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Impact of survey timing on distribution and indices of Greenland halibut in NAFO Div. 0A and Divs. 1CD

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Abstract

Bottom trawl surveys in Div. 1CD and 0A used in the assessment of Greenland halibut *Reinhardtius hippoglossoides* were earlier than usual in 2019. In 2019, Div. 0A Greenland halibut were located shallower than typical for this survey, with highest abundance and biomass near the shallowest extent of the survey in areas closest to shore; this distribution is not characteristic of previous 0A-south surveys. This suggests that a portion of the stock may have extended beyond the surveyed area. The 2019 survey point for Div. 0A should not be considered comparable to the earlier series given the significant difference in survey timing and resulting difference in stock distribution during the survey. While distribution in Div. 1CD was shallower than usual, there was no evidence that the proportion of the stock available to this survey was different than other years, and based on timing is considered comparable for the Div. 1CD survey. Note that differences in gear performance resulting from the vessel change in 2019 (Nogueira and Treble 2020) confound the analysis of survey timing presented here, though the exact impact of this cannot be quantified.

Introduction

Two multi-species bottom trawl surveys were carried out in 2019 in Northwest Atlantic Fisheries Organization (NAFO) Subarea 0 and 1, earlier than previous years. A survey in southern Division 0A (0A-South) (to approximately 72° N) was conducted during August 15-25, 2019 (Treble 2020), and a survey in Division 1CD from July 31 to August 12, 2019 (Nogueira and Estevez-Barcia, 2020). This is the earliest both surveys have been conducted (Figure 1). Most of the 0A and 1CD surveys have taken place between the end of September and the end of October, or mid- to late September respectively. While Greenland halibut have been shown to exhibit seasonal differences in distribution in SA1 (Jorgensen 1997) and in other regions (Siwike and Coutré 2020) it is not known if Greenland halibut in Div. 0A exhibit similar behavior. This document examines distribution (spatial, depth) relative to survey timing to try to determine if this earlier survey point should be considered comparable to previous surveys in 0A-South. A change in survey vessel was also made in 2019 and this is considered in a separate document (Nogueira and Treble 2020).

Methods

Temperature

Bottom temperatures from the 2019 survey were compared to those of previous years to determine whether a difference in thermal habitat availability in 2019 - given the earlier survey timing –may have impacted the distribution of Greenland halibut in this area. Temperature at depth in 2019 fell well within the typical range observed in previous surveys (Figure 2) (see also Treble 2020, Table 3), with the exception of a few locations near 600-800m in Div. 1CD that were colder than normal. Given this similarity, potential impacts of temperature were not explored further here.

Distribution

Generalized additive models (GAMs) were applied to set by set abundance (A; number per tow, standardized for swept area) data to examine the influence of depth on the distribution of Greenland halibut. Model variables included set depth (depth) and survey year (y), with error ε,

$$A \sim s(\text{depth}, y) + \varepsilon$$

where s indicates a spline smoother.

Given the hypothesis that Greenland halibut may have been further inshore in 2019 due to the earlier timing, an additional GAM was applied to abundance looking at the combined influence of set depth and distance from shore (dist),

$$A \sim te(\text{depth}, \text{dist}, \text{by}=y) + \varepsilon$$

Where te indicates a tensor product. GAMs were fit with a negative binomial distribution using the gam() function within mgcv package v.1.4 in R version 3.6.1 (R Core Team, 2019). Smoothing parameters were estimated using restricted maximum likelihood with fREML computation. Distance from shore was computed in ArcGIS Pro based on Euclidian distance between the set position and the shoreline inferred from GEBCO2019 bathymetric data.

Results & Discussion

Divs. 1CD

Generalized Additive Models (GAMs) of abundance by depth (Figure 3) indicate that in most years abundance generally increases with depth in the Div. 1CD survey. However, in 2019 (and 2015), a different pattern was observed with abundance higher in the mid-ranges of the surveyed depths. While this distribution is different than other years, it does not suggest that fish were beyond the surveyed area and there is no evidence that the proportion of the stock available to the survey was different than other years. This is also reflected in GAMS of abundance by depth and distance from shore (Figure 4). Length frequencies in 2019 were consistent with previous years (Figure 5**Error! Reference source not found.**).

Div. 0A

GAMs of abundance by depth in Div. 0A (Figure 6) indicate that in most years there is a decrease at the shallow and deep extremes of the depth range surveyed, with the highest amounts of found in the mid range of the survey. However, in 2019, this decrease at the shallow depths was not observed, with smoothers showing a flat top from roughly 400m (the shallowest sampled in the survey) to 700m. This is consistent with measures of total survey abundance and biomass, for which the proportion of the biomass in 2019 found in the shallowest strata groupings (401 to 600m, 601 to 800m) were the highest in the time series (Figure 7). Abundance showed similar trends, with higher than average proportions in the shallowest depth classes (Figure 8).

Model results for the combined influence of depth and distance from shore were consistent with that observed for depth. In most years, biomass was highest in mid depth ranges, and across a broad distance from shore. However, in 2019, biomass was more associated with the shallowest areas closest to shore (Figure 9). Results suggests that a greater than usual proportion of the stock was found in shallower waters in the 2019 survey. This is consistent with earlier observations by Jorgensen (1997) from SA1 during 1988 to 1993 which noted Greenland halibut tended to occupy shallow depths in Div. 1B during Aug-Sept. and were more widely dispersed in Sept.-October, including deeper depths to the south in 1D. Greenland halibut in the Bering Sea and Aluetian Islands, another large offshore area, also exhibit annual periodicity in depths occupied with deeper water occupied in January and February and shallower water during July to September (Siwike and Coutré 2020).

Length frequencies (Figure 10) indicate that in 2019 the shallow strata contained a higher proportion of larger fish than typical for this survey, and there is an absence of small fish at all depth strata.

Analyses suggest that in 2019 a portion of the stock likely extended shallower and/or more inshore than the extent of the survey area, in a manner that is not typical of previous surveys in Div. 0A. However, the extent to which the survey missed Greenland halibut that would have otherwise been available later in the season cannot be quantified. Given knowledge of Greenland halibut distribution in this area from previous surveys (Treble 2007 and 2009), there is no evidence that any considerable number of Greenland halibut would be shallower than 400m on the western Baffin Shelf. The habitat in these waters is dominated by cold, less saline Arctic Ocean outflows and abundance of Greenland halibut, shrimp and other Atlantic fish species is low. However, Greenland halibut are known to extend into inshore areas along deep cross-shelf channels that contain warmer Atlantic water (e.g. DFO 2008; Devine et al. 2019). Tagging studies from the inshore waters adjacent to the 0A-South survey area indicate seasonal movements of Greenland halibut from inshore fjord systems in summer to the offshore later in the year (Barkley et al. 2018). Broad scale timing and extent of inshore/offshore movements in the larger stock area are not yet known.

Length frequency distributions in 0A-South have been quite variable, compared to 1CD, over the survey time series and the factors driving these differences are not known. It has been hypothesized that Baffin Bay is used by juvenile Greenland halibut as a feeding/rearing area and we could be seeing evidence in 0A-South of strong year classes coming from the productive west Greenland banks that are adjacent (i.e. Divisions 1AB). Abundance of age 1 Greenland halibut have been above average in 2011, 2013 and 2017 (Treble and Nogueira 2019).

GAMs also indicated that Greenland halibut in Div. 0A were distributed deeper and farther from shore than usual in 2017, when the survey occurred slightly later than typical. This is largely driven by the occurrence of two large sets in deep water in the northeastern portion of the survey area (see Treble 2018), indicating an isolated area of high abundance in deep water, rather than a widespread difference in distribution across the surveyed area. In addition, length proportions by depth (Figure 11) were generally consistent with previous years. However, further investigations into the comparability of 2017 and impact of late survey timing in that year may be warranted.

Conclusion

Differences in distribution of Greenland halibut in 2019 were evident in both Div. 0A-South and Div. 1CD. Although distribution in Div. 1CD was atypical, it does not suggest a different proportion of the stock was available in 2019 relative to other years. However, in Div. 0A-South, the largest proportion of the abundance was in the shallowest areas and located nearshore, suggesting that the portion of the stock that was surveyed in 2019 is likely inconsistent with previous years. Given this uncertainty introduced by the change in survey timing, the 2019 survey point for Div. 0A-South should not be considered comparable to the earlier series due to a seasonality effect. There is no evidence of a similar seasonality effect in Div. 1CD.

It is notable that differences in gear performance at depth, resulting from the vessel change in 2019 (see Nogueira and Treble 2020), confound the analysis of survey timing presented here. However the relative impact of timing and catchability differences cannot be separated, and the relative impact of each factor has not been quantified.

While a number of factors will impact stock distribution in any given year (e.g. oceanographic conditions, recruitment dynamics, etc.), distributional differences noted here highlight a need for consistency in survey timing to avoid introducing additional uncertainty into the interpretation of survey indices.

References

BARKLEY, A. N., "Implications of Developing Deep-Sea Arctic Fisheries for Greenland Halibut (*Reinhardtius hippoglossoides*): Inshore Stock Connectivity and Capture Induced Stress of Ecologically Important Fish Species" (2015). Electronic Theses and Dissertations. 5429. https://scholar.uwindsor.ca/etd/5429

BARKLEY , A. N., Fisk, A. T., Hedges, K. J., Treble, M. A., & Hussey, N. E. (2018). Transient movements of a deep-water flatfish in coastal waters: Implications of inshore-offshore connectivity for fisheries management. Journal of applied ecology, 55(3), 1071-1081.

DEVINE, B.M., Wheeland, L.J., Neves, B.D., & Fisher, J.A. (2019). Baited remote underwater video estimates of benthic fish and invertebrate diversity within the eastern Canadian Arctic. *Polar Biology, 42*, 1323-1341.

DFO. 2008. Cumberland Sound Greenland Halibut (Turbot) Inshore Fishery. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/040.

JØRGENSEN, O. A. 1997. Movement Patterns of Greenland Halibut, *Reinhardtius hippoglossoides* (Walbaum), at West Greenland, as Inferred from Trawl Survey Distribution and Size Data. J. Northw. Atl. Fish. Sci., Vol. 21: 23–37.

NOGUEIRA A., & ESTAVEZ-BARCIA, D. 2020. Results for Greenland halibut survey in NAFO Divisions 1C-1D for the period 1997-2019.

R CORE TEAM (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

SIWICKE, A. and COUTRÉ , K. 2020. Periodic movements of Greenland turbot Reinhardtius hippoglossoides in the eastern Bering Sea and Aleutian Islands. Fisheries Research 229, 13 pp.

TREBLE, M. A. and Noguiera, A. 2018. Assessment of the Greenland Halibut Stock Component in NAFO Subarea 0 + Division 1A (Offshore) and Divisions 1B-1F. NAFO SCR 18/40. 33 pp.

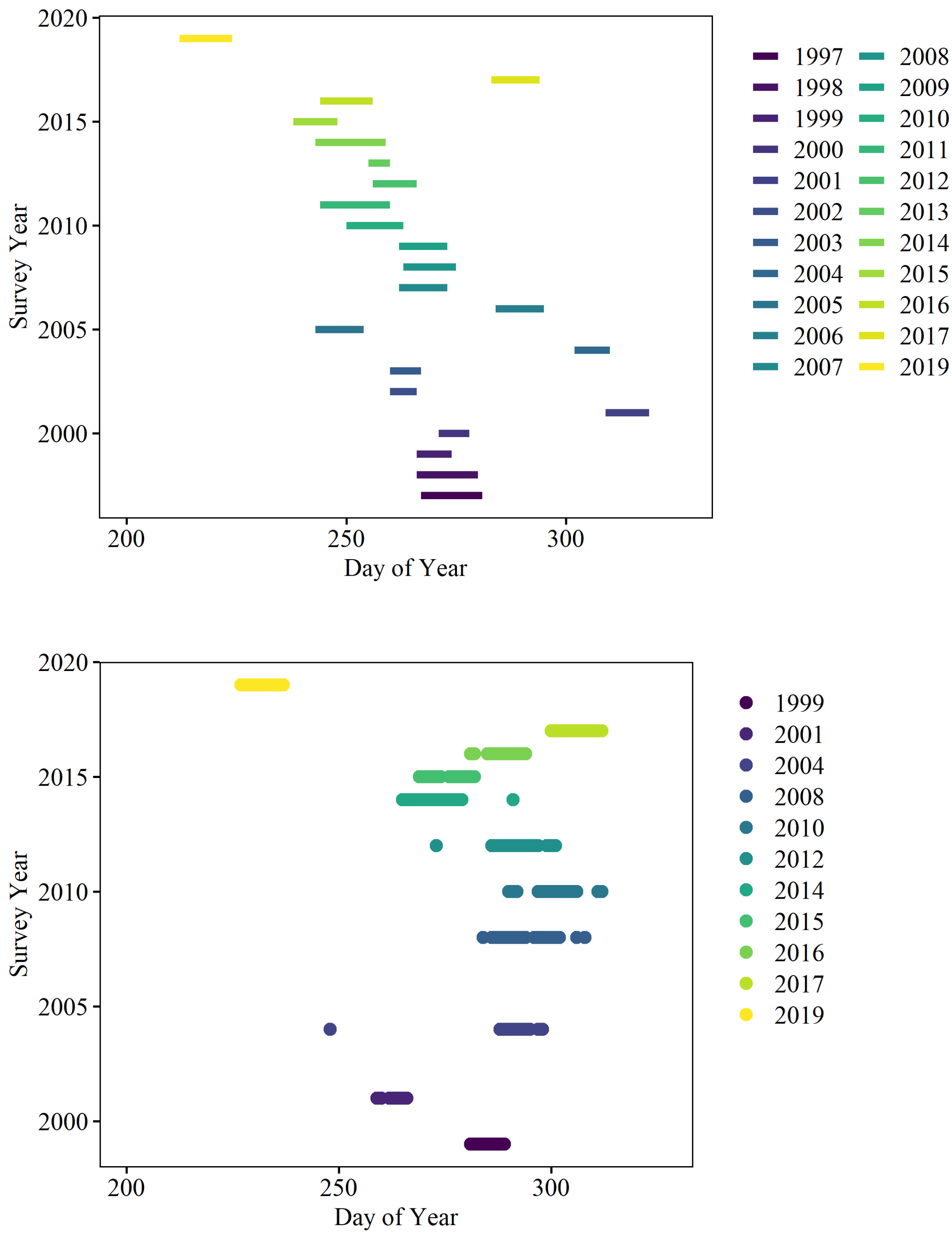
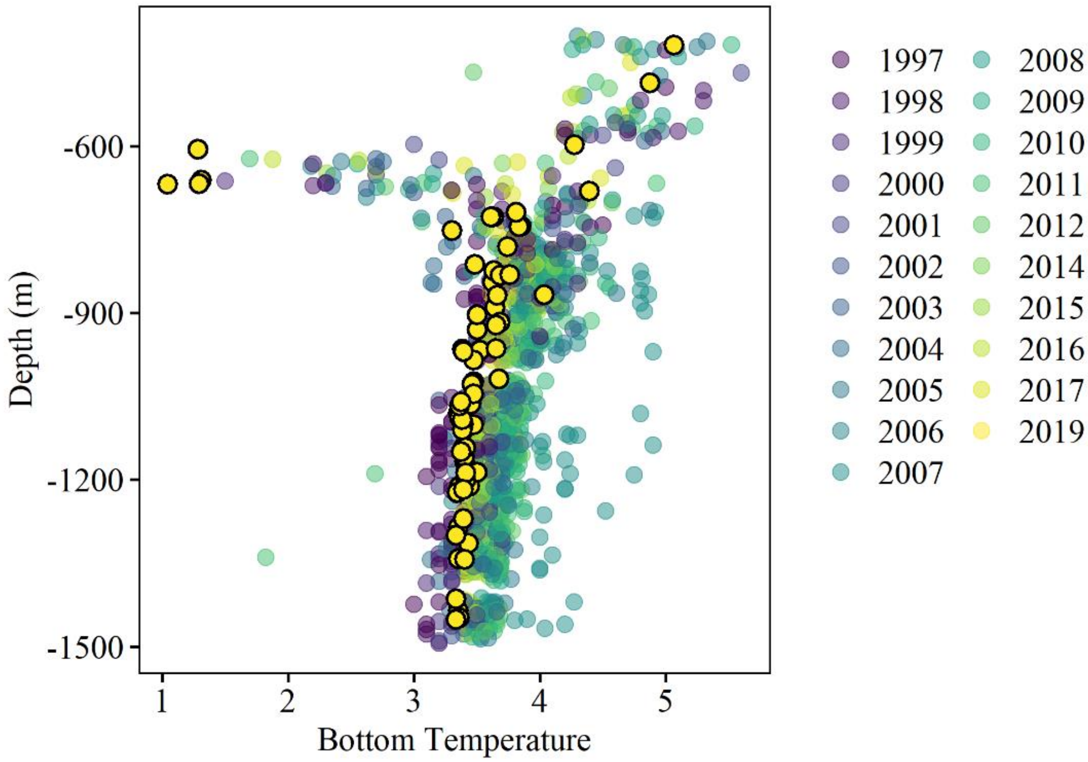


Figure 1. Survey timing (day of year) for the Div. 1CD (top) and Div. 0A-South (bottom) survey. The 2019 survey was the earliest in the time series. The duration of the Div. 0A-south survey has varied as additional areas have been added to the main 0A-South area in some years (e.g. shelf areas in 2008, northern Div. 0A in 2004, 2010 and 2012, and Div. 0B in 2014, 2015 and 2016). Also the 2008 duration is affected by the re-stratification done in 2008, which resulted in 4 sets from the earlier 0A-North survey being subsequently assigned to 0A-South.



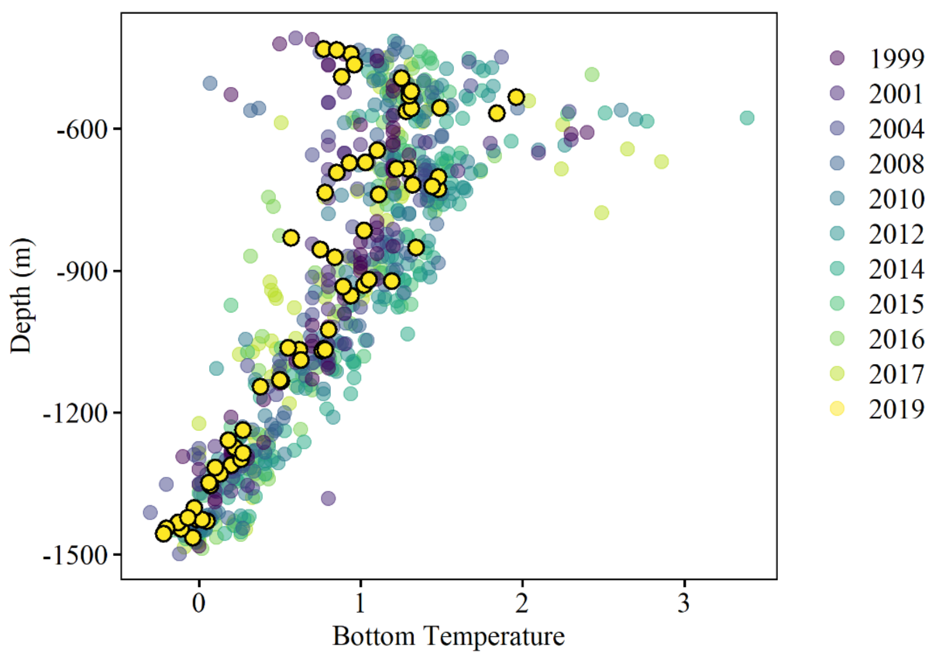


Figure 2. Bottom temperature by set depth from trawl mounted CTD in Div. 1CD (top), and 0A (bottom). Generally, 2019 values fall well within the typical range observed during the survey.

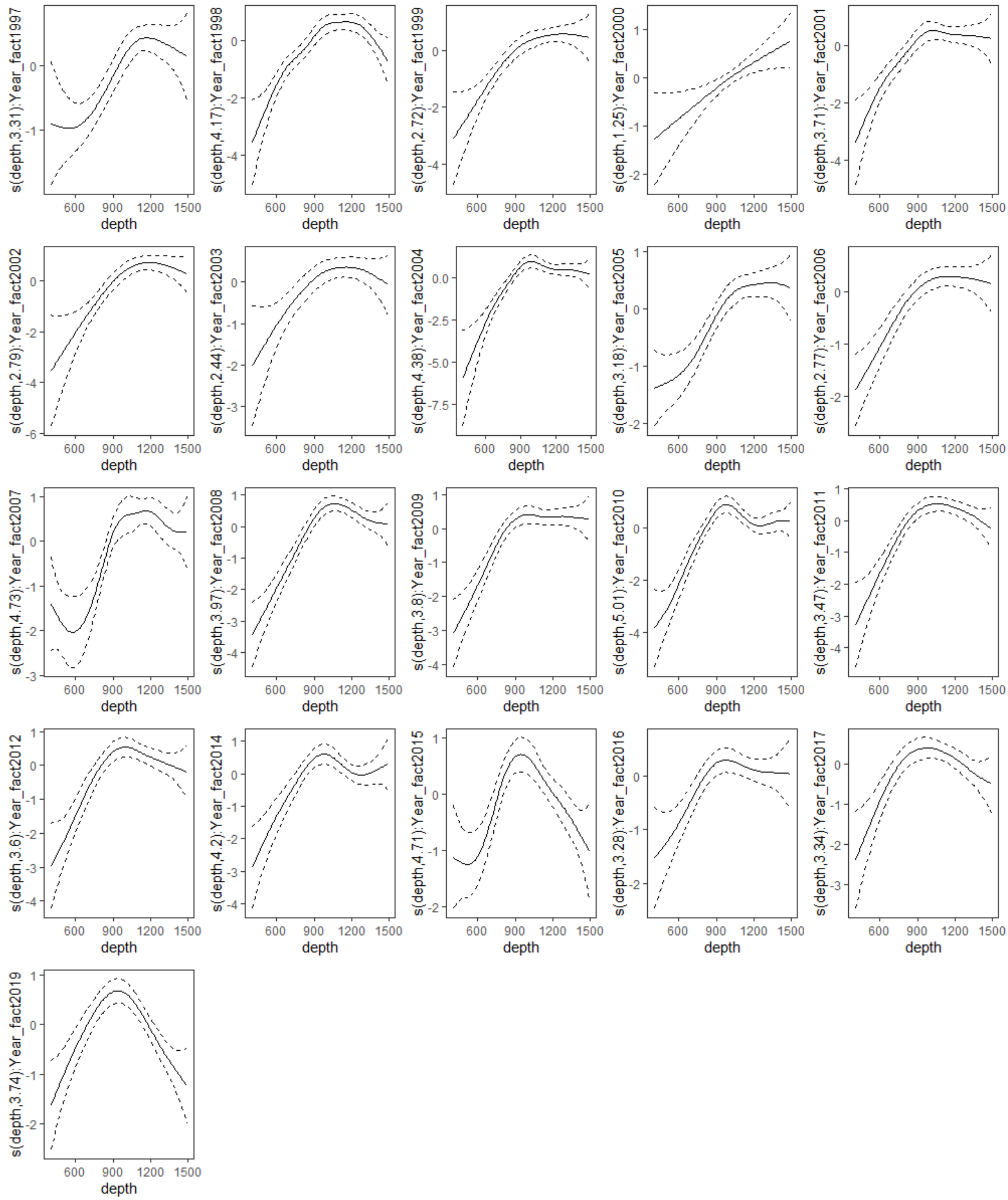


Figure 3. Annual GAM smoothers of abundance (number per tow) by set depth in Div. 1CD. Smoothers for all years were significant.

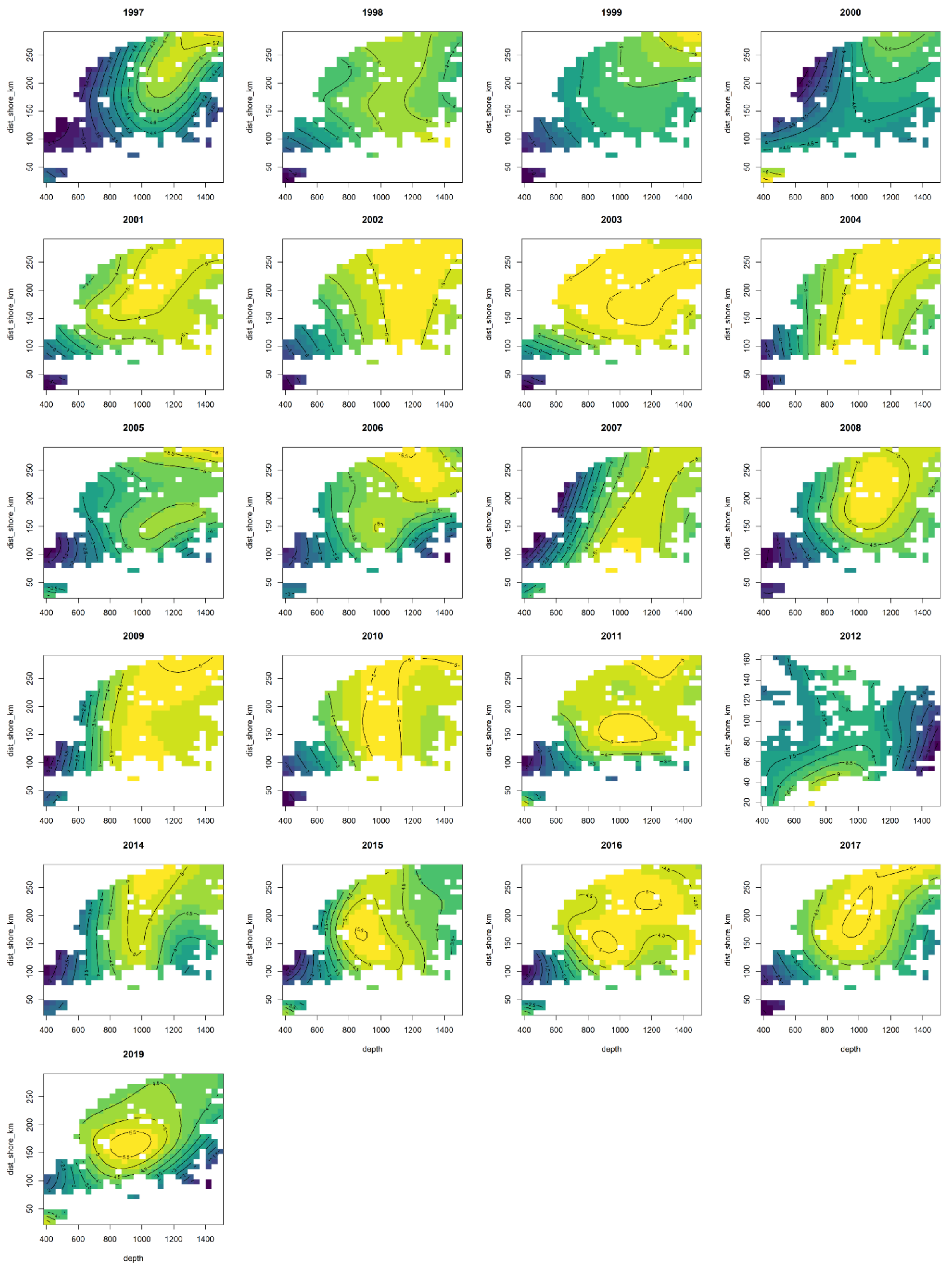


Figure 4. Annual GAM tensor products of abundance (number per tow) by set depth (m) and distance from shore (km) in Div. 1CD, where yellow indicates a more positive effect, purple more negative.

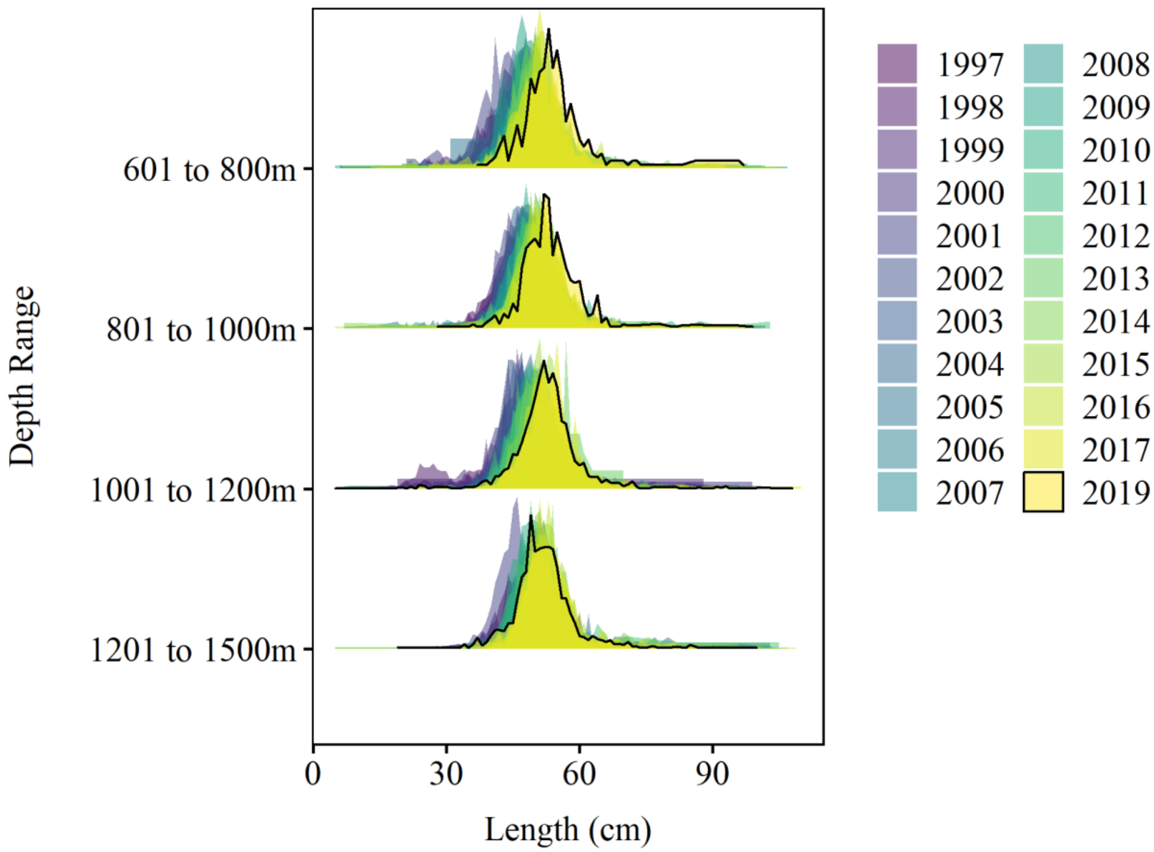


Figure 5. Length frequencies (proportional abundance by length) for Div. 1CD in 2019 were consistent with previous years. Note: frequencies were constructed from raw measurements and are not scaled to strata/area/etc.

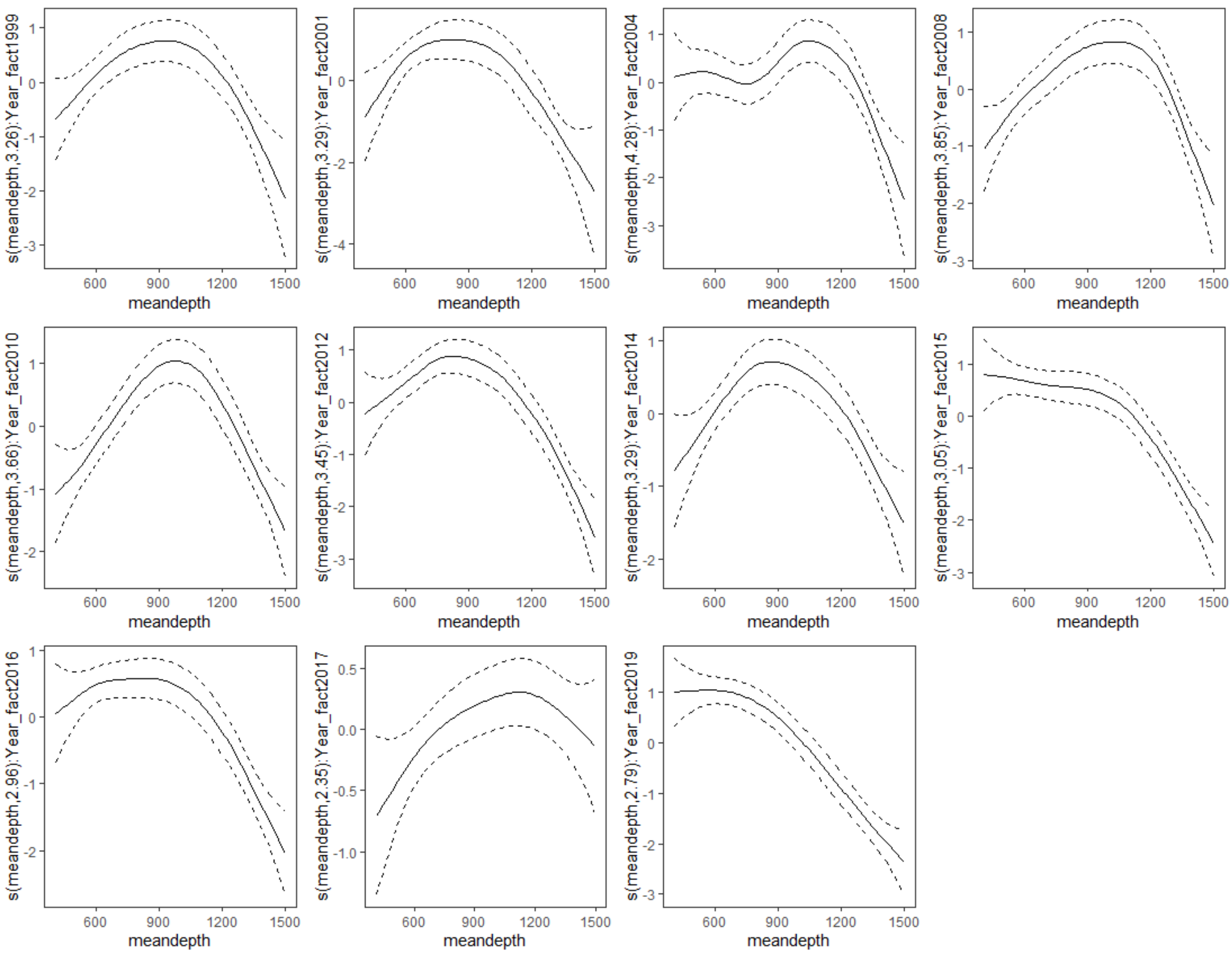


Figure 6. Annual GAM smoothers of abundance (number per tow) by set depth in Div. 0A. Smoothers for all years were significant, with the exception of 2017 where there was not a significant effect of depth (p=0.09; See Appendix 3).

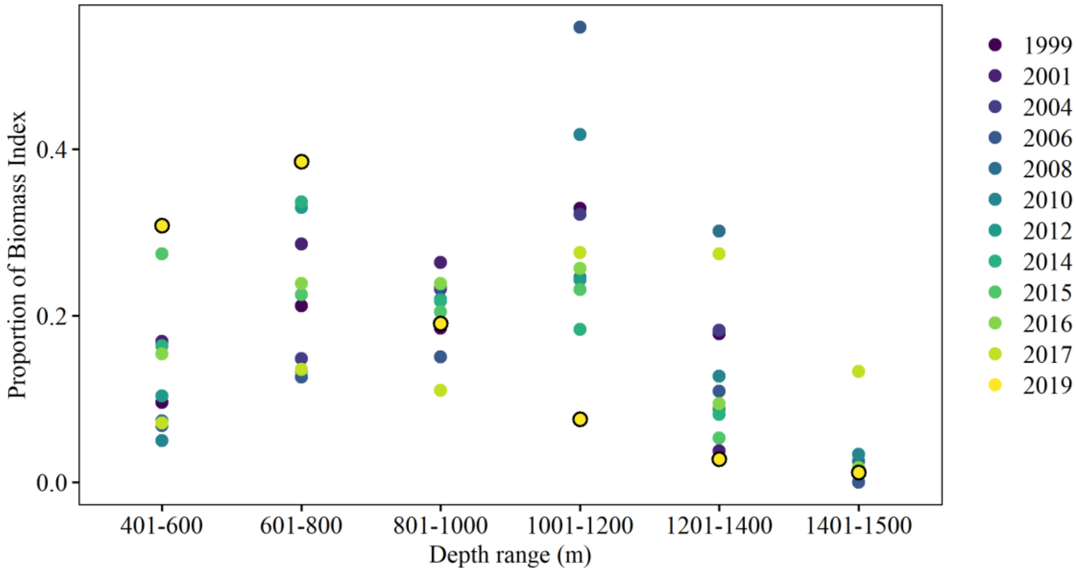


Figure 7. Proportion of survey biomass, by depth in Div. 0A. Biomass is skewed shallower in 2019, with amounts in shallowest bins the highest observed in the series. 2019 is outlined in black.

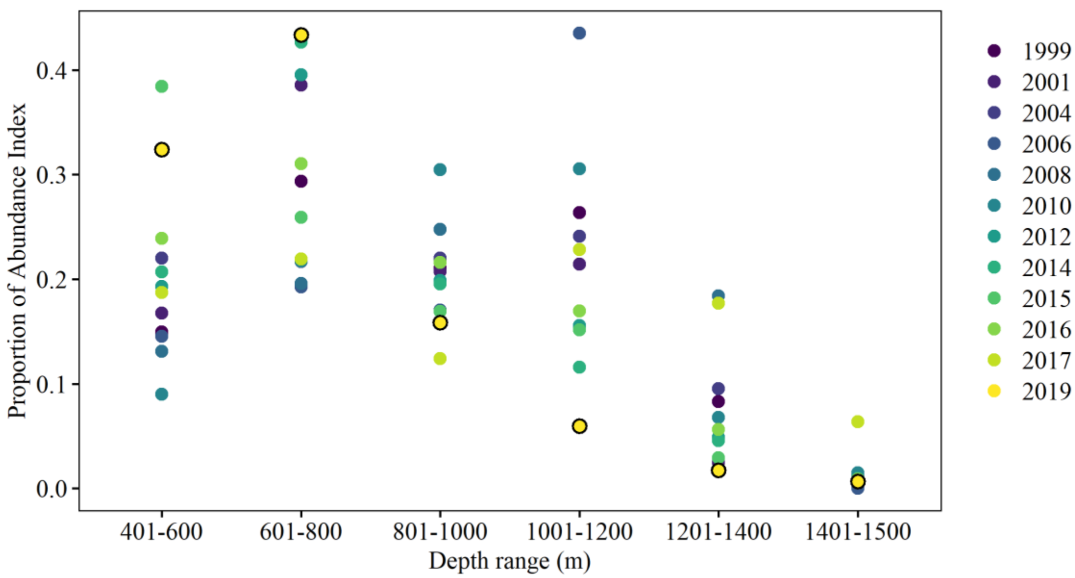


Figure 8. Proportion of survey abundance, by depth in Div. 0A. Values for 2019 fall generally within the range of those observed in previous years, though shallower bins tend towards the high end, and deeper bins, the low.

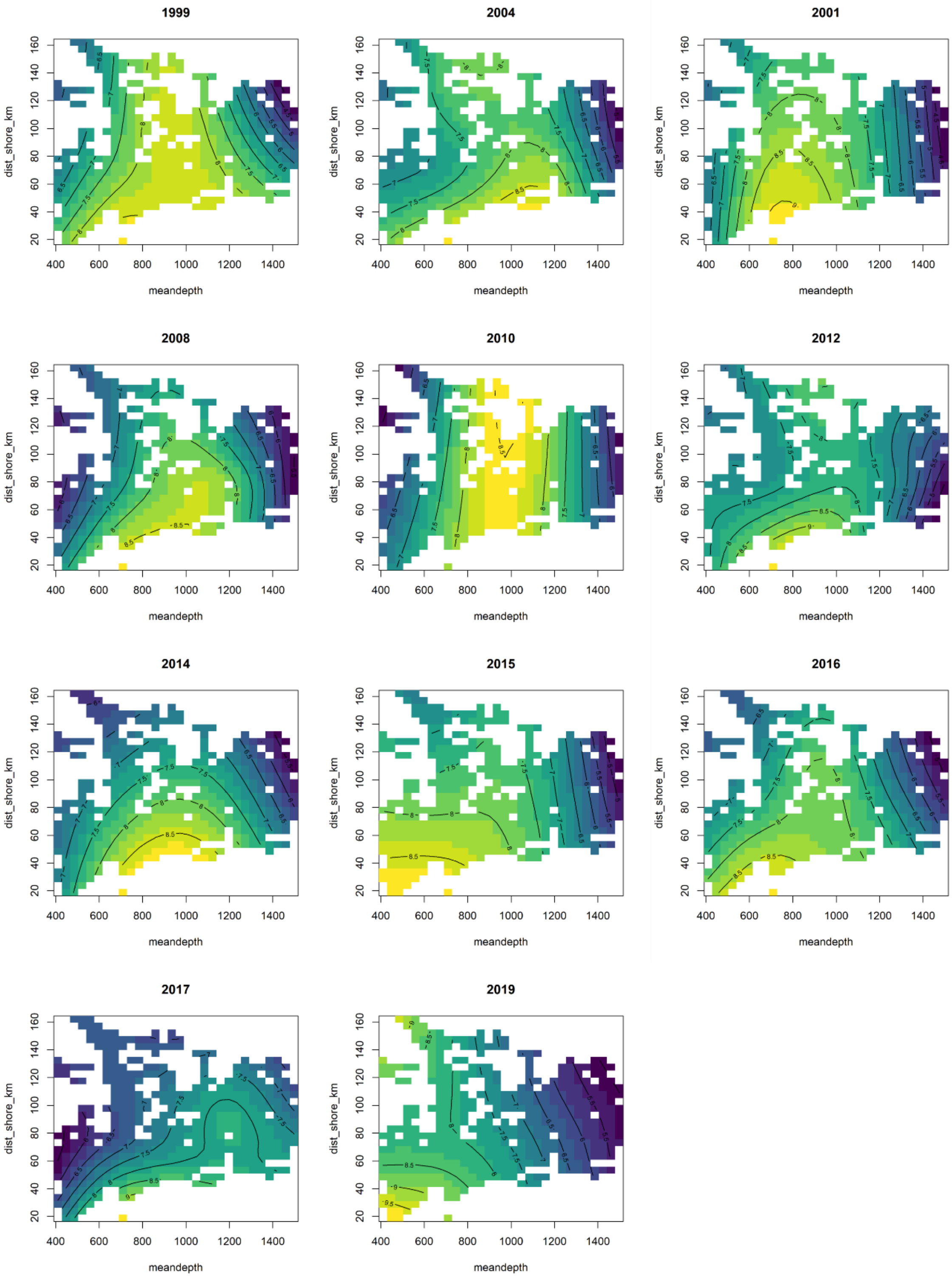


Figure 9. Annual GAM tensor products of abundance (number per tow) by set depth (m) and distance from shore (km) in Div. 0A, where yellow indicates a more positive effect, purple more negative.

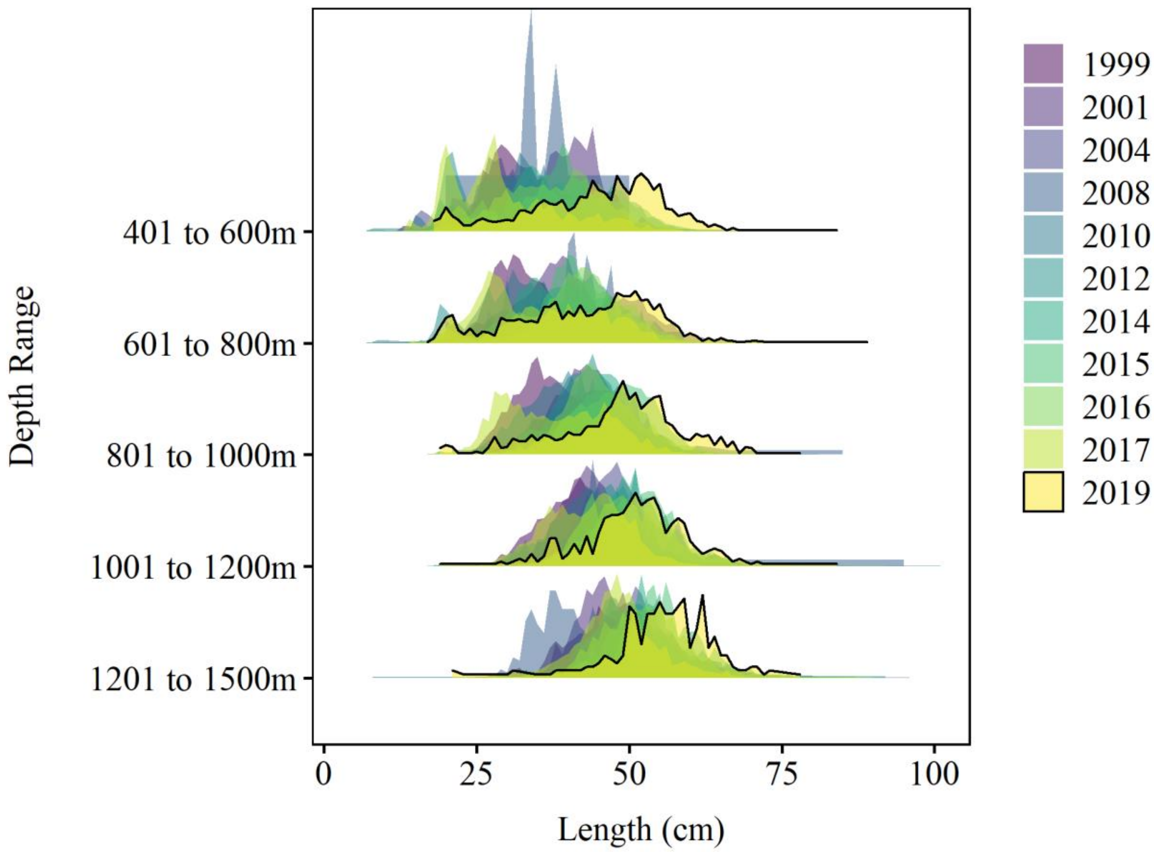


Figure 10. Length frequencies (proportional abundance by length) for Div. 0A by depth range suggest a greater than typical proportion of fish in the shallower depth strata were large (>50cm) in the 2019 survey. Note: frequencies were constructed from raw measurements and are not scaled to strata/area/etc.

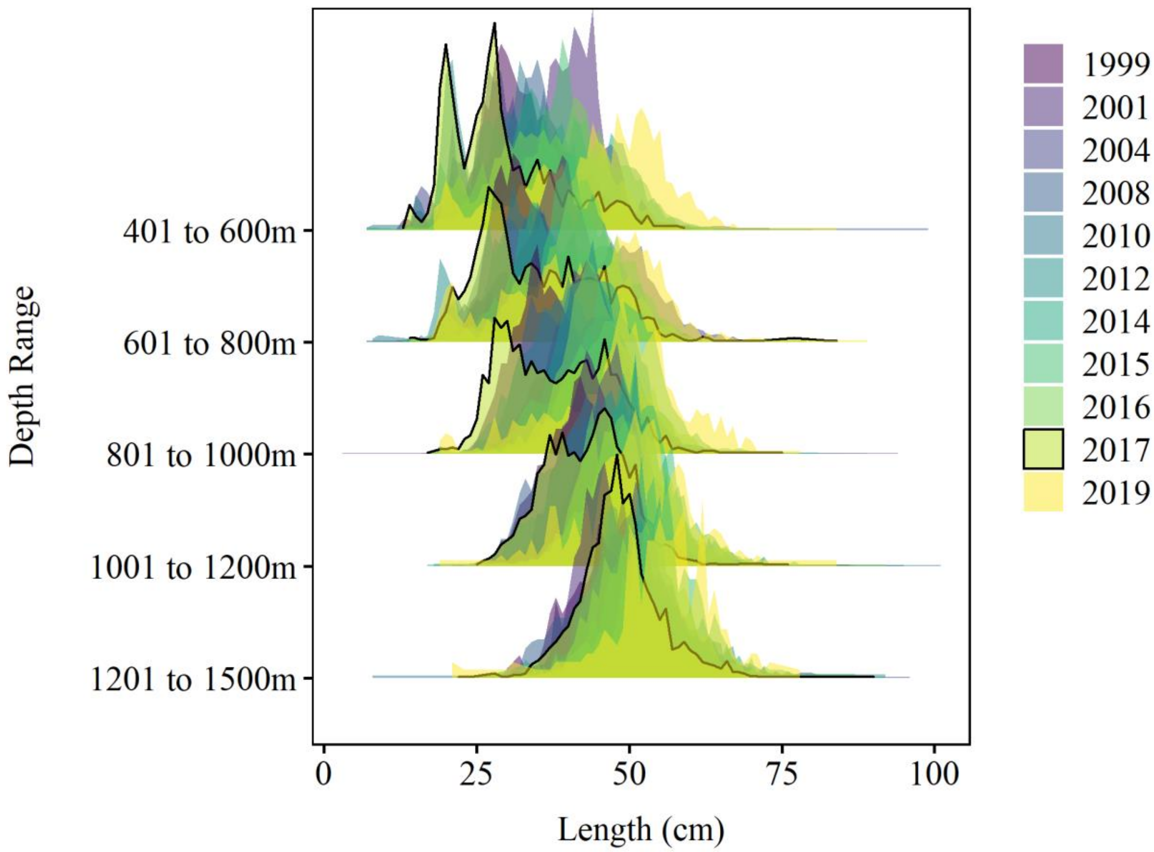


Figure 11. Length frequencies (proportional abundance by length) for Div. 0A by depth range suggest a greater than typical proportion of fish in the shallower depth strata were large (>50cm) in the 2017 survey. Note: frequencies were constructed from raw measurements and are not scaled to strata/area/etc.

APPENDIX 1: Summary of GAM results for Div. 1CD, Abundance by Depth

Family: Negative Binomial(2.224)
Link function: log

Formula:
num ~ s(depth, by = Year_fact)

```
Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  4.53895    0.02047   221.8   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                         edf Ref.df Chi.sq  p-value
s(depth):Year_fact1997 3.308  4.097  38.82 9.50e-08 ***
s(depth):Year_fact1998 4.170  5.115  81.76 5.88e-16 ***
s(depth):Year_fact1999 2.715  3.378  44.96 3.24e-09 ***
s(depth):Year_fact2000 1.247  1.452  11.32 0.004622 **
s(depth):Year_fact2001 3.705  4.581  50.55 1.07e-09 ***
s(depth):Year_fact2002 2.791  3.484  36.40 2.01e-07 ***
s(depth):Year_fact2003 2.440  3.017  15.77 0.001300 **
s(depth):Year_fact2004 4.375  5.363  63.78 4.58e-12 ***
s(depth):Year_fact2005 3.180  3.897  46.80 3.07e-09 ***
s(depth):Year_fact2006 2.773  3.444  38.88 5.79e-08 ***
s(depth):Year_fact2007 4.730  5.711  52.43 1.19e-09 ***
s(depth):Year_fact2008 3.968  4.908 109.68  < 2e-16 ***
s(depth):Year_fact2009 3.802  4.709  66.15 1.01e-12 ***
s(depth):Year_fact2010 5.007  6.120  84.96 4.83e-16 ***
s(depth):Year_fact2011 3.473  4.313  58.14 1.94e-11 ***
s(depth):Year_fact2012 3.602  4.449  45.19 1.10e-08 ***
s(depth):Year_fact2014 4.201  5.180  35.51 1.59e-06 ***
s(depth):Year_fact2015 4.712  5.743  44.89 3.90e-08 ***
s(depth):Year_fact2016 3.285  4.095  23.87 0.000111 ***
s(depth):Year_fact2017 3.343  4.183  25.61 5.24e-05 ***
s(depth):Year_fact2019 3.741  4.619  49.61 1.84e-09 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.268   Deviance explained = 40.8%
-REML = 6429.2  Scale est. = 1         n = 1166
```

APPENDIX 2: Summary of GAM results for Div. 1CD, abundance by depth and distance from shore

Family: Negative Binomial(3.089)
Link function: log

Formula:
num ~ te(depth, dist_shore_km, by = Year_fact)

```
Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)   4.4253     0.0189   234.1   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                                        edf Ref.df Chi.sq  p-value
te(depth,dist_shore_km):Year_fact1997  8.435 10.617  65.03 9.09e-10 ***
te(depth,dist_shore_km):Year_fact1998 11.145 13.622 136.76  < 2e-16 ***
te(depth,dist_shore_km):Year_fact1999  7.445  9.501  71.73 1.70e-11 ***
te(depth,dist_shore_km):Year_fact2000  5.349  6.279  27.85 0.000142 ***
te(depth,dist_shore_km):Year_fact2001 11.479 14.015  98.02 1.15e-14 ***
te(depth,dist_shore_km):Year_fact2002  6.164  7.188  67.92 6.08e-12 ***
te(depth,dist_shore_km):Year_fact2003  9.363 11.622  59.22 2.15e-08 ***
te(depth,dist_shore_km):Year_fact2004  7.107  8.054 105.92  < 2e-16 ***
te(depth,dist_shore_km):Year_fact2005 11.689 14.025 120.35  < 2e-16 ***
te(depth,dist_shore_km):Year_fact2006 11.156 13.804  95.04 4.21e-14 ***
te(depth,dist_shore_km):Year_fact2007  7.156  7.997 113.75  < 2e-16 ***
te(depth,dist_shore_km):Year_fact2008  9.977 12.456 160.94  < 2e-16 ***
te(depth,dist_shore_km):Year_fact2009  8.679 10.485  96.71 6.37e-16 ***
te(depth,dist_shore_km):Year_fact2010  9.003 11.016 114.50  < 2e-16 ***
te(depth,dist_shore_km):Year_fact2011 13.915 16.256 131.62  < 2e-16 ***
te(depth,dist_shore_km):Year_fact2012 10.634 13.048  72.51 2.93e-10 ***
te(depth,dist_shore_km):Year_fact2014  9.059 11.018  60.49 7.30e-09 ***
te(depth,dist_shore_km):Year_fact2015 12.668 15.050 118.55  < 2e-16 ***
te(depth,dist_shore_km):Year_fact2016 13.004 15.349 102.19 8.84e-15 ***
te(depth,dist_shore_km):Year_fact2017  8.191 10.386  52.80 1.29e-07 ***
te(depth,dist_shore_km):Year_fact2019 12.902 15.388 134.37  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.385   Deviance explained = 62.1%
-REML = 6222.2  Scale est. = 1         n = 1166
```

APPENDIX 3: Summary of GAM results for Div. 0A, Abundance by Depth

Family: Negative Binomial(1.27)
Link function: log

Formula:
count ~ s(meandepth, by = Year_fact)

```
Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)   7.5154     0.0327   229.8   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                             edf Ref.df  Chi.sq  p-value
s(meandepth):Year_fact1999 3.265  4.067  27.832 1.50e-05 ***
s(meandepth):Year_fact2001 3.288  4.063  44.983 4.55e-09 ***
s(meandepth):Year_fact2004 4.284  5.248  29.157 2.75e-05 ***
s(meandepth):Year_fact2008 3.845  4.728  46.893 7.19e-09 ***
s(meandepth):Year_fact2010 3.661  4.523  63.410 2.68e-12 ***
s(meandepth):Year_fact2012 3.446  4.248  84.062  < 2e-16 ***
s(meandepth):Year_fact2014 3.288  4.078  37.451 1.72e-07 ***
s(meandepth):Year_fact2015 3.049  3.765  97.189  < 2e-16 ***
s(meandepth):Year_fact2016 2.957  3.655  63.543 8.13e-13 ***
s(meandepth):Year_fact2017 2.352  2.915   6.509   0.0876 .
s(meandepth):Year_fact2019 2.790  3.456 127.882  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.0876   Deviance explained = 36.9%
-REML = 6475.3  Scale est. = 1         n = 755
```

APPENDIX 4: Summary of GAM results for Div. 0A, abundance by depth and distance from shore

Family: Negative Binomial(1.472)
Link function: log

Formula:
count ~ te(meandepth, dist_shore_km, by = Year_fact)

```
Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  7.42273    0.03113   238.4   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                                           edf Ref.df Chi.sq  p-value
te(meandepth,dist_shore_km):Year_fact1999 7.623  9.311  56.05 1.48e-08 ***
te(meandepth,dist_shore_km):Year_fact2001 6.249  7.143  58.71 4.28e-10 ***
te(meandepth,dist_shore_km):Year_fact2004 8.788 11.002  38.90 5.55e-05 ***
te(meandepth,dist_shore_km):Year_fact2008 8.863 10.973  68.50 2.24e-10 ***
te(meandepth,dist_shore_km):Year_fact2010 6.488  7.446  77.36 1.36e-13 ***
te(meandepth,dist_shore_km):Year_fact2012 9.989 12.251 110.66  < 2e-16 ***
te(meandepth,dist_shore_km):Year_fact2014 5.993  6.957  75.44 1.21e-13 ***
te(meandepth,dist_shore_km):Year_fact2015 5.998  6.957 120.58  < 2e-16 ***
te(meandepth,dist_shore_km):Year_fact2016 7.704  9.591  96.40 2.54e-16 ***
te(meandepth,dist_shore_km):Year_fact2017 9.765 12.190  37.46 0.000223 ***
te(meandepth,dist_shore_km):Year_fact2019 7.279  9.441 153.25  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.115   Deviance explained = 49.4%
-REML = 6379.3  Scale est. = 1         n = 755
```