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Seasonal distribution of yellowtail flounder in Georges Bank scallop access areas as inferred from the seasonal bycatch survey

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ABSTRACT

This report summarizes the spatial distribution and seasonal trends in yellowtail flounder bycatch in three scallop access areas on Georges Bank during 2013. Yellowtail bycatch rates were expressed in terms of catch per unit effort (CPUE) as the number of yellowtail caught per thirty minute dredge tow. Observed CPUE was higher in Closed Area II (CAII; mean CPUE = 4.7, range = 0.0 – 44.0) and the open access areas to the southwest of CAII (SWP: 1.6, 0.0 – 28.0) than in Closed Area I (CAI: 0.8, 0.0 – 10.2). Catches were generally low in CAI throughout the year, but exhibited strong seasonal fluctuations in CAII and SWP, with two localized areas of higher catch evident in the fall and winter. Highest catches occurred at bottom temperatures of approximately 10-12^{o}C and depths of 65-75 m.

Introduction

The seasonal bycatch survey (funded by the Scallop Research Set-Aside program) is conducted by the Coonamessett Farm Foundation (CFF) in collaboration with the School for Marine Science and Technology and the Virginia Institute of Marine Science. Survey trips are conducted every six weeks at fixed locations in the scallop access areas of Closed Areas I (CAI) and II (CAII) and in open access areas on the southwest portion (SWP) of GB. The year-round nature and frequency of trips allows for identification of seasonal trends in yellowtail abundance in surveyed areas. This report summarizes spatial and temporal trends in yellowtail abundance in CAI, CAII, and the SWP during 2013. The influences of depth and temperature on yellowtail catch are also investigated.

Methods

Field sampling

Eight trips aboard seven different commercial scallop vessels were made at six week intervals to scallop access areas in CAI, CAII, and the SWP during 2013 (Table 1). Station locations were based on a fixed, gridded design (Fig. 1). Seventy-five stations were consistently sampled on each trip (31 CAI, 30 CAII, 14 SWP). In April (the first trip of the 2013 funding year), 16 new stations in the SWP were added to the survey. In CAI, stations were separated by 5.4 km E to W and 7.2 km N to S. Stations in CAII and the SWP were separated by 8.6 km E to W and 11.1 km N to S.

On each trip, the vessel was outfitted with one standardized 4.6 m wide Turtle Deflector Dredge (TDD) and one 4.6 m wide New Bedford-style dredge (NBD). Only catch data from the TDD (which was supplied by CFF and remained the same over the course of the survey) are presented here. The TDD had an 8 by 40 ring apron, a 10 by 40 ring bag, 6 by 18 ring sides and a 2 ring skirt. It had 14 ring diamonds and 121 link sweeps made from 5/8 inch Grade 70 long-link chain attached to the bag and diamonds with ¼ inch dog chain. The twine top had a stretched mesh length of 10.5 inches; the hanging ratio was 2:1. The dredge was also equipped with turtle mats made from 3/8 inch grade 70 chain, with 9 rows of ticklers and 13 rows of up and downs.

Captains were instructed to pass through the station coordinates at some point during the tow and to record the time the gear was on bottom, with a goal tow duration of 30 minutes and a minimum acceptable tow time of 20 minutes. Target tow speed was 4.8 knots, and dredges were towed with a 3:1 wire scope. Tows shorter than 20 minutes or those with gear or other issues were deemed invalid and re-towed until acceptable. For each tow, start and end coordinates, depth, sea state, and weather conditions were recorded by the captain. One temperature (Vemco Minilog) and one temperature-depth logger (Star-Oddi DST milli-TD) were deployed in steel sheaths welded onto the TDD between the bale wheels. Loggers were programmed to record every thirty seconds. Data were downloaded at the end of each survey trip.

Following each tow, the catch from each dredge was sorted by species. All yellowtail were counted and measured to the nearest cm. Bycatch rates for each tow were expressed in terms of catch per unit effort (CPUE) as the number of yellowtail caught in the TDD per half hour, the target duration for each tow.

Analysis

Generalized additive mixed models (GAMM; Wood 2006, 2011) were constructed to investigate spatial and seasonal trends in yellowtail catches. There were a large number of tows with zero yellowtail in all three areas (CAI: 157, 63%; CAII: 62, 26%; SWP: 118, 57%). Therefore, a Tweedie error distribution (which can accommodate continuous data with many zeros; Tweedie 1984; Dunn and Smith 2005) and a log link function were assumed (Shono 2008). For model fitting, tow location was estimated as the midpoint of the great circle distance between the start and end points of each tow using the "geosphere" package (Hijmans et al. 2012) in R (R Core Team 2013). Midpoint coordinates were projected into the universal transverse mercator coordinate system (zone 19) using the R package "rgdal" (Bivand et al. 2013).

While the survey was designed to minimize differences due to tow duration, vessel speed, wire scope, or dredge design, different vessels were employed over the course of the study. Therefore, vessel was incorporated as a random effect to account for variability due to differences in captain skill/experience, engine power or other technical characteristics of the vessels employed, and other differences not accounted for by the covariates of interest. The response, the expected CPUE of yellowtail flounder in tow *i*, was modelled as:

$$(1)\quad \log(\mu_i) = \beta_0 + f_1(\mathrm{month}_i, \mathrm{northing}_i, \mathrm{easting}_i) + f_2(\mathrm{wave}_i) + f_3(\mathrm{hour}_i) + v_i$$

where $\mu_i = E\,[\mathrm{CPUE}_i]$, β_0 is an intercept term, $f_{1\text{-}3}$ are smooth functions of the covariates associated with tow *i*, and v_i represents the random effect of vessel. Differences in the spatial distribution of the catch by month are represented by f_1, which is a tensor product interaction of a two-dimensional isotropic smooth for location and a one-dimensional smooth for month. The tensor product construction of this interaction term allows for CPUE to be modeled as a smooth function of location and month while being invariant to their relative scaling (Wood 2006). A thin plate regression spline (TPRS; Wood 2006) was used to represent CPUE as a function of geographic coordinates (northing and easting). The effect of month was represented with a cyclic cubic regression spline to ensure continuity between the first and last month of the year (Wood 2006). Maximum wave height was incorporated in f_2 using a TPRS to account for differences in gear performance due to weather conditions. Hour of the day was included as a TPRS in f_3 to reflect differences in diel catchability (Casey & Myers 1998). The resulting model produces a smooth surface from which the expected yellowtail CPUE can be estimated at any location in a given month within the study area. Given that stations in CAI and CAII/SWP are separated by approximately 100 km in space, two separate models were constructed for CAI and CAII/SWP to avoid smoothing over areas that were not sampled.

Depth and bottom temperature were highly correlated with longitude and month, respectively; therefore their effects were investigated separately using a model of the form:

(2) $\log(\mu_i) = \beta_0 + f_2(\text{wave}_i) + f_3(\text{hour}_i) + f_4(\text{depth}_i, \text{temperature}_i) + v_i$

where f_4 is a tensor product interaction between the average depth and bottom temperature of each tow i. For this model, data from all three areas were combined to identify overall trends. The interaction term between depth and bottom temperature was included to reflect seasonal differences in the depth distribution of yellowtail catches. The effects of both depth and temperature were represented using TPRS.

For each model described above, the Tweedie index parameter (p) was set to the value that maximized the penalized log-likelihood for all model variants (CAI: p = 1.06; CAII/SWP: p = 1.15; temperature-depth: p =1.35). All models were fit via maximum likelihood estimation using the “mgcv” package (Wood 2006, 2011) in R (R Core Team 2013).

Model selection and spatial prediction

Model fit was evaluated based on the Akaike Information Criterion (AIC; Akaike 1973). Interaction and individual terms were retained in the model if their inclusion resulted in lower AIC values and explained a higher proportion of the deviance. The AIC difference (Δ_i) of each model was calculated based on the lowest observed AIC value (AIC_{min}) as $\Delta_i = AIC_i - AIC_{min}$; models with $\Delta_i < 2$ were considered indistinguishable in terms of fit (Burnham and Anderson 2002). Residual plots were examined to check model fit and assumptions.

For models based on geographic coordinates, prediction areas were roughly bounded based on the distribution of tow midpoints. Based on the selected models, the expected yellowtail CPUE was estimated over each prediction area to generate a smooth surface. Monthly and average values were plotted to illustrate seasonal trends and identify areas with highest overall catches.

Results

A total of 696 valid tows was completed during 2013. Over the eight survey trips, a total of 1,697 yellowtail flounder were collected in the TDD. Yellowtail were caught in all three access areas on every trip, but catch varied by area and month (Table 1). Average catches were higher in CAII (mean CPUE: 4.7, range: 0.0 – 44.0) than the SWP (1.6, 0.0 – 28.0) or CAI (0.8, 0.0 – 10.2). In CAII, the average CPUE was highest in the fall and winter (Fig. 2); there was some evidence of a similar trend in catches in the SWP, but it was not as distinct. Catches in CAI were generally low throughout the year (Fig. 2). For tows in which yellowtail were caught, depth ranged from 48 to 93 m (Fig. 3) and bottom temperatures from 5.7 to 15.0^{o}C.

Spatio-temporal trends in CPUE

The results of the GAMM analyses provided a detailed description of the spatial distribution underlying the monthly trends in overall abundance for each area. For CAI, variation in CPUE was best described by models including the month-location smoother, suggesting difference in the spatial distribution of yellowtail catch by month (Table 2a). Differences in fit between models including the month-location smoother and those including the smoother and wave height and/or hour of the day were minimal (Table 2a). Variation in CPUE in CAII/SWP was best described by the model incorporating the month-location smoother and maximum wave height (Table 2b). Examination of the resulting smoother for wave height indicated that larger waves were associated with reduced yellowtail catches (Fig. 4). The selected models for each area explained a large proportion of the observed variation (deviance explained > 0.50 in both cases; Table 2), and residual plots indicated that the assumptions and the selected values of the Tweedie index parameter were appropriate.

The predicted CPUE in both regions suggested changes in the distribution and abundance of yellowtail by month (Fig. 5, 6). In CAI, predicted CPUE was generally low in all months (CPUE < 6.5 for all locations) but was highest along the northwestern boundary in September and October (Fig. 5f, g). Catch in CAII/SWP exhibited greater variation over the year (Fig. 6). The predicted CPUE (assuming a wave height of 1 m) was relatively low over large portions of the area, with localized areas of higher catch (CPUE> 10) in the northeastern portion of CAII and just south of the border between CAII/SWP during the fall and winter (Fig. 6). These two areas also exhibited the highest average catches over the course of the year (Fig. 7).

Environmental predictors

The best fitting model based on environmental predictors included the tensor product smooth for temperature and depth as well as wave height (Table 3). All models explained less of the observed variation than models based on geographic coordinates (deviance explained < 0.30 in all cases), though fit was not directly comparable due to the different datasets used. Catches were highest at temperatures of approximately 10-12^{o}C and depths of 65-75 m (Fig. 8).

Discussion

This report described seasonal trends in the spatial distribution and abundance of yellowtail flounder in three scallop access areas on GB in 2013, as inferred from the CFF seasonal bycatch survey. In CAI, yellowtail catches were generally low throughout the year, with slightly higher catches occurring in the northwestern portion of the area in the fall (Fig. 5). There was a stronger seasonal component to catches in CAII/SWP, with two localized areas of higher catch evident during the fall and winter (Fig. 6). In Canadian waters, yellowtail bycatch rates were highest from April to June in the “yellowtail hole” adjacent to the northeastern bound of the scallop access area in CAII (DFO 2007). Therefore, the high CPUE in the northeastern portion of the access area in CAII in July, September, and October (Fig. 6) may represent migration from Canadian waters. The seasonal, localized nature of yellowtail catches may be useful in terms of designating effective time/area closures to avoid yellowtail bycatch in the Atlantic sea scallop fishery.

Models based on geographic coordinates explained a greater proportion of the variation in CPUE than those based on environmental predictors. This was not surprising; location encompasses other factors not accounted for by the model based on temperature and depth (*e.g.* substrate type, prey availability), which may influence the distribution of yellowtail. Based on catch data from commercial otter trawl vessels, Hyun et al. (in press) identified bottom water temperature as the most important factor affecting depth-weighted catches of yellowtail on GB, and estimated optimal water temperatures of 6-8^{o}C. Our results suggested that highest bycatch rates occurred at slightly higher temperatures (10-12^{o}C). However, Hyun et al. (in press) covered a broader portion of GB but did not survey in the closed areas. Therefore, our results may be more indicative of conditions when yellowtail flounder migrate into/aggregate within the bounds of surveyed areas and are available to scallop dredges, which is likely regulated by factors other than water temperature alone.

The selected models successfully explained a large degree of variability in catches in both CAI and CAII/SWP (deviance explained: CAI = 0.51; CAII/SWP = 0.70). However, the current report only investigated seasonal trends within one year. Additionally, this analysis did not account for other factors that may affect catchability, such as changes due to the limited mobility of fish during the spawning season or slower escape responses due to depleted energy reserves following the spawning season. Future analyses will incorporate the entire survey time series (2011-2014) to examine inter-annual trends in abundance and determine whether the trends modeled for 2013 hold true for other recent, as well as future, years.

Literature Cited

Akaike H (1973) Information theory as an extension of the maximum likelihood principle. *In* Second international symposium on information theory. *Edited by* B.N. Petrov and F. Csaki. Akademiai Kiado, Budapest, Hungary, pp. 267-281.

Bivand R, Keitt T, and Rowlingson B (2013) rgdal: Bindings for the geospatial data abstraction library. R package version 0.8-14. URL http://CRAN.R-project.org/package=rgdal

Burnham, K.P., and Anderson, D.R. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Springer, New York.

Casey JM, and Myers RA (1998) Diel variation in trawl catchability: is it as clear as day and night? *Canadian Journal of Fisheries and Aquatic Sciences* 55:2329-2340.

Department of Fisheries and Oceans Canada (2007) Scallop fishery area/time closure to reduce yellowtail flounder bycatch on Georges Bank in 2007. Department of Fisheries and Oceans Canadian Science Advisory Secretariat Science Response 2007/001.

Dunn PK (2013) tweedie: Tweedie exponential family models. R package version 2.1.7.

Hijmans RJ, Williams E, and Vennes C (2012) geosphere: Spherical Trigonometry. R package version 1.2-28. URL http://CRAN.R-project.org/package=geosphere

Hyun S, Cadrin SX, and Roman S (In press) Fixed and mixed effects models for fishery data on depth distribution of Georges Bank yellowtail flounder. *Transactions of the American Fisheries Society.*

R Core Team (2013) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/

Shono H (2008) Application of the Tweedie distribution to zero-catch data in CPUE analysis. *Fisheries Research* 93:154-162.

Wood SN (2006) Generalized additive models: an introduction with R. Chapman and Hall/CRC, Boca Raton, FL.

Wood SN (2011) Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *Journal of the Royal Statistical Society: Series B* 73(1):3-36.

Tables

Table 1. Sampling dates, vessel employed, and the mean yellowtail flounder catch per unit effort (CPUE; expressed as the number of yellowtail caught per half hour) for each survey trip conducted during 2013. The range of CPUE for individual stations within each scallop access area is indicated in parentheses below. CAI = closed area I; CAII = closed area II; SWP = open access area on the southwest portion of Georges Bank.

		CPUE		
Sampling Dates	**Vessel**	**CAI**	**CAII**	**SWP**
1/29 – 2/2	Polaris	0.5 *(0.0 – 2.0)*	6.9 *(0.0 – 44.0)*	4.9 *(0.0 – 28.0)*
3/16 – 3/22	Vanquish	0.3 *(0.0 – 1.2)*	1.3 *(0.0 – 11.3)*	0.9 *(0.0 – 4.8)*
4/28 – 5/3	Endeavor	0.6 *(0.0 – 3.0)*	3.1 *(0.0 – 10.0)*	1.9 *(0.0 – 7.1)*
6/15 – 6/20	Zibet	1.4 *(0.0 – 6.0)*	2.2 *(0.0 – 7.0)*	1.2 *(0.0 – 14.0)*
7/27 – 8/1	Venture	0.9 *(0.0 – 4.4)*	4.9 *(0.0 – 22.4)*	0.5 *(0.0 – 4.9)*
9/10 – 9/15	Atlantic	1.2 *(0.0 – 10.2)*	10.6 *(0.0 – 37.3)*	0.9 *(0.0 – 12.6)*
10/27 – 11/1	Regulus	0.5 *(0.0 – 8.1)*	6.4 *(0.0 – 25.2)*	2.5 *(0.0 – 25.5)*
12/7 – 12/12	Vanquish	0.8 *(0.0 – 6.3)*	2.5 *(0.0 – 10.5)*	1.5 *(0.0 – 7.7)*

Table 2. Relative goodness-of-fit for candidate catch per unit effort (CPUE) model for yellowtail flounder in scallop access areas in a) Closed Area I (n = 248) and b) Closed Area II and the southwest portion of Georges Bank (n = 352). Models are ranked from best to worst fitting. Catch per unit effort was expressed as the number of yellowtail caught per thirty minute tow. All models included vessel as a random effect.

a)

Model	***edf***	**Deviance Explained**	**AIC**	Δ_i
f(month, northing, easting) + *f*(hour)	37.73	0.51	511.10	0.00
f(month, northing, easting)	37.48	0.51	511.47	0.37
f(month, northing, easting) + *f*(hour) + *f*(wave)	38.26	0.51	512.05	0.96
f(month, northing, easting) + *f*(wave)	38.37	0.52	513.73	2.63
f(northing, easting) + *f*(month)	14.21	0.30	543.99	32.89

b)

Model	***edf***	**Deviance Explained**	**AIC**	Δ_i
f(month, northing, easting) + *f*(wave)	65.76	0.70	1440.07	0.00
f(month, northing, easting) + *f*(hour) + *f*(wave)	66.31	0.68	1442.27	2.20
f(month, northing, easting)	61.58	0.67	1473.73	33.66
f(month, northing, easting) + *f*(hour)	62.15	0.67	1475.39	35.32
f(northing, easting) + *f*(month)	19.51	0.42	1721.26	281.19

Note: northing and easting = tow midpoint coordinates projected into the universal transverse mercator coordinate system (zone 19); wave = maximum wave height (m); hour = hour of the day; *edf* = total model estimated degrees of freedom; AIC = Akaike information criterion; Δ_i = AIC difference. *f* indicates a smooth function; see text for specifics on the types of smooth functions used for each covariate.

Table 3. Relative goodness-of-fit for models assessing the effect of temperature (^{o}C) and depth (m) on catch per unit effort (CPUE) of yellowtail flounder in scallop access areas on Georges Bank (n = 696). Models are ranked from best to worst fitting. Catch per unit effort was expressed as the number of yellowtail caught per thirty minute tow. All models included vessel as a random effect.

Model	***edf***	**Deviance Explained**	**AIC**	Δ_i
f(temperature, depth) + *f*(wave)	24.15	0.29	2,589.01	0.00
f(temperature, depth) + *f*(hour) + *f*(wave)	25.16	0.29	2,590.13	1.13
f(temperature, depth)	18.56	0.25	2,618.55	29.55
f(temperature) + *f*(depth)	15.38	0.22	2,644.48	55.47
f(temperature)	12.56	0.18	2,685.68	96.68
f(depth)	10.25	0.17	2,689.54	100.53

Note: wave = maximum wave height (m); hour = hour of the day; *edf* = total model estimated degrees of freedom; AIC = Akaike information criterion; Δ_i = AIC difference. *f* indicates a smooth function; see text for specifics on the types of smooth functions used for each covariate.

Figures

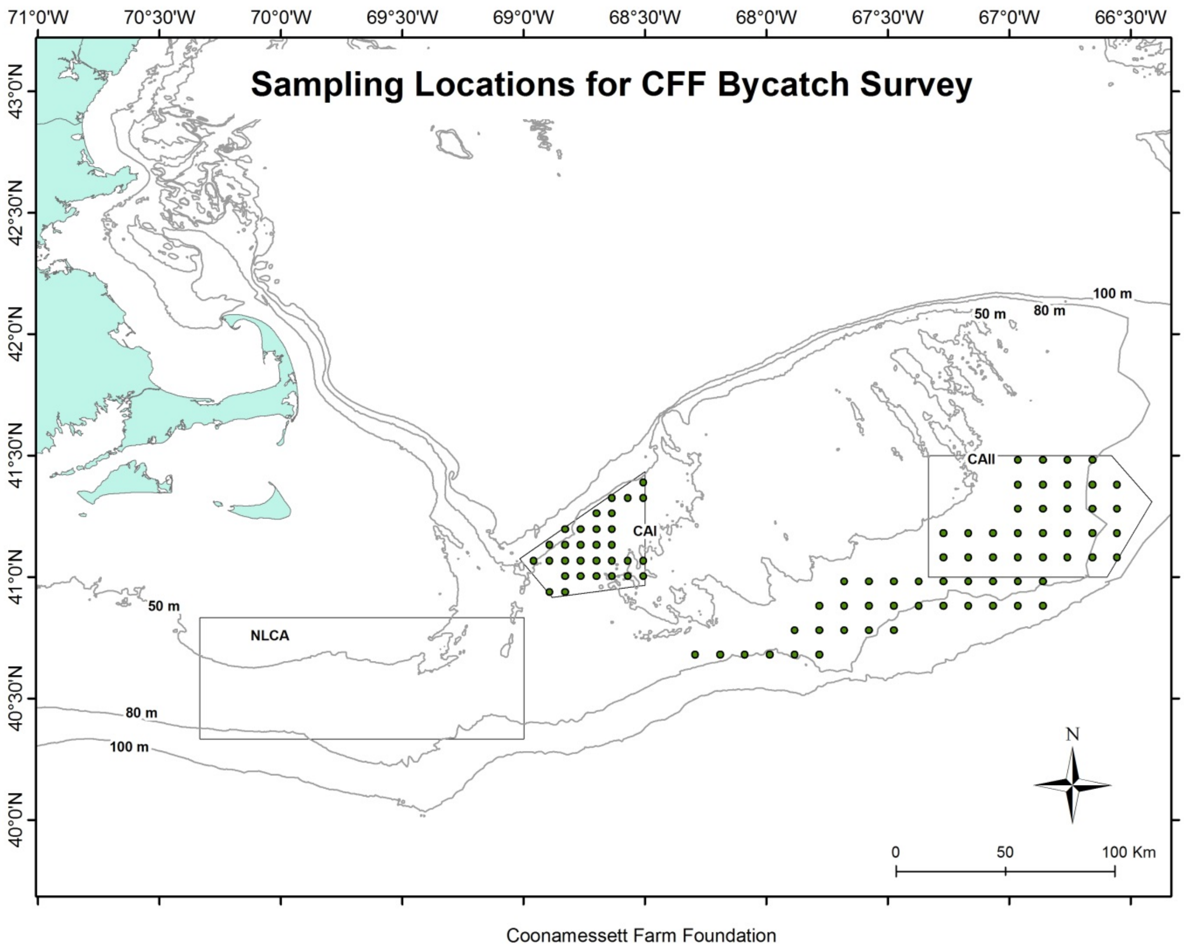

Figure 1. Map of surveyed scallop access areas and station locations in Closed Area I (CAI), Closed Area II (CAII), and on the southwest portion of Georges Bank.

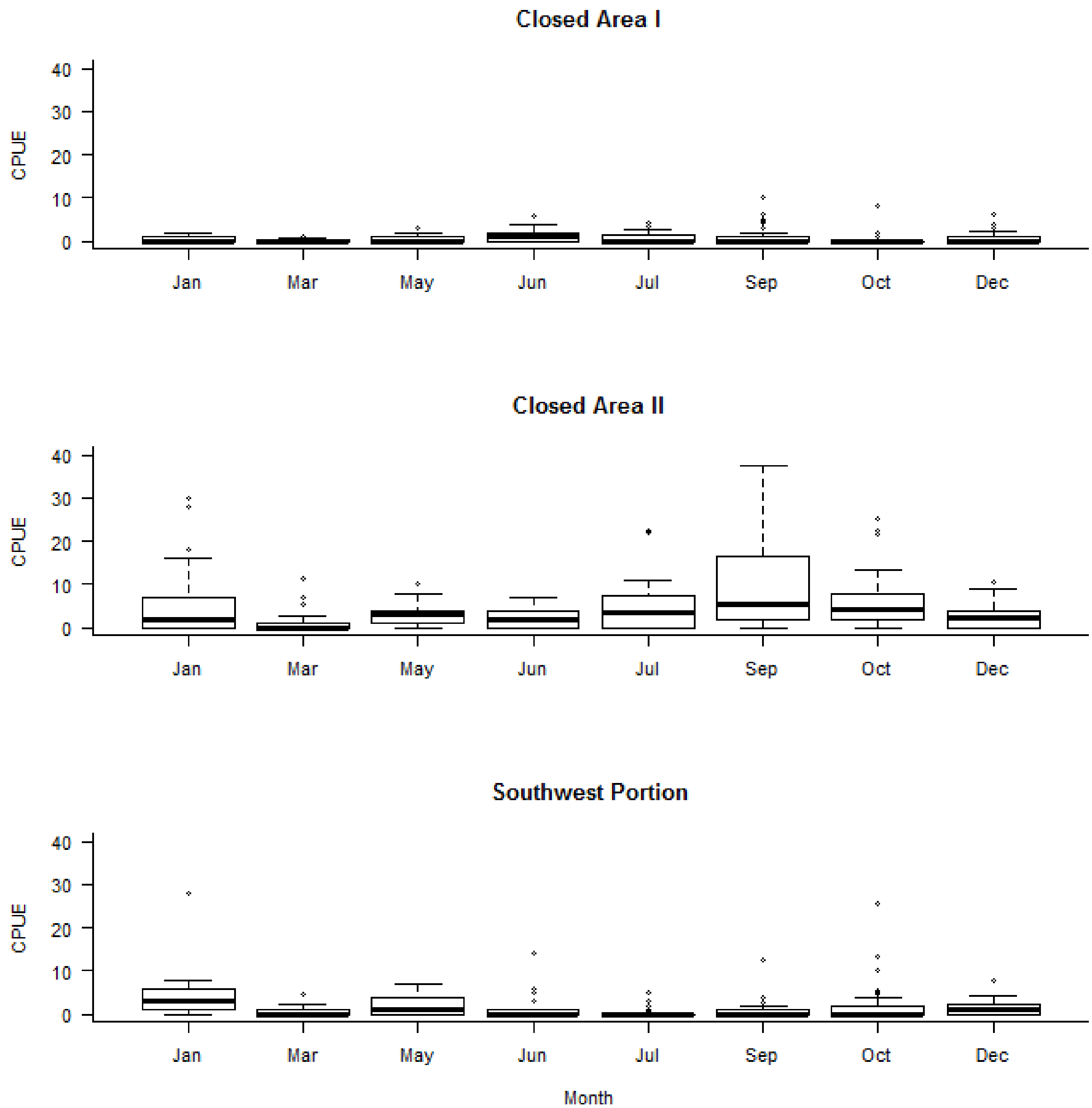

Figure 2. Boxplot of catch per unit effort (expressed as the number of yellowtail caught per half hour) by month for stations surveyed in the scallop access areas in Closed Area I, Closed Area II, and the southwest portion of Georges Bank.

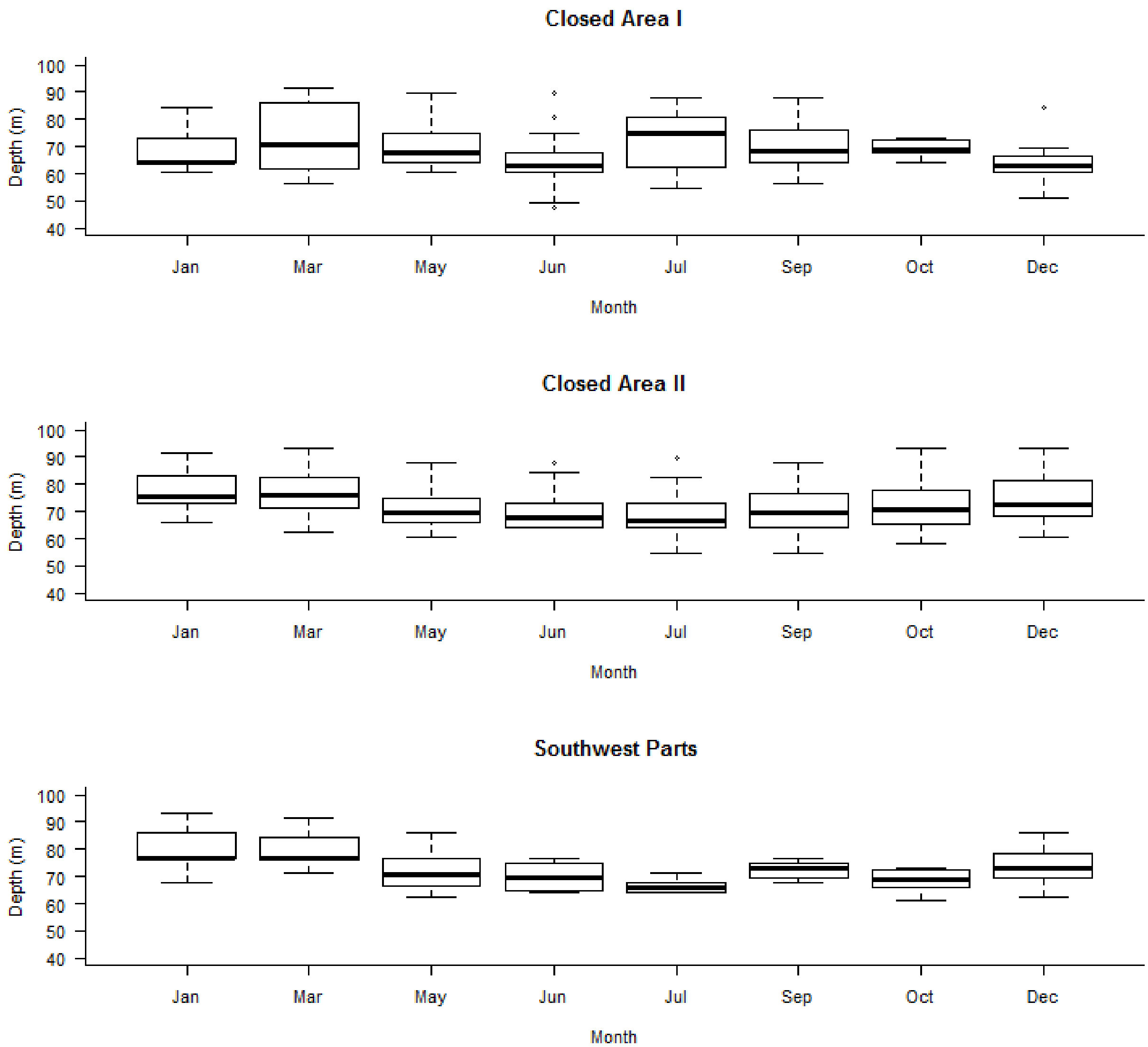

Figure 3. Boxplot of the depth of tows with yellowtail flounder catch by month for stations surveyed in the scallop access areas in Closed Area I, Closed Area II, and the southwest portion of Georges Bank. Tows that caught no yellowtail were excluded.

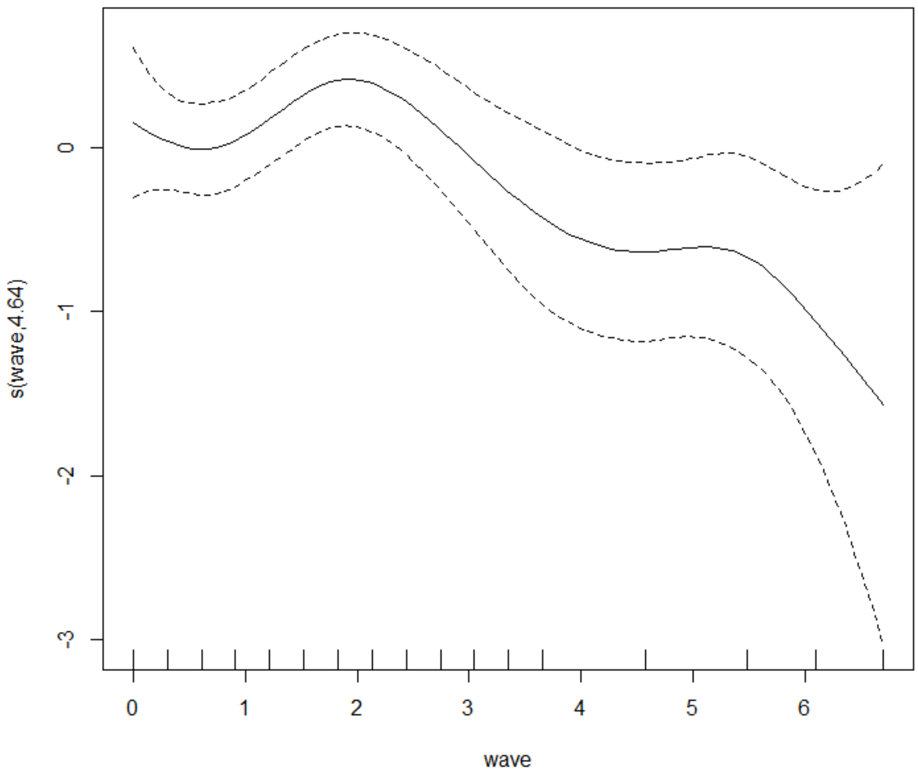

Figure 4. The relationship between yellowtail catch per unit effort (CPUE; expressed as the number of yellowtail caught per thirty minute tow) and maximum wave height (m) as estimated using a generalized additive mixed model. The y-axis represents the centered effect of wave height on CPUE; negative values indicate reduced CPUE. Larger waves were associated with reduced yellowtail catches. Dashed lines are ± two standard errors of the estimate.

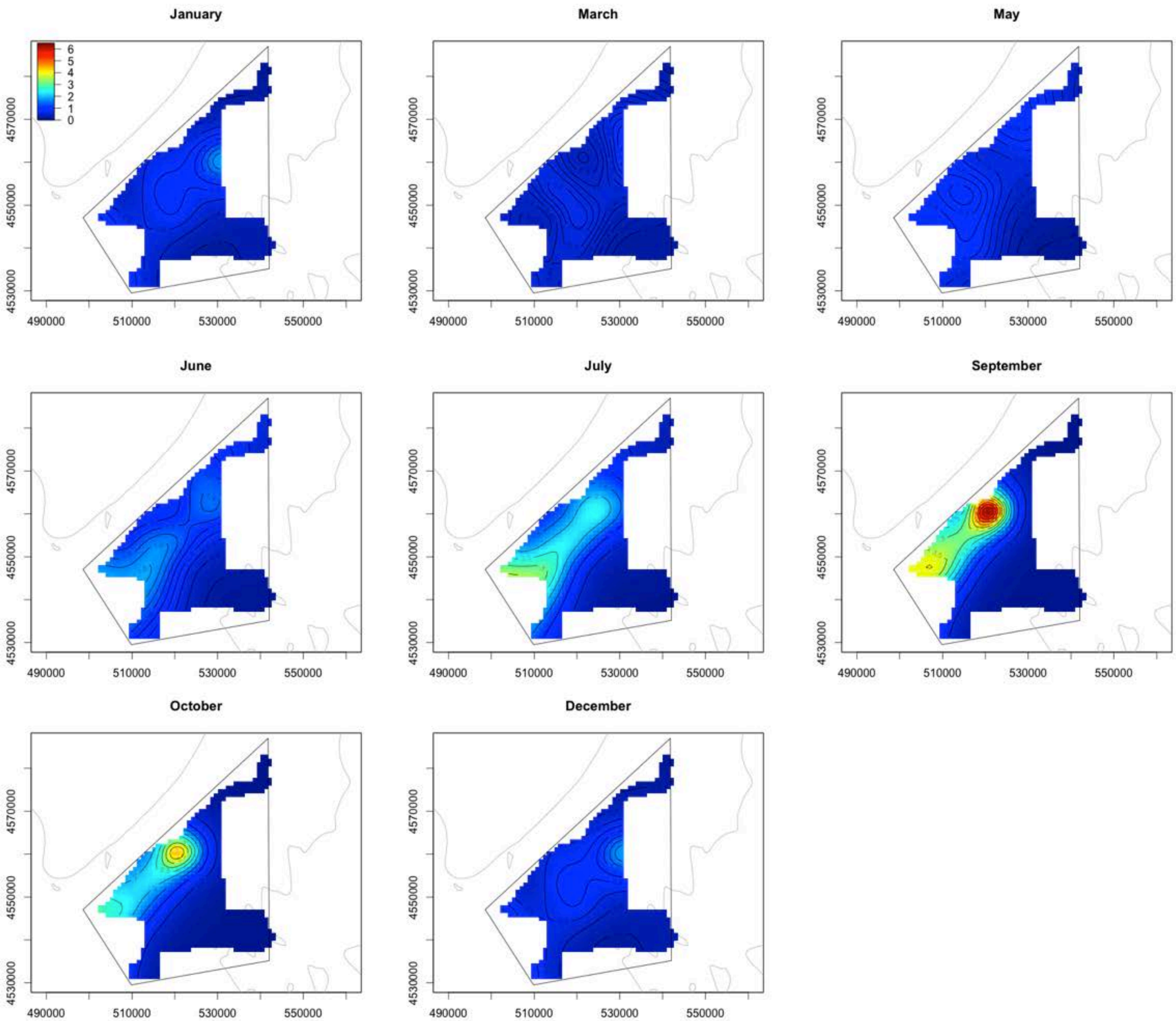

Figure 5. Monthly yellowtail catch per unit effort (CPUE; expressed as the number of yellowtail caught per thirty minute tow) predicted for the scallop access area in Closed Area I (CAI). Black lines denote the boundaries of the access area. Coordinates are expressed in the universal transverse mercator coordinate system (zone 19).

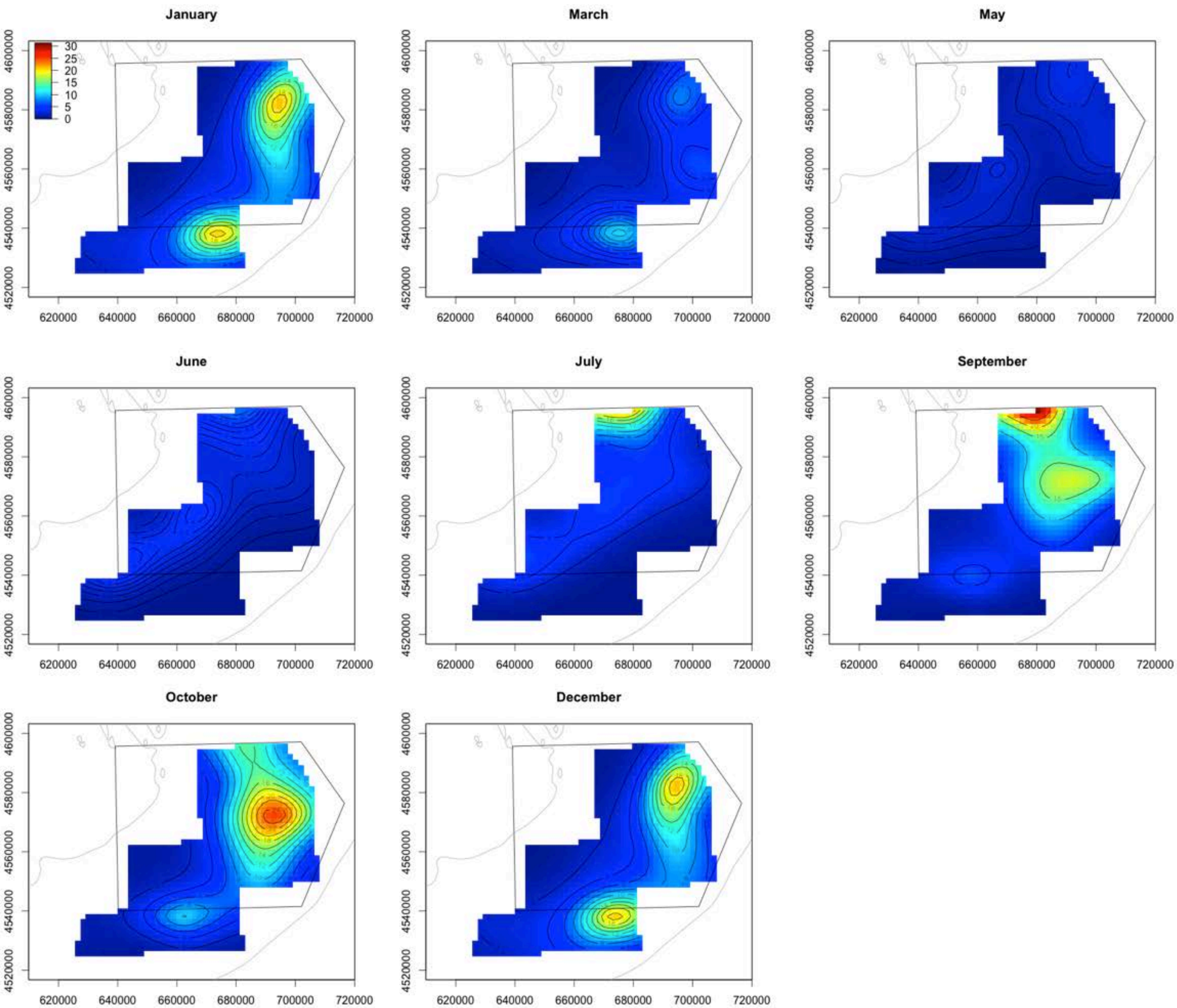

Figure 6. Monthly yellowtail catch per unit effort (CPUE; expressed as the number of yellowtail caught per thirty minute tow) predicted for scallop access areas in Closed Area II (CAII) and the open access area southwest of CAII. Black lines denote the boundaries of access areas in CAII. Coordinates are expressed in the universal transverse mercator coordinate system (zone 19). Note the difference in the scale bar from Figure 5.

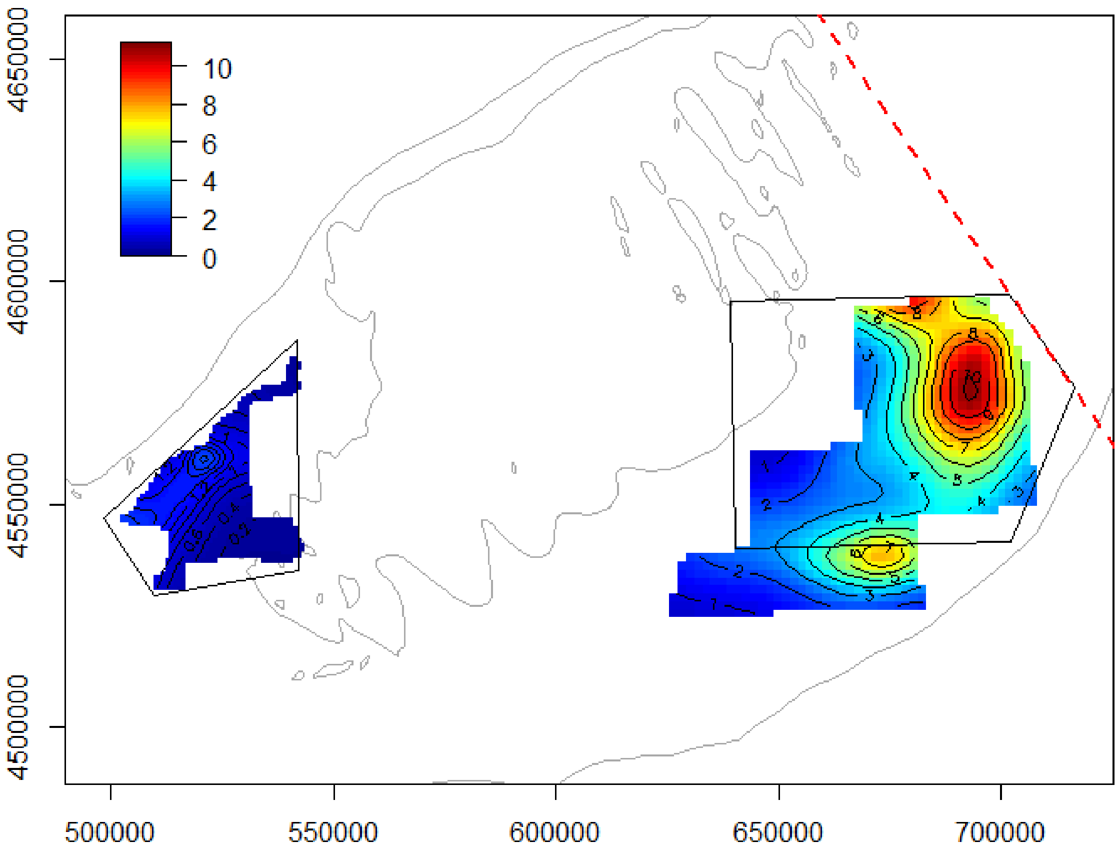

Figure 7. Average yellowtail catch per unit effort (CPUE; expressed as the number of yellowtail caught per thirty minute tow) predicted for scallop access areas on Georges Bank in 2013. Black lines denote the boundaries of access areas in Closed Area I and Closed Area II. The red dashed line indicates the boundary between U.S. and Canadian waters. Coordinates are expressed in the universal transverse mercator coordinate system (zone 19).

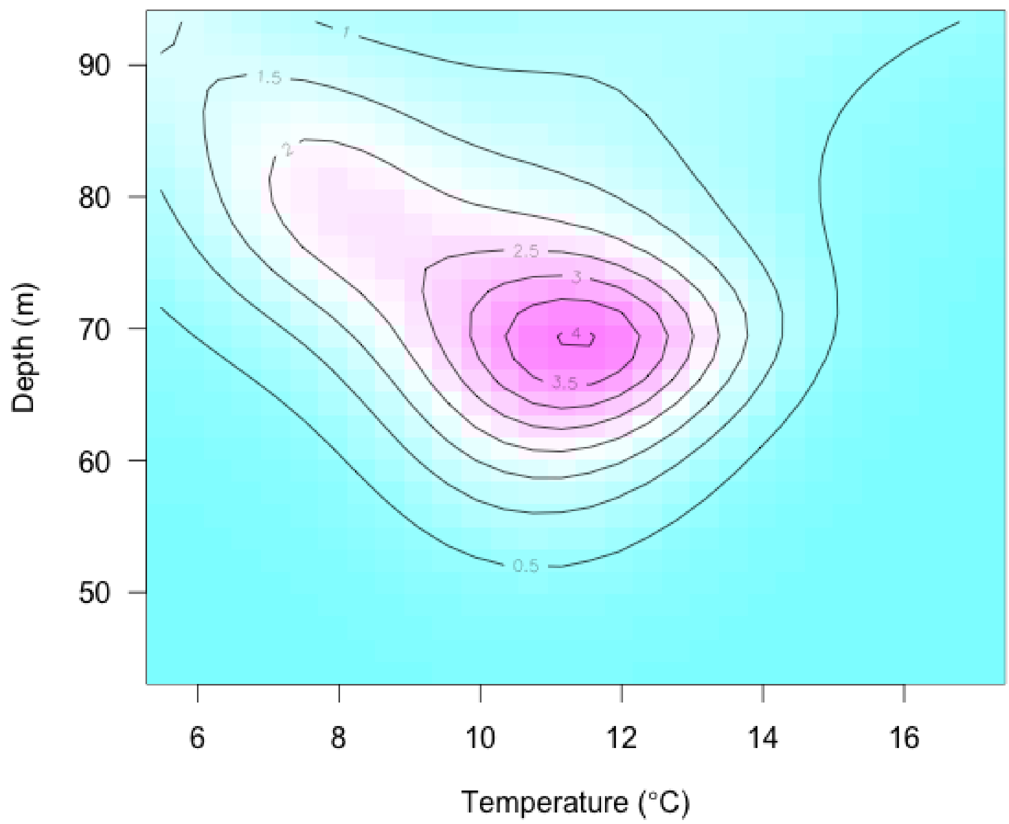

Figure 8. Fitted model smooth for the effect of depth and temperature on yellowtail flounder catch per unit effort (CPUE; expressed as the number of yellowtail caught per thirty minute tow). Model-predicted catches were highest at temperatures of approximately 10-12°C and depths of 65-75 m.