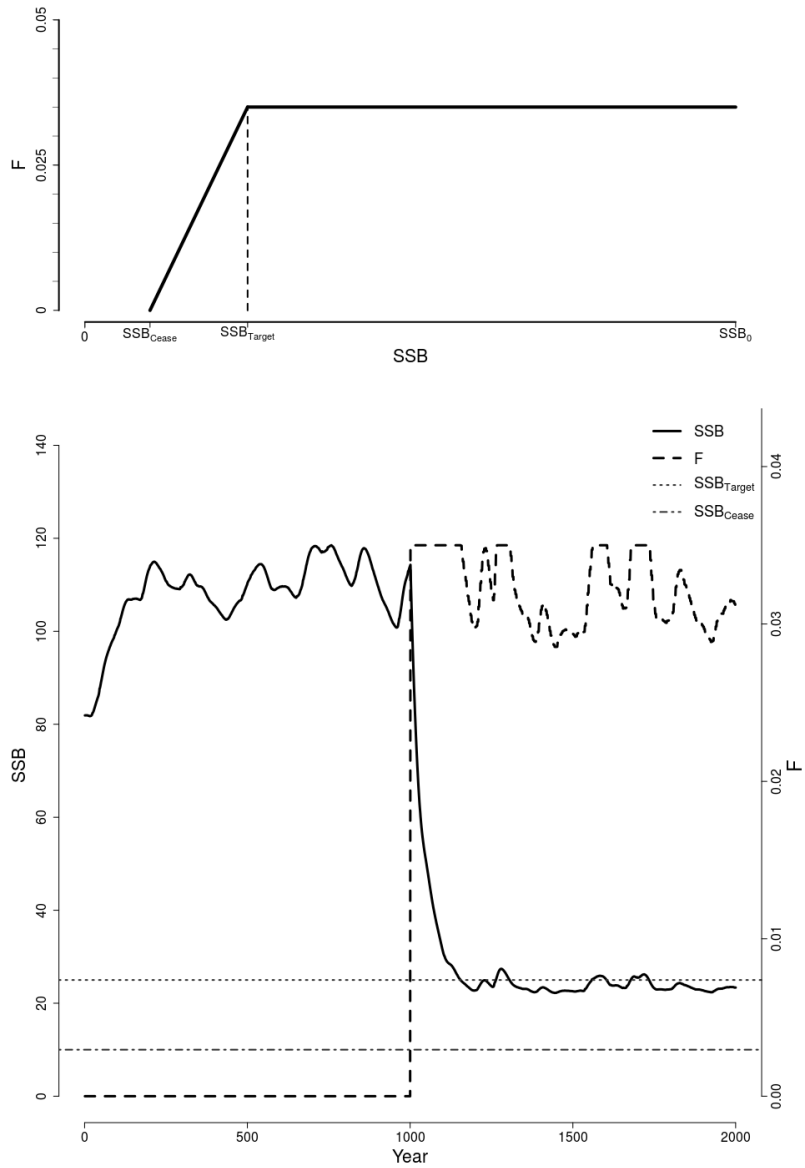

Figure 243: Control rule for ocean quahog in terms of F and SSB. Fishing mortality is constant unless SSB drops below SSB_{Target}, it then declines linearly until it reaches 0 at SSB_{Cease}. Panel (B) The control rule applied in a simulation run. Fishing mortality was constant when $SSB_t > SSB_{Target}$, and was reduced when $SSB_t < SSB_{Target}$. Simulated SSB units are arbitrary.

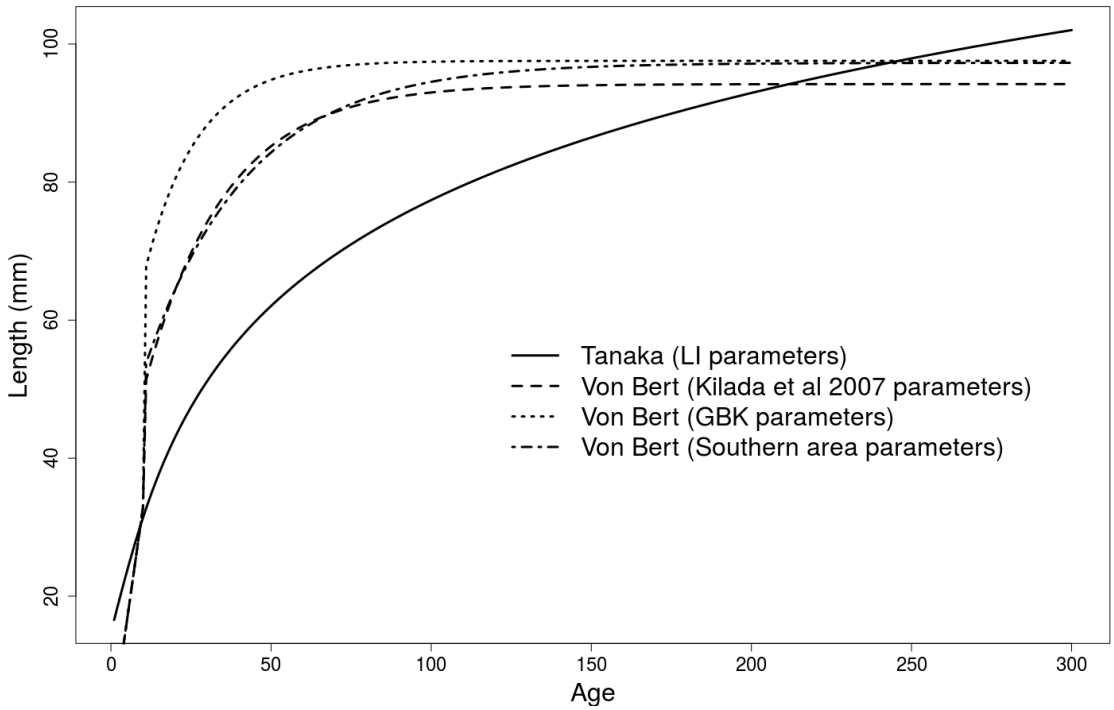

Figure 244: Tanaka growth curve compared to the Beverton-Holt growth curves used in the previous MSE analysis.

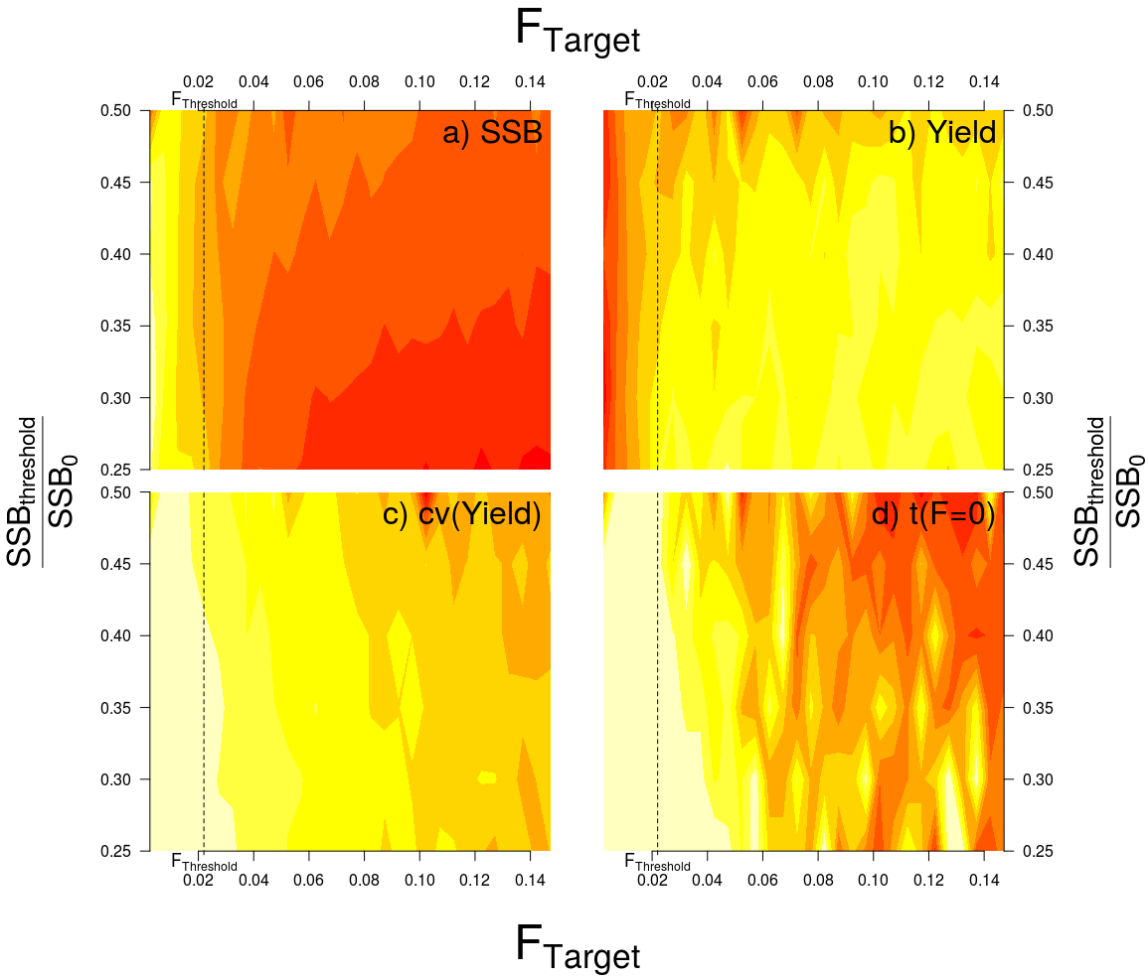

Figure 245: Contour plots showing the combined effects of F_{Target} and the fraction of SSB_0 that corresponds to the control rule threshold ($\frac{SSB_{threshold}}{SSB_0}$ over 100 years on: (a) $\frac{\overline{SSB}}{SSB_0}$, (b) $\frac{\overline{Y}}{SSB_0}$, (c) cv(Y) and (d) $t_{F=0}$. In each plot the darker colors are associated with less preferred values (*e.g.* in plot (a) the lowest $\frac{\overline{SSB}}{SSB_0}$ occurs on the right side, where F_{Target} is high, and in plot (c) the highest variation in yield occurs on the right side, where F_{Target} is high). The current $F_{Threshold}$ (0.022; Northeast Fisheries Science Center 2013) is marked with a dashed line. This plot was reproduced based on the results of Hennen (2015).

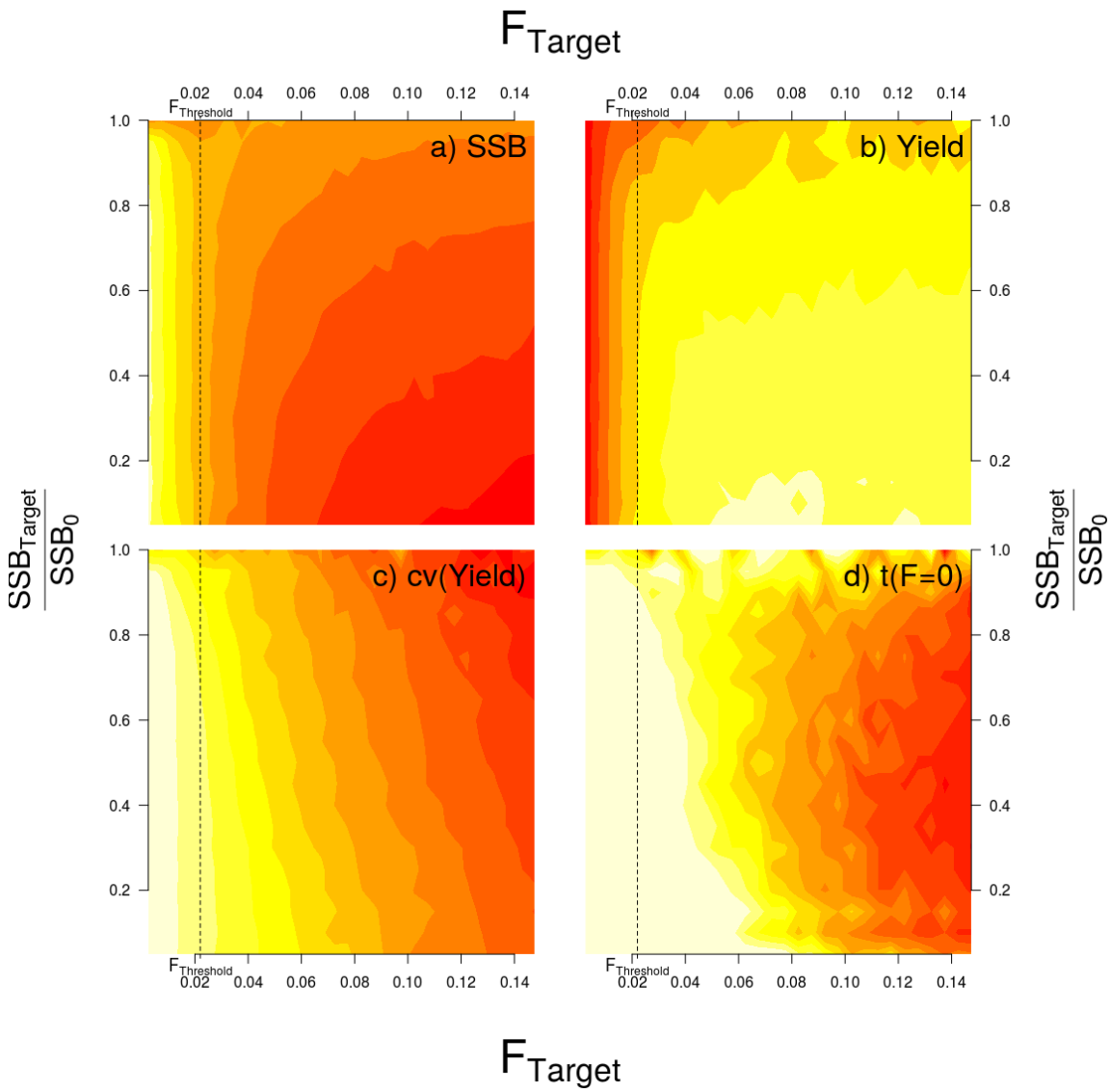

Figure 246: Contour plots showing the combined effects of F_{Target} and the fraction of SSB_0 that corresponds to the control rule target ($\frac{SSB_{Target}}{SSB_0}$ or SSB_{Target}) over 100 years on: (a) $\frac{\overline{SSB}}{SSB_0}$, (b) $\frac{\overline{Y}}{SSB_0}$, (c) cv(Y) and (d) $t_{F=0}$. In each plot the darker colors are associated with less preferred values (*e.g.* in plot (a) the lowest $\frac{\overline{SSB}}{SSB_0}$ occurs on the right side, where F_{Target} is high, and in plot (c) the highest variation in yield occurs on the right side, where F_{Target} is high). The current $F_{Threshold}$ (0.022; Northeast Fisheries Science Center 2013) is marked with a dashed line. In these simulations, a problem with the random number generator used in Hennen (2015) was corrected.

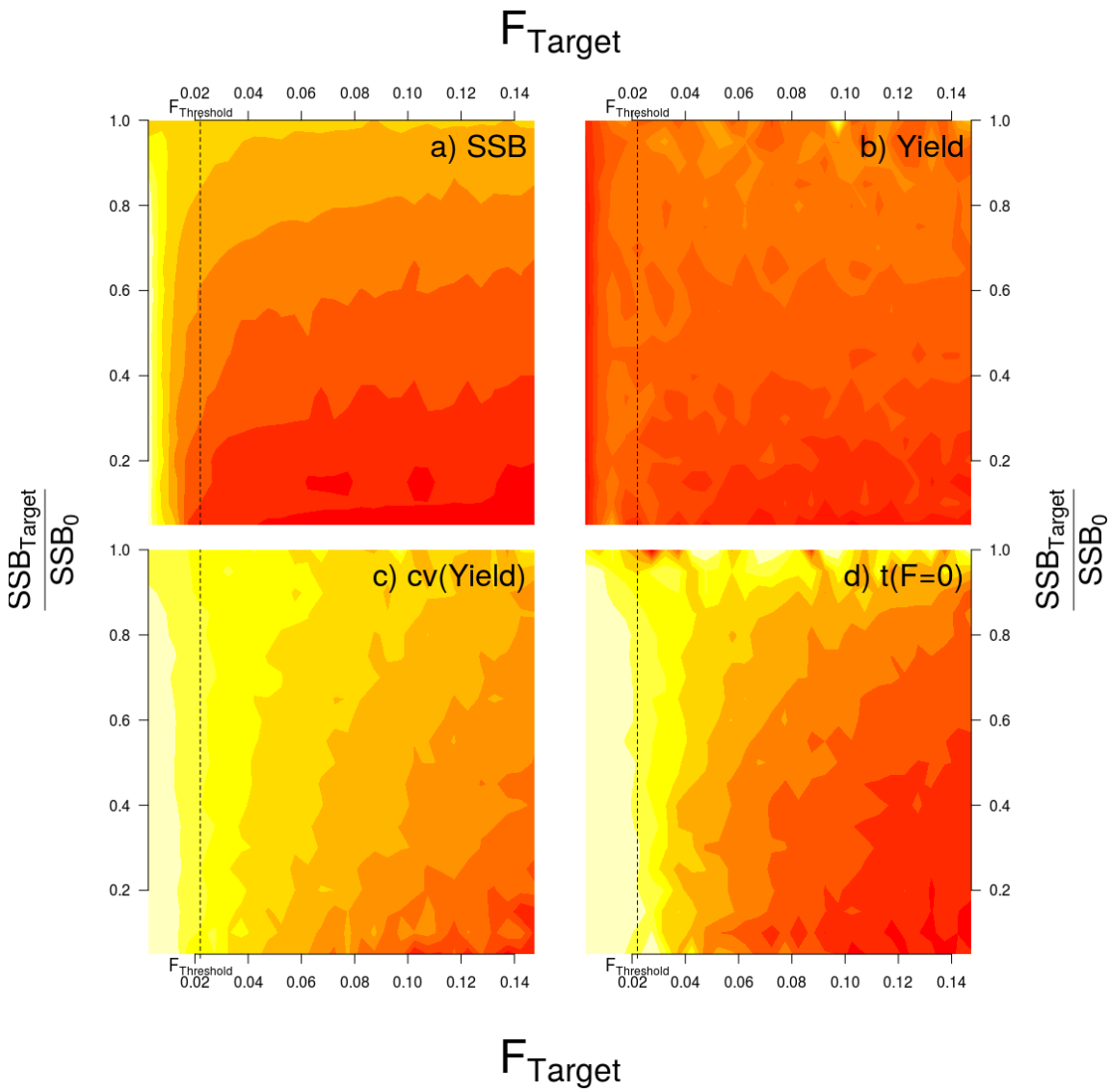

Figure 247: Contour plots showing the combined effects of F_{Target} and the fraction of SSB_0 that corresponds to the control rule target ($\frac{SSB_{Target}}{SSB_0}$ or SSB_{Target}) over 1000 years on: (a) $\frac{\overline{SSB}}{SSB_0}$, (b) $\frac{\overline{Y}}{SSB_0}$, (c) cv(Y) and (d) $t_{F=0}$. In each plot the darker colors are associated with less preferred values (*e.g.* in plot (a) the lowest $\frac{\overline{SSB}}{SSB_0}$ occurs on the right side, where F_{Target} is high, and in plot (c) the highest variation in yield occurs on the right side, where F_{Target} is high). The current $F_{Threshold}$ (0.022; Northeast Fisheries Science Center 2013) is marked with a dashed line. In these simulations, a problem with the random number generator used in Hennen (2015) was corrected.

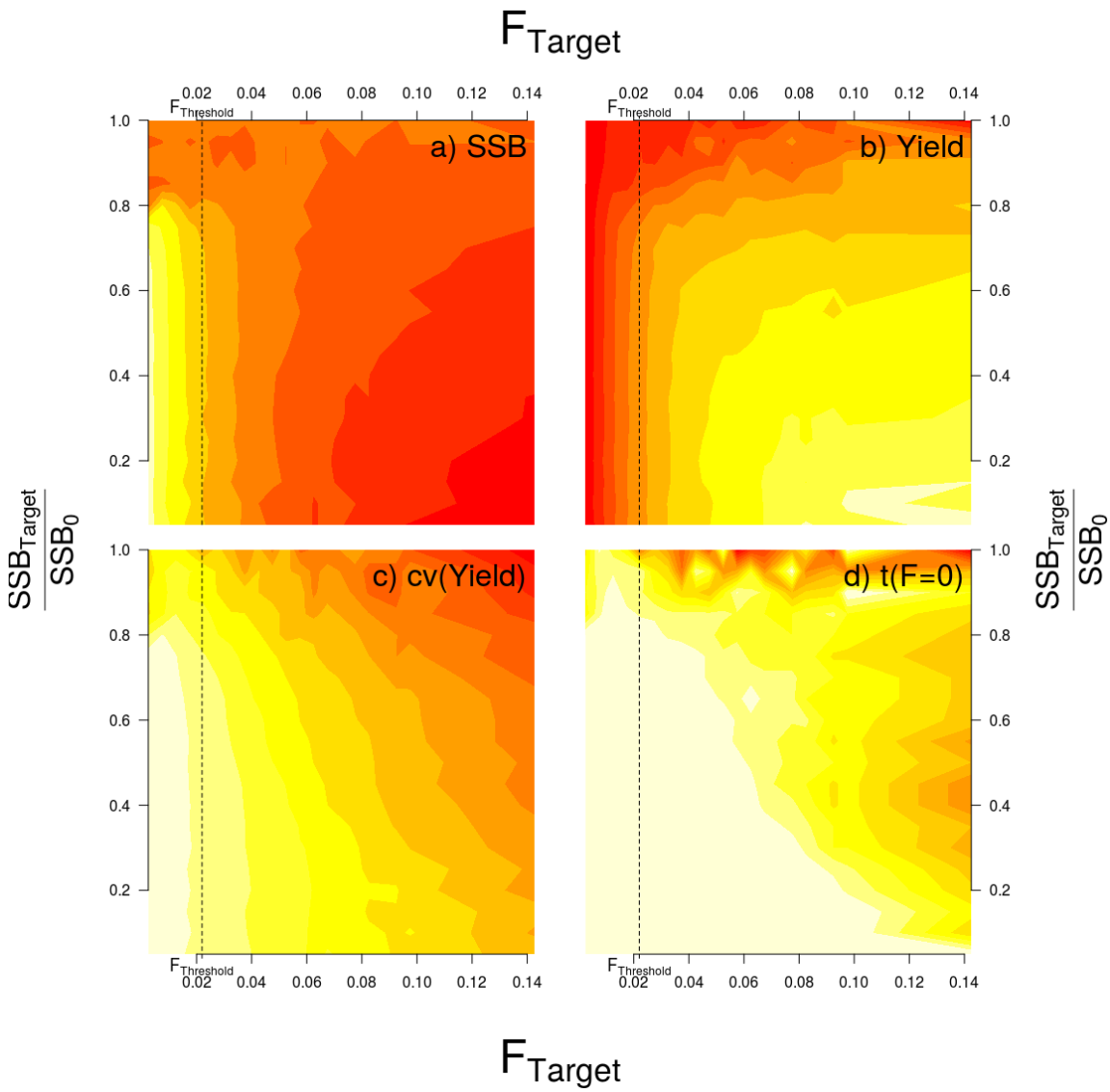

Figure 248: Contour plots showing the combined effects of F_{Target} and the fraction of SSB_0 that corresponds to the control rule target ($\frac{SSB_{Target}}{SSB_0}$ or SSB_{Target}) over 100 years on: (a) $\frac{\overline{SSB}}{SSB_0}$, (b) $\frac{\overline{Y}}{SSB_0}$, (c) cv(Y) and (d) $t_{F=0}$. In each plot the darker colors are associated with less preferred values (*e.g.* in plot (a) the lowest $\frac{\overline{SSB}}{SSB_0}$ occurs on the right side, where F_{Target} is high, and in plot (c) the highest variation in yield occurs on the right side, where F_{Target} is high). The current $F_{Threshold}$ (0.022; Northeast Fisheries Science Center 2013) is marked with a dashed line. In these simulations, the growth model used in Hennen (2015) was replaced with eq. 7.

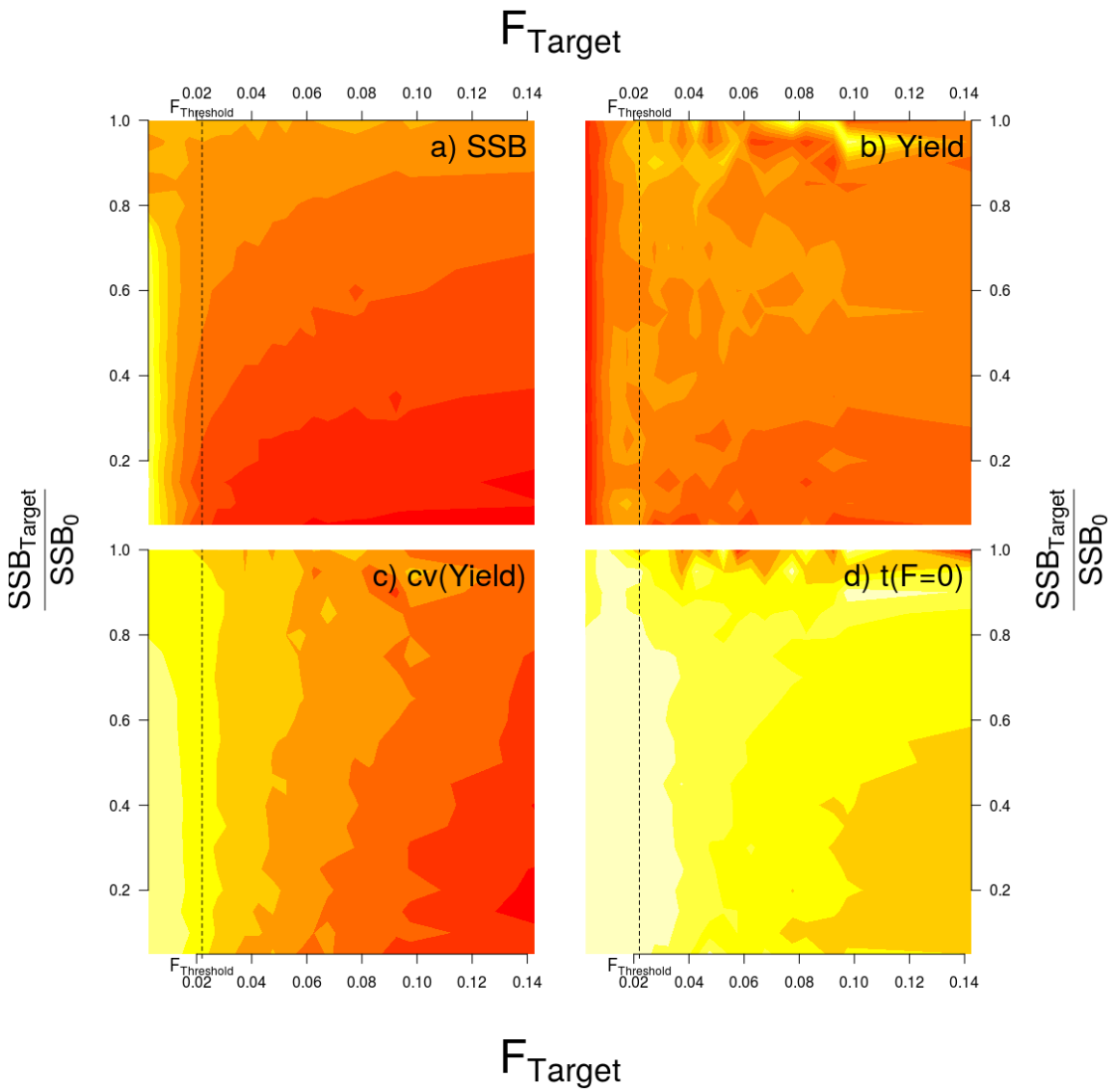

Figure 249: Contour plots showing the combined effects of F_{Target} and the fraction of SSB_0 that corresponds to the control rule target ($\frac{SSB_{Target}}{SSB_0}$ or SSB_{Target}) over 1000 years on: (a) $\frac{\overline{SSB}}{SSB_0}$, (b) $\frac{\overline{Y}}{SSB_0}$, (c) cv(Y) and (d) $t_{F=0}$. In each plot the darker colors are associated with less preferred values (*e.g.* in plot (a) the lowest $\frac{\overline{SSB}}{SSB_0}$ occurs on the right side, where F_{Target} is high, and in plot (c) the highest variation in yield occurs on the right side, where F_{Target} is high). The current $F_{Threshold}$ (0.022; Northeast Fisheries Science Center 2013) is marked with a dashed line. In these simulations, the growth model used in Hennen (2015) was replaced with eq. 7.

Appendix 9 Empirical ocean quahog assessment

Empirical estimates

Empirical biomass, fishing mortality and other estimates for ocean quahogs are based on survey data, catch data and field based estimates of size-selectivity and capture efficiency, but do not involve the SS3 or KLAMZ assessment models. However, empirical and assessment model approaches are not entirely independent because catch and survey data, size-selectivity and capture efficiency estimates used in empirical calculations were also used in stock assessment models. The primary purpose for developing empirical approaches is to check assessment model assumptions and estimates. However, empirical estimates might suffice if model based estimates were not accepted by reviewers. In summary, catch based "VPA" and minimum biomass/maximum fishing mortality calculations indicate that fishing mortality rates are low for the stock as a whole, while total stock biomass is high. Stock biomass is lower and fishing mortality rates are higher in the southern NJ and DMV regions than in GBK, SNE and LI in the north.

VPA

Empirical "VPA" estimates for ocean quahog were included in previous ocean quahog assessments (NEFSC 2009) and assume that recruitment, growth and natural mortality rates cancel so that changes in stock size are due to fishing. These assumptions are reasonable for a long-lived stock near its unfished equilibrium biomass, that is lightly exploited. VPA calculations were anchored at the average efficiency corrected swept area estimate for fishable biomass (1,361 thousand mt in the north and 1,671 thousand mt in the south) from surveys during 1997-2016 when areas were completely surveyed and relatively accurate tow distance measurements from sensor data were available. The capture efficiency estimates were means from field studies (e=0.194 during 1997-2012 and e=0.608 during 2012-2016). Fishable biomass was the sum of survey catch at length divided by survey selectivity at length (to approximate population size composition) then multiplied by fishery selectivity at size. The middle year for both regions = floor [(last year + first year) / 2] = 2006 so the averages were used as VPA biomass estimates for 2006 (B2006) and used to anchor calculations for other years. For example, the VPA biomass estimate B2007=B2006+C2006 where C2006 is catch biomass and $B_{2008} = B_{2007} + C_{2007}$ while $B_{2005} = B_{2006} - C_{2005}$ and $B_{2004} = B_{2005} - C_{2004}$. Fishing mortality rates were calculated from the ratio of catch and biomass in the same year (e.g. $F_{2006} = C_{2006}/B_{2006}$) and nearly identical to mortality rates that would have been obtained by solving the catch equation because mortality rates were low. Results indicate that fishable biomass during 1978-2016 was stable in the north while declining at an average rate of about 1% per year (range 0.5% -1.2%) in the south. Stock biomass declined by about 0.6% per year (range 0.3%-0.7%) in the stock as a whole (Figures 250-251).

Minimum swept area fishable biomass

Lower bounds for stock size and upper bounds for fishing mortality during 2012-2016 were calculated using mean fishable biomass per tow from surveys and assume that survey capture efficiency was one (so that swept area biomass estimates are smaller than true fishable biomass). Years prior to 2012 were excluded because of changes in capture efficiency and because the analysis focused on recent conditions. The data were from two surveys in the south during 2012 and 2015 and two surveys in the north (GBK) during 2013 and 2016 (Table 63). CVs for the biomass estimates were the CVs for the survey data plus 0.15 to account for uncertainty in selectivity, tow distance and stock area. Catch includes landings plus 5% for incidental mortality.

Mean minimum swept-area biomass and catch for the whole stock during 2012-2016 was estimated as the sum of the four regional estimates divided by 2 (Table 63). The variance (standard error squared) of mean whole stock biomass was the sum of the squared standard errors for the four regional estimates divided by 4. Lower bounds for the 95% confidence intervals around biomass were estimated using gamma distributions with shape and scale parameters from the point estimate, variance and method of moments. Fishing mortality was catch divided by biomass and the upper 95% bound was catch divided by the lower bound for biomass.

The lower 95% bound for whole stock fishable biomass during 2012-2016 was 1,683 thousand mt and the upper bound for whole stock F was 0.013 (Table 63). Upper bounds for the two annual F estimates ranged 0.0004-0.0005 in the north and 0.036-0.038 in the south.

Smoothed survey trends

This analysis of smoothed survey trends for ocean quahogs is based on generalized additive model (GAM) regression and mean kilograms per square meter for all size groups in surveys beginning in 1997 that covered the entire region (1997, 1999, 2002, 2008, 2011, 2013, 2016 on GBK and 1997, 1999, 2002, 2005, 2008, 2011, 2012, 2015 in the south). The change to a modified commercial dredge for survey work in 2012 was accommodated by multiplying survey catches for 2012-2016 by the ratio of mean estimated capture efficiencies in the two gears (research dredge/modified commercial dredge = 0.194/0.608 =0.319). Years prior to 1997 were not used because sensor data was not available for accurate estimation of tow distance which changed from year to year and is sensitive to depth.

The GAM used to calculate trends for the northern (GBK) and southern areas was: gam1 = gam(kgpertow2 $\sim$ te(yr) + dredge, data = d2, weights = kg2.invarwt, link = "log") where kgpertow2 is mean kg per square meter after adjusting for changes in relative capture efficiency and s() is a thin-plate smooth regression function with $\leq$ 5 degrees of freedom. The term dredge is a dummy variable that potentially accommodates differences between the old and new survey beginning in 2012, beyond the differences in swept area and estimated dredge efficiency. The term kg2.invarwt is an inverse variance weight based on the stratified random CVs for mean kg per square meter. A 95% confidence interval for the trend line (width +/- 1.96 times the point-wise standard error for the fitted curve) understates uncertainty because the variances of relative capture efficiency and gear selectivity were not included.

The dredge term was not included in final models because it was never statistically significant. The final model for GBK explained 98% of the total deviance with about 6 parameters, however the estimated trend was implausible because it was too variable to represent changes in a very long lived species like ocean quahogs with low recruitment and almost no fishing (Figure 252). The estimated trend for the southern region was nearly linear suggesting a decline of about 16% during 1997-2015 or about 0.8% per year (Figure 252).

The same modeling approach was used for individual regions in the south (4%-78% of total deviance explained using 2-3 parameters, Figure 253). Results show relatively strong declines in ocean quahog biomass in the DMV region since 1997 with mixed trends to the north.

Changes in stock distribution

The proportion of total stock biomass in the GBK, SNE, LI, NJ, and DMV regions was calculated for years in which the survey covered the entire stock (1986, 1989, 1992, 1994, 1997, 1999, 2002, 2008 and 2011 using the old survey dredge). The new survey covers half of the stock each year so 2012 (south) and 2013 (north) were combined and labeled 2012, while 2015 (south) and 2016 (north) were combined and labeled 2015. Mean catch weight per tow (kg m-2) for all size groups in each region was converted to population weight per tow using experimentally derived selectivity curves and then multiplied times the area of each region. Changes in tow distance measurements and capture efficiency were ignored because they tend to cancel out in calculating annual proportions.

Results (Figure 254) show that ocean quahog biomass has become concentrated in the northernmost GBK region since the mid-1980s, while declining in the southern NJ and DMV regions.

Table 63: Empirical lower 95% bounds for fishable ocean quahog biomass and 95% upper bounds for fishing mortality during 2012-2016 based on survey swept-area biomass assuming capture efficiency e = 1. The CV is from the survey mean weight per tow plus 15%. Confidence interval bounds are based on gamma distributions with shape and scale parameters from the method of moments. Fishing mortality for the whole stock is the average annual catch/average whole stock biomass. Biomass and catch are in units of 1000 mt. F is equal to catch/biomass, and the last two columns are biomass 95% upper bound (BLB) and F 95% upper bound (FUB).

Area	Year	Biomass	CV	Catch	F	Shape	Scale	BLB	FUB
South	2012	911	0.3	16.66	0.0183	11.47	79.45	463	0.036
GBK	2013	718	0.28	0.17	0.0002	12.44	57.71	376	0.0005
South	2015	819	0.33	14.32	0.0175	9.25	88.63	379	0.0377
GBK	2016	917	0.25	0.22	0.0002	15.73	58.27	521	0.0004
Whole stock	Mean	1683	0.15	15.68	0.0093	47.21	35.64	1237	0.0127

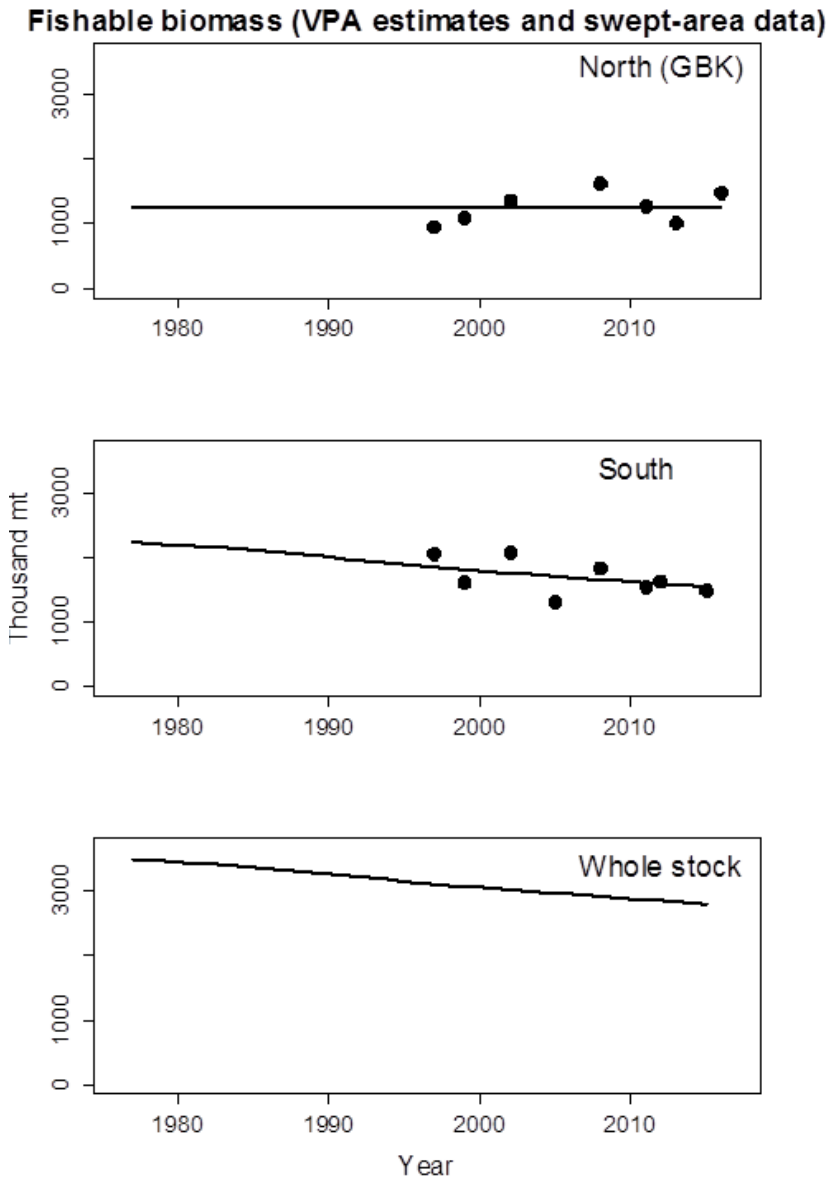

Figure 250: VPA fishable stock biomass estimates for ocean quahog during 1978-2016 with efficiency corrected swept-area biomass data from surveys during 1997-2016 in the northern and southern areas.

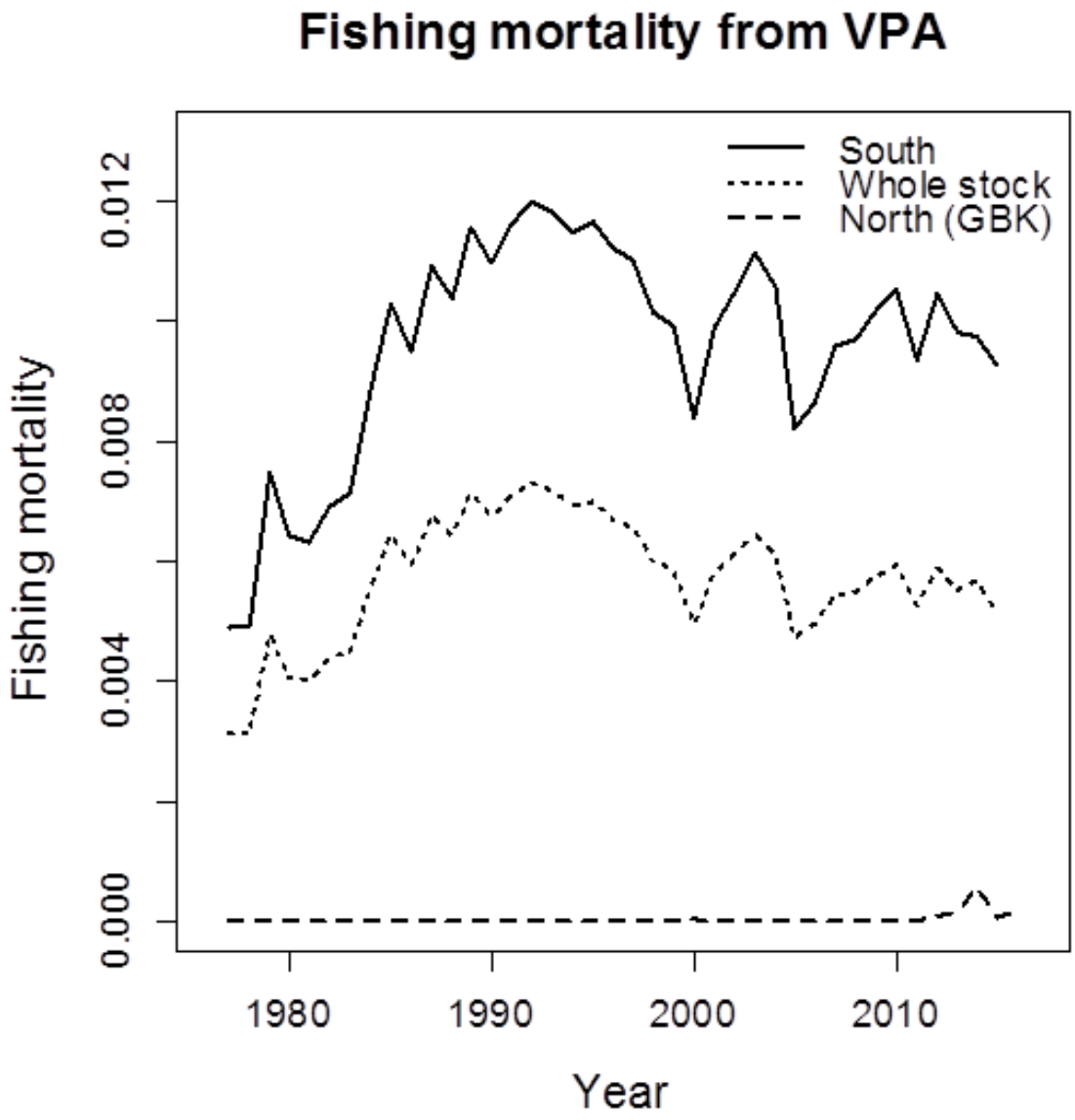

Figure 251: VPA fishing mortality estimates for ocean quahog during 1997-2016.

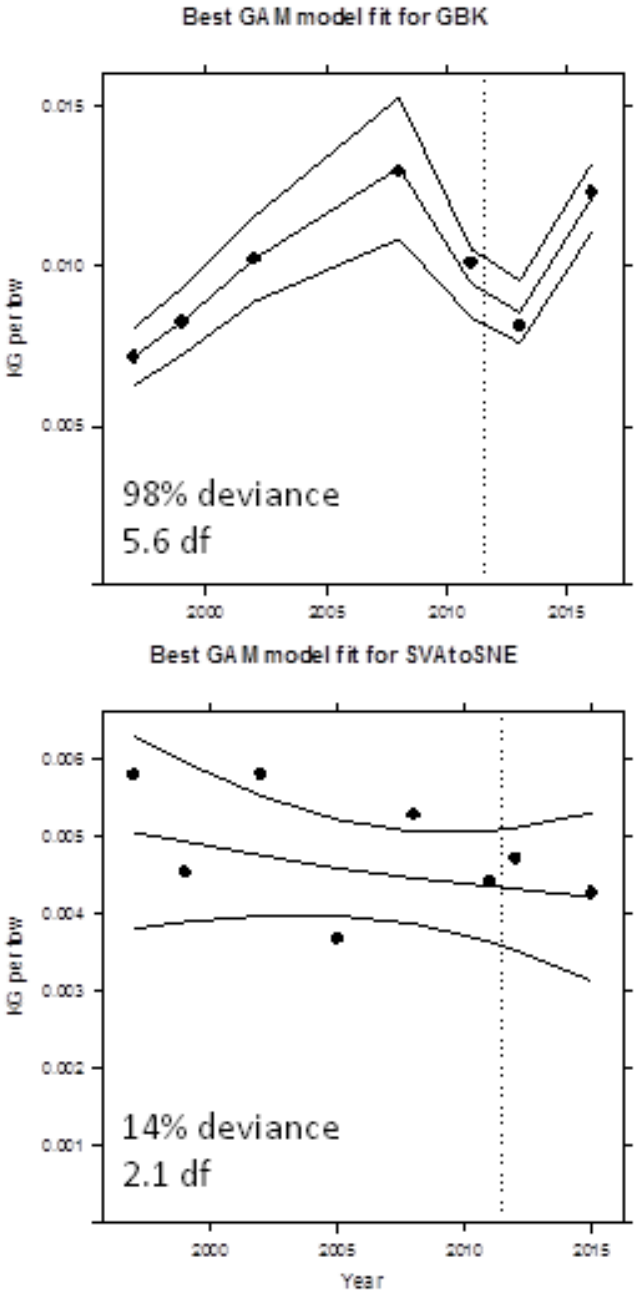

Figure 252: Smoothed survey trends for ocean quahog in the north (GBK) and south during 1997-2016 with a 95% confidence interval. The vertical line shows the introduction of a new survey dredge in 2012. Annotations give the percent of total deviance explained and effective degrees of freedom for the fitted lines.

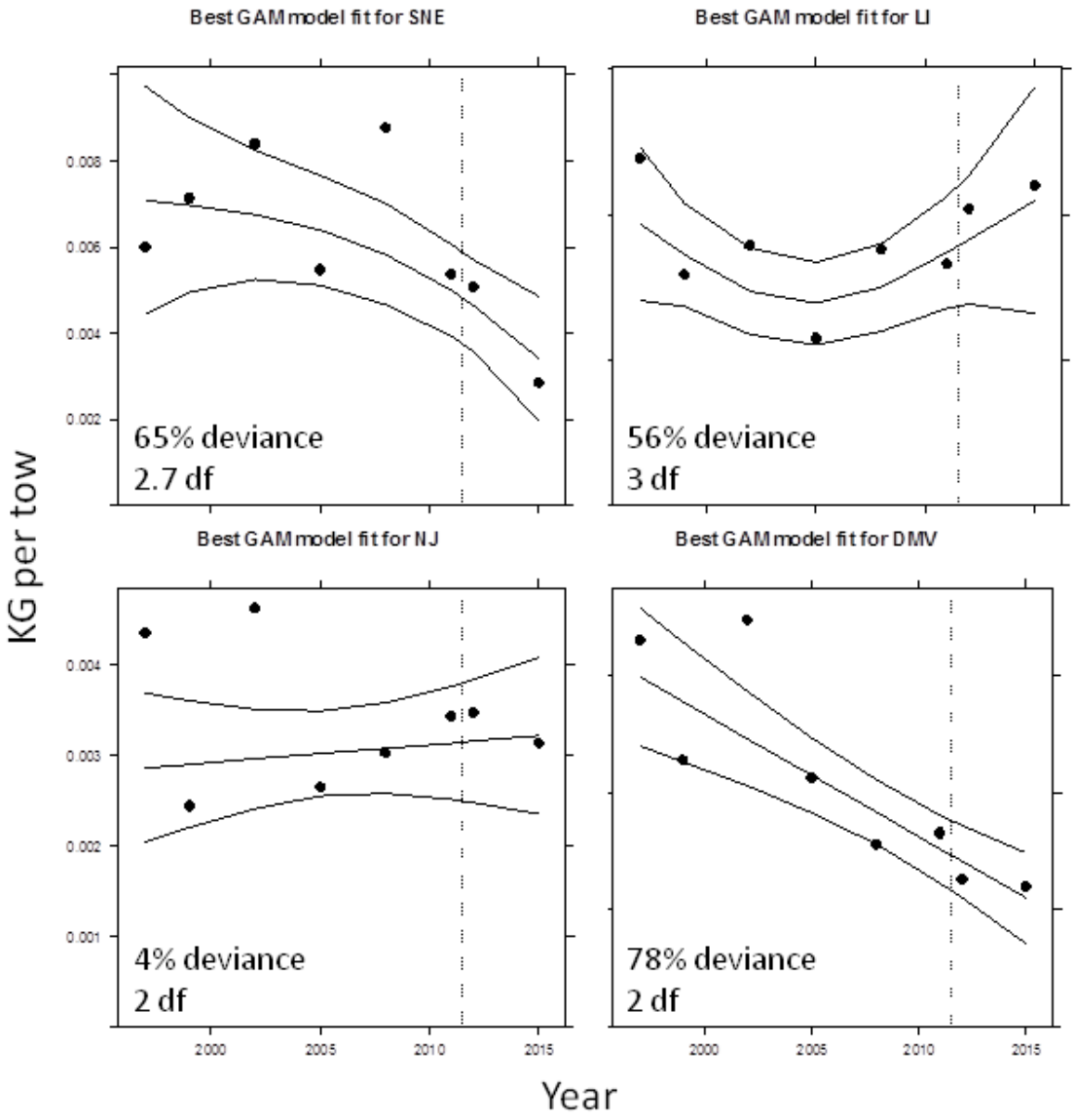

Figure 253: Smoothed survey trends for ocean quahog in the Southern New England (SNE), Long Island (LI), New Jersey (NJ) and Delmarva (DMV) regions (all part of the southern area) during 1997-2015 with a 95% confidence interval. The vertical line shows the introduction of a new survey dredge in 2012. Annotations give the percent of total deviance explained and effective degrees of freedom for the fitted lines.

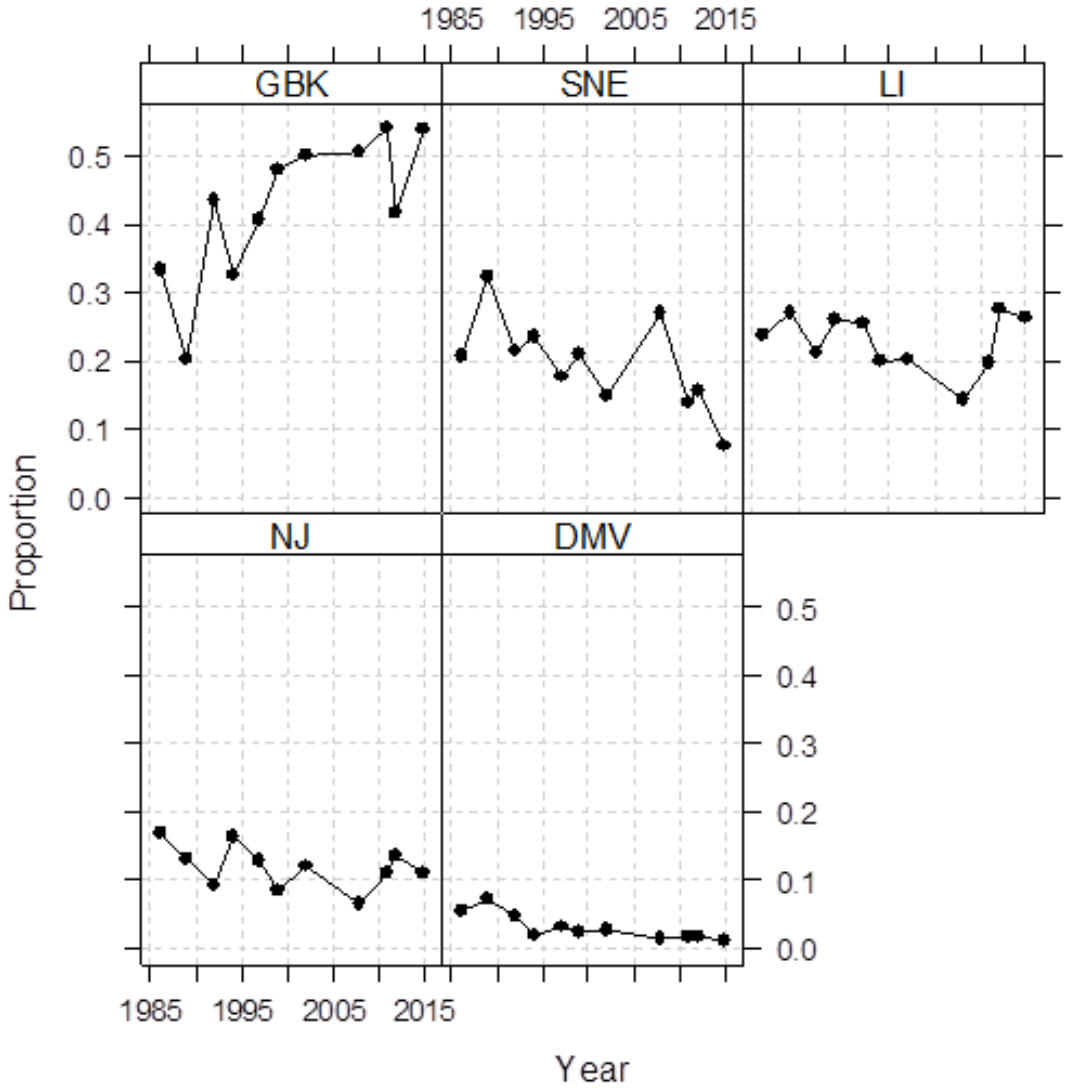

Figure 254: Proportions of total ocean quahog stock biomass in each region during 1986-2016 based on years in which the entire stock was surveyed using the old survey dredge. Data collected with the new survey dredge during 2012 (south) and 2013 (north) were combined and labeled 2012 to cover the entire stock area. Similarly, data for 2015 and 2016 were combined and labeled 2015. The estimates for a single year sum to one.

Appendix 10 Appendix to the SAW Assessment ToR

Clarification of Terms used in the SAW/SARC Terms of Reference

On "Acceptable Biological Catch" (DOC Nat. Stand. Guidel. Fed. Reg., v. 74, no. 11, 1-16-2009):

Acceptable biological catch (ABC) is a level of a stock or stock complex's annual catch that accounts for the scientific uncertainty in the estimate of [overfishing limit] OFL and any other scientific uncertainty. . . " (p. 3208) [In other words, OFL ABC.]

ABC for overfished stocks. For overfished stocks and stock complexes, a rebuilding ABC must be set to reflect the annual catch that is consistent with the schedule of fishing mortality rates in the rebuilding plan. (p. 3209)

NMFS expects that in most cases ABC will be reduced from OFL to reduce the probability that overfishing might occur in a year. (p. 3180)

ABC refers to a level of "catch" that is "acceptable" given the "biological" characteristics of the stock or stock complex. As such, [optimal yield] OY does not equate with ABC. The specification of OY is required to consider a variety of factors, including social and economic factors, and the protection of marine ecosystems, which are not part of the ABC concept. (p. 3189)

On "Vulnerability" (DOC Natl. Stand. Guidelines. Fed. Reg., v. 74, no. 11, 1-16-2009):

"Vulnerability. A stocks vulnerability is a combination of its productivity, which depends upon its life history characteristics, and its susceptibility to the fishery. Productivity refers to the capacity of the stock to produce MSY and to recover if the population is depleted, and susceptibility is the potential for the stock to be impacted by the fishery, which includes direct captures, as well as indirect impacts to the fishery (e.g., loss of habitat quality)." (p. 3205)

Participation among members of a SAW Assessment Working Group:

Anyone participating in SAW assessment working group meetings that will be running or presenting results from an assessment model is expected to supply the source code, a compiled executable, an input file with the proposed configuration, and a detailed model description in advance of the model meeting. Source code for NOAA Toolbox programs is available on request. These measures allow transparency and a fair evaluation of differences that emerge between models.

Appendix 11 Survey performance 2016

Introduction

The 2016 survey covered a portion of the stock area including the SNE and most of GBK subareas. There were 189 total tows and two selectivity tows. At least some sensor information was recorded on every tow. Therefore there were 187 standard survey tows on which sensors were deployed and sensor data was recorded.

The 2016 survey used a modified commercial dredge with 3 on board data recorders. There was an inclinometer (Star Oddi) and two (Madge Tech) pressure sensors: one in the pump manifold measuring the pressure in the hydraulic jets used to loosen the sediments around clams and one measuring the ambient pressure at fishing depth. The inclinometer measured the pitch, roll, and yaw of the dredge as it was towed and was used to determine if the dredge was in a fishing position, which was the basis for determining "time fishing" on each tow. The pressure sensors were used to make sure that the pump was achieving sufficient pressure to maintain capture efficiency.

Survey performance

Sensors deployed during the 2016 survey suggest speed over ground was slightly less than 2012, but consistent with the years since (Figure 255). Pump pressure was close to the 2012 median (Figure 255) and well within the confidence bounds observed then. Neither pump pressure nor vessel speed appeared to be less than expected based on ship board instruments during operations and the sensor data have substantial coefficients of variation. The values observed are probably well within normal operating tolerance and are probably not suggestive of changes in dredge performance.

Determination of time fishing

The determination of time fishing, the "fishing seconds" for each tow was based on a measurement of the pitch of the dredge during each second of the tow. Roll and yaw were relatively stable for the large modified commercial dredge and rarely fluctuated from baseline levels during fishing events. Pitch was recorded by an inclinometer which functioned consistently. Data from each instrument was smoothed using a 7 second moving average and then parsed for time above or below the median fishing angle for that tow.

In order to account for median pitch $> 0^o$, the determination of time fishing was based on a critical deviation from median pitch, rather than an absolute critical pitch angle. The choice of critical deviation has implications for the calculation of tow distance for each tow. When the dredge is above or below the critical deviation it is assumed to be pitched too steeply for the blade to penetrate the sediment. If the dredge is pitched within Δ_{crit} (the critical deviation) of $\tilde{\phi}_t$ (the median pitch for tow t), it assumed to be near enough to parallel to the bottom that the blade should penetrate and thus be actively fishing.

An ideal critical deviation is as close to zero as possible, but not so small that it includes poor dredge performance seconds. When the dredge is bouncing over rough terrain it is unlikely to be fishing effectively and those seconds should be excluded. There is however, a certain amount of pitch that is within fishing tolerance and a certain amount of noise in the data. If the critical deviation is too small, many seconds when the dredge is actually fishing would be excluded, which would tend to bias estimates of tow distance down. It is therefore important to find a critical deviation that is neither too small, nor too large.

The choice of Δ_{crit} was informed by an examination of the total and average tow distances based on different critical deviations. Total tow distance summed across all tow and average tow distance over all tows was compared when different values of Δ_{crit} were used. In general higher values of Δ_{crit} result in longer tows because the dredge is considered to be in fishing position for a greater proportion of the tow (Figure 256). We selected a Δ_{crit} of 4° because it produced an average tow distance that was near the nominal tow distance (0.25 nm, a value equal to the nominal tow speed 3 kt multiplied by the nominal tow time 5 min) and because it seemed reasonable based on examination of the engineering schematic of the dredge being used (*Figure not yet available*).

Time fishing during the 2016 survey was less than the nominal tow time in most cases due to the lower average tow speed discussed above (Figure 257).

Effects of depth

Depth is typically associated with longer tows due to the scope of the towing wire that must be deployed to assure good dredge performance. Additional scope requires longer retrieval times and may result in some additional time fishing while the slack in the wire is spooled up. This effect was evident (though noisy) during the 2016 survey (Figure 257).

Temperature

Temperature was recorded from the dredge and averaged over fishing seconds for all tows during the 2016 survey (Figure 258). Temperature was correlated with depth (Figure 258).

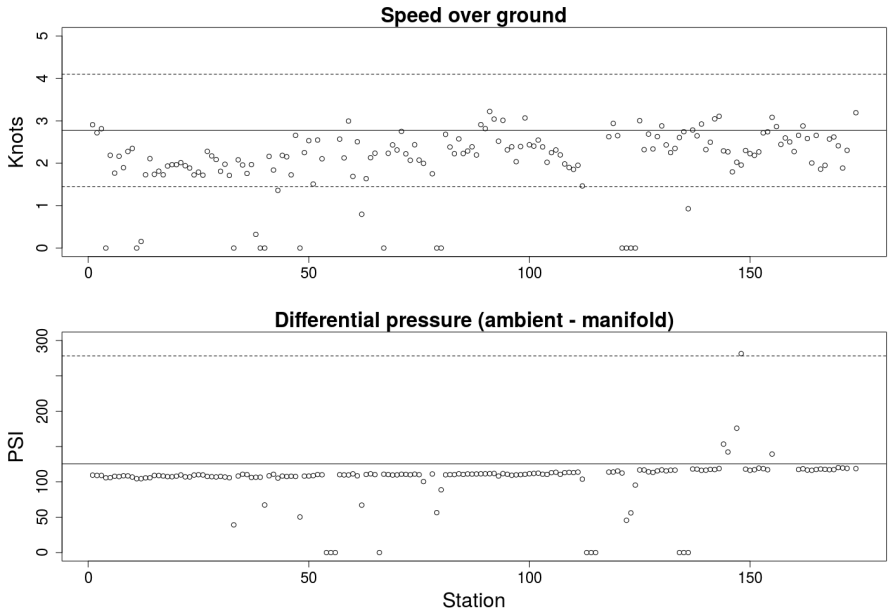

Figure 255: Speed over ground and differential pressure for each tow in the 2016 survey. The solid horizontal line is the median and the dashed horizontal lines are the 95% normal confidence bounds observed speed over ground in 2012. Differential pressure is the difference between the pressure in the dredge manifold, which indicates the absolute pressure realized by the dredges hydraulic jets, and the ambient pressure at fishing depth. The solid horizontal line is the median and the dashed horizontal lines are the 95% normal confidence bounds observed differential pressure in 2012. Instrument failure or lost data are represented by differential pressure equal to 0.

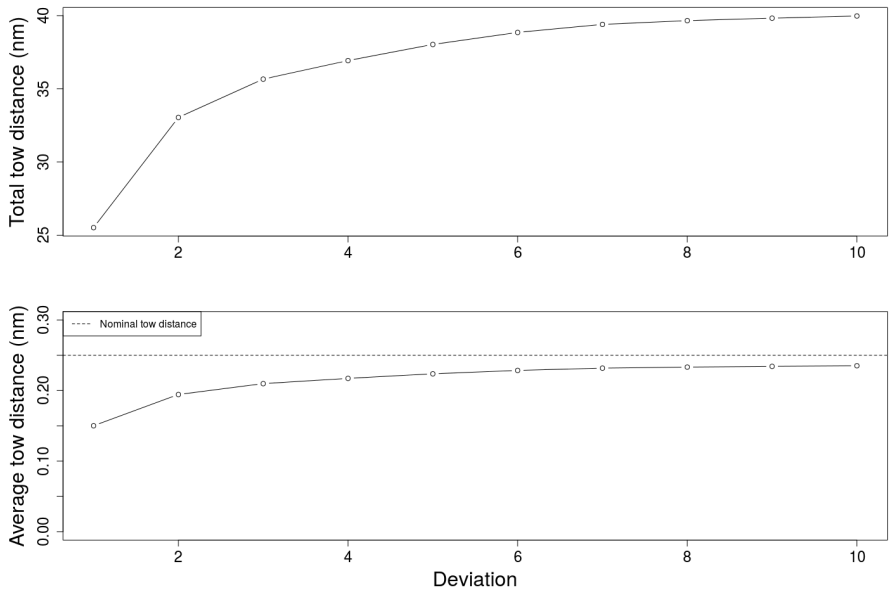

Figure 256: Average and total tow distance over all stations by critical deviation angle. The dashed line in the lower figure represents the nominal tow distance.

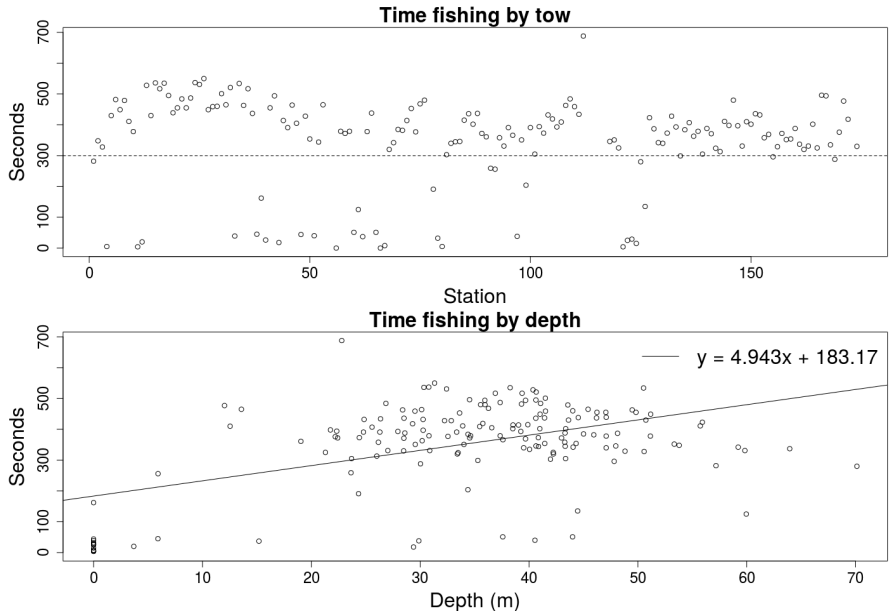

Figure 257: Time fished by station and depth. Depth significantly predicts tow time. The p value for slope was < 0.001, though the results were noisy and $R^2 < 0.14$ for the regression line shown.

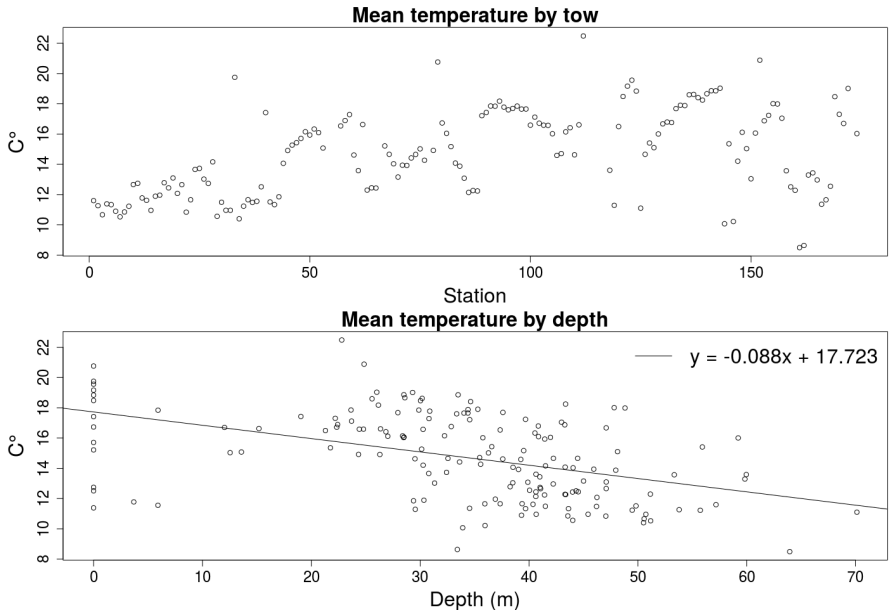

Figure 258: Temperature by station and depth. Depth significantly predicts temperature. The p value for slope was < 0.001 and $R^2 > 0.43$ for the regression line shown.

Appendix 12 Attendees and agenda from working group meetings

Meeting 1

Attendees: Larry Jacobson, Kelsey Kuykendall, Sara Pace, Chase Long, Jessica Coakley, Eric Powell, Tom Hoff, Toni Chute, Doug Potts, Bob Glenn, Dan Hennen, Tom Alspach, Dave Wallace, Jon Duquette, Vic Nordahl, Nancy McHugh.

Ocean quahog stock assessment for SAW/SARC 63 (October 17-18) and
Clam survey design (October 19-20) meetings

Clark Conference Room, NEFSC, Woods Hole, MA

-

Quahog assessment

1) Welcome, door code, introductions - Larry
2) TOR - Larry
3) Major assessment topics (VMS, new survey, MSE update, growth, reanalysis of depletion studies through 2011, and ??) - Larry
4) Management (MAFMC) update - Jessica
5) Research activities (NEFSC, academics, other agencies)
    a. Age and growth - Roger/Eric
    b. Stock-recruit? - Eric
    c. Other?
6) Commercial data (ITQ fishery) - Dan
7) Industry perspectives - Larry
8) Survey (federal) - Dan
    a. Sensor data and gear performance
    b. Trends
    c. Swept-area stock size
9) Fishery and survey (ME) – Robert/Toni

Clam survey (surfclams and ocean quahogs)

1) TOR, rights and responsibilities - Larry
2) Review (BRIEF-mostly for benefit of outsiders)
    a. Life history/distribution/fishery/management/stock status - Larry
    b. Original (brief) and current (detailed) survey operations - Vic
    c. Selectivity and depletion studies - Dan
    d. Assessment, EFH, ecosystem and other data uses – Dan/others
3) Objectives (management, assessment, ecosystem, EFH and other?) -Larry
    a. List
    b. Current problems. Objectives satisfied? Room for improvement?
4) Analyses to date
    a. Larry's work
    b. Appendix 14 in surfclam assessment - Toni
    c. Ancillary data analysis - Powell
    d. Scallop example and clam calculations - Stephen Smith
    e. Habitat suitability modeling for witch flounder - Friedland
       WEDNESDAY AT 2 PM
5) Work for next meeting - Larry

Meeting 2

Attendees: Larry Jacobson, Jessica Coakley, Eric Powell, Tom Hoff, Toni Chute, Doug Potts, Dan Hennen, Tom Alspach, Dave Wallace, Mike Bergman, Vic Nordahl.

Ocean quahog SAW Working Group & Clam Survey Working Group
Clark Conference Room, NEFSC, Woods Hole, MA
December 19-23 (Monday-Friday)
Draft Agenda

Go to front desk in main building when you first arrive to obtain parking permits make security arrangements.

Start at 1 pm on Monday and at 9 am otherwise. Finish at 5 pm except at noon on Friday.

We will work on the quahog assessment from Monday till mid- or late Wednesday and then spend the rest of the week on the clam survey (but plans can change).

Conference call: Tel: 886-836-6169 (Participant code: 5443237)

Web conference:
https://noaast.adobeconnect.com/r6egmbhh6oz/
Conference number: 866 836-6169

Ocean quahog SAW Working Group

Meeting materials at: http://www.nefsc.noaa.gov/invertebrates/SARC-63_Ocean_quahogs/ (and subdirectory Mtg_2) – username "invertebrates", password "rule"

1) Introductions, arrangements and meeting materials, rapporteur
2) TOR
3) Business from last meeting
    a. Survey data
    b. Habitat
4) Growth
    a. More growth curves
    b. Cohort biomass
    c. Pop Dy model
5) Maine fishery for mahogany quahogs (Wednesday AM, probably)
6) Estimate F, B and uncertainty
    a. KLAMZ, build a bridge and SS3
    b. Sensitivity analyses
    c. Historical and standard retrospective analysis
    d. Empirical assessment results
7) Reference points
    a. Current (old)
    b. Updated

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